Institution: Queen Mary University of London		
Unit of Assessment: 9		
Title of case study: 'Physics Research in School Environments' PRiSE: Enabling school student and teacher access to cutting-edge physics		
Period when the underpinning research was undertaken: 2015–2019		
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:**
Dr. Martin Archer	Public Engagement & Outreach Officer	Dec 2014–Aug 2020
Prof. Richard Nelson	Professor of Astronomy	Sep 2000–present
Dr. Guillem Anglada-Escudé	Reader in Astronomy	Sep 2013–Jul 2019
Dr. Jeanne Wilson	Reader in Particle Physics	Jan 2010–Jul 2019
Period when the claimed impact occurred: 2015-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Queen Mary researchers transformed their space science, astronomy, and particle physics research into accessible 6-month research projects for schools, providing mentorship and guidance to students as part of a collaborative engagement programme named PRiSE. A diverse group of 1,300 mostly A-level students from 67 schools participated, facilitated by 88 teachers. As a result, 96% of students reported increased confidence, and, 3 years on, 93% were pursuing STEM subjects in higher education with 50% undertaking a physics degree (compared to national rates of 59% and 10% of A-level Physics students, respectively). Based on the results from PRiSE, SEPnet, a leading UK outreach network, adapted their public engagement strategy and 7 academic institutions internationally have adopted the programme's novel outreach model. Students developed highly valuable and otherwise inaccessible research skills as a result of engaging with real and ongoing research, and teachers developed their professional skills and practice**,** reporting increased knowledge and capabilities, new lesson content, and increased confidence. 70% of schools returned for multiple years after completing an initial project, reflecting the longer-term impacts of PRiSE on understanding, learning, and participation over both individual and school-wide scales.

2. Underpinning research (indicative maximum 500 words)

To spur increased uptake of physics and astronomy in diverse, under-engaged audiences, researchers based in Queen Mary's School of Physics converted three inspirational 'big questions' from academia into school-appropriate formats: space weather, extrasolar planets, and neutrinos. These projects were implemented under the banner of Physics Research in School Environments (PRiSE) – a programme of sustained research-based schools engagement actively supported by the researchers themselves.

Space weather

Space weather is a topic of priority in space science, as it poses a threat to space-based technology. This is largely driven by how the stream of charged particles emanating from the Sun, the solar wind, interacts with the Earth's magnetic shield in space, the magnetosphere. Queen Mary's Dr. Archer proved a 45-year-old theory that the boundary of the magnetosphere resonates when struck by impulses [3.1]. To transform this topic into something intrinsically engaging and tangible, Archer took the novel approach of converting these inaudible waves into audio format. This enabled students to explore and analyse them using widely accessible off-the-shelf audio software. As a result of this project, PRiSE students became co-authors on a peer-reviewed paper that showed that resonances in the Earth's magnetosphere – ie the 'whistle' sounds that they discovered – were more prevalent than previously thought [3.2].

Extrasolar planets

Hunting for planets beyond our Solar System is a core focus of astronomical research, and one in which Prof. Nelson and Dr. Anglada-Escudé have played leading roles. They led international research efforts culminating in the discovery of our nearest neighboring exoplanet, Proxima b [3.3], and have detected Earth-sized planets using the 'transit photometry' method of detecting and characterising extrasolar planets [3.4], whereby a planet causes a small, but observable,

dip in stellar brightness as it passes across the disc of its 'parent' star. For PRiSE, they reframed this planet-hunting research from the perspective of A-level physics and computer programming, enabling students to apply newly acquired Python skills to the study of real data from NASA's high-profile Kepler and TESS missions. This led to the discovery of a transiting, Earth-sized planet around the nearby M dwarf, GJ 357 [3.4].

Neutrinos

Thought to be one of the most abundant particles in the Universe, the neutrino is also one of the most elusive, as it only weakly interacts with matter and is therefore incredibly difficult to detect. It is being explored by flagship international facilities such as the SNO+ collaboration, in which Dr. Wilson has held key roles. SNO+ hunts for neutrinos in a liquid scintillator underground, using photomultiplier tubes for detection, and cosmic ray muons for calibration [3.5]. To convey the excitement of such cutting-edge research to PRiSE students, Wilson gave schools simplified scintillator-photomultiplier detectors, providing students with hands-on experience using a complex detector, as included in A-level physics objectives. Students gathered and analysed their own data, exploring the properties of cosmic rays, and thus contributed to the testing of the above-mentioned detection-calibration system [3.5] that is essential for neutrino experiments.

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

[3.1] MO Archer, H Hietala et al. (2019). Direct observations of a surface eigenmode of the dayside magnetopause. *Nature Communications,* 10 (615). doi:10.1038/s41467-018-08134-5.

[3.2] MO Archer, MD Hartinger, … & Eltham Hill School Year 12 Physics students (2018). First results from sonification and exploratory citizen science of magnetospheric ULF waves. *Space Weather*, *16 (11)*, 1753-1769. doi:10.1029/2018SW001988.

[3.3] G Anglada-Escudé, PJ Amado, … RP Nelson et al. (2016). A terrestrial planet candidate in a temperate orbit around Proxima Centauri. *Nature 536*, 437-440. doi:10.1038/nature19106.

[3.4] R Lugue, E Pallé, … G Anglada-Escudé et al. (2019). Planetary system around the nearby M dwarf GJ357 including a transiting hot Earth-sized planet optimal for atmospheric characterization. *Astronomy & Astrophysics, 628, 39*. doi:10.1051/0004-6361/201935801.

[3.5] R Alves, S Andringa, … & JR Wilson (2015). The calibration system for the photomultiplier array of the SNO+ experiment. *Journal of Instrumentation 10, 03002*. doi:10.1088/1748-0221/10/03/P03002.

Evidence of the quality of the research:

[EQR. 1] PI, RP Nelson. (Apr 2015 – Mar 2019). Astronomy Research at Queen Mary 2015-2018. [ST/M001202/1]. *STFC*. STFC Consolidated Grant. GBP1,237,643.

[EQR. 2] PI, J Wilson. (Nov 2011 – Jun 2017). Probing fundamental properties of the neutrino at the SNO+ Experiment [ID 278310]. *ERC*. ERC Starting Grant. EUR1,345,471.

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

By transforming their scientific methods and findings into truly tangible and engaging science education projects, the PRiSE researchers enabled both students and teachers to access, interact with, and contribute to cutting-edge physics research, thus closing the divide between "real" and "school" physics that cultivates inequitably low participation. This has had lasting impacts on aspirations, attitudes, behaviours, skillsets, and national and international public engagement strategy.

PRiSE engaged a diverse range of 1,326 students, many from underrepresented groups

Over 1,300 (mostly A-level) students and 88 teachers participated from 67 London schools [5.1]. The programme engaged more disadvantaged groups than national statistics (women, ethnic minorities, multiple deprivation, students on free school meals) and exhibits far greater diversity than schemes such as HiSPARC, ORBYTS and IRIS (Figure 1). Through PRiSE, Queen Mary

has shown that students' ability to participate and progress in physics research is independent of gender, social or ethnic background [5.2].

The researchers supported schools over 6-month-long projects each year [5.1, 5.3]: a sustained timeframe chosen to overcome limitations of typical one-off outreach attempts in delivering lasting change in student aspirations and skillsets. Students and teachers ranked researcher interaction, via workshops, school visits, monthly Q&A webinars, printed/multimedia resources, and emails, as the most valued support element of PRiSE [5.1]. Young researchers often lack mentorship; PRiSE empowered students to engage and present their experiences at Queen Mary student conferences attended by researchers, teachers, family, and friends: *"The opportunity to work on these real-world projects with world-class researchers like Dr Archer is really exciting. It's amazing how relevant the A-level is to Dr Archer's research. A lot of the ideas that are being touched on are exactly the sort of stuff we're learning about in the classroom. It's a really lovely, mutually supportive activity"* (teacher from deprived area) [5.4]; "What was fantastic about the student conference was the presence of families and teachers. The pride was palpable. The role that itself will play in building the aspirations of the students is incalculable*"* (public engagement professional) [5.3].

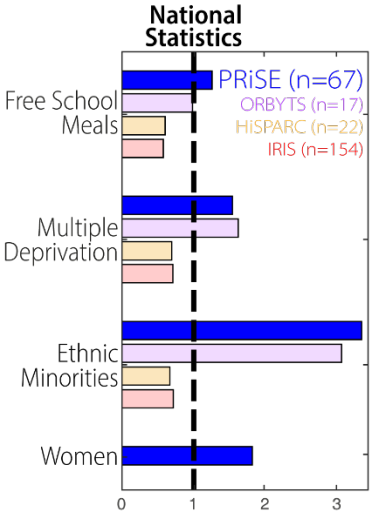

Figure 1: compares normalised medians for PRiSE vs national statistics and other schemes for engagement with disadvantaged groups. Data by sex not available for all schemes. Adapted from [5.2]. Copyright [2020].

PRiSE has boosted student confidence and uptake of STEM subjects in higher education

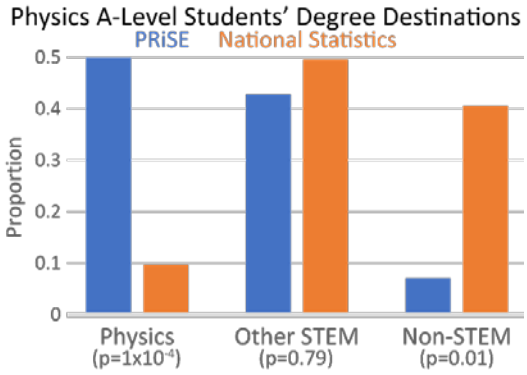

Figure 2: Degree destinations for Physics A level students for PRiSE vs national statistics. Reprinted from [5.5]. Copyright [2021].

Before and after self-reporting shows 96% of participants increased their confidence in scientific topics and methods relevant to the underpinning research. Students report, corroborated by teachers, developing on average 2-3 skills each that they otherwise would not have been able to access. These even remained in students' minds during follow-up surveys three years later [5.5]. Interviews have demonstrated the impact of PRiSE and the effect of a) media attention for the research [5.4] and b) the ability to contribute to novel research [3.2]: *"*It was truly amazing to hear how significant the event we found was, and that it will be forming the basis of a proper scientific paper"; "Hearing that kids at other schools have actually produced a paper, it gives you hope that it's actually something I can do"; "It's really cool because in the physics we learn at school we're often hundreds of years behind what leading physics researchers already discovered, but actually being at the forefront of stuff that's new and relevant is really exciting" (students from deprived areas) [5.4].

80% of students reported being more likely to continue with either physics or STEM education as a direct result of their involvement in PRiSE (note that they reported no overall tendency towards physics aspirations beforehand) [5.5]. Three years post-PRiSE, 50% are undertaking physics degrees, and 93% are studying a STEM subject, statistically significant increases on national rates (10% and 59% of A-level Physics students respectively, Figure 2): *"*I am now pursuing a physics degree from Cambridge. Thanks for helping me find my enthusiasm for Physics!" (ethnic minority student from deprived area) [5.5]. By contrast, many other (even sustained) outreach programmes show no real lasting impact in similar surveys [5.6].

PRiSE has improved teacher confidence and skill, and raised schools' STEM profiles
Systematic thematic analysis of feedback identified eight areas (Figure 3) of impact on teachers' practice and their schools, with subsequent quantitative analysis showing these as widespread. Teachers on average benefitted from 6.2 out of the 8 categories [5.5].

Gained new physics knowledge	Gained new research-based lesson content	Developed skills relevant to the research	Gained confidence in discussing research with students
Gained confidence in mentoring students	Shared student research work across their school	Raised the profile of STEM across their school	Developed a relationship with Queen Mary

Figure 3: the 8 areas of impact on teachers' practice and their schools. Adapted from [5.5]. Copyright [2021].

Teachers have thus reconnected with their subject at an academic level, while experiencing personal and professional development: "It has consolidated my understanding and teaching of exoplanets. I used some of the techniques in teaching detection of exoplanets in the astro topic of AQA's A-level going beyond the syllabus"; "I am now more aware of what our students are capable of – not just listening to visiting speakers but being actively engaged in real-world research" [5.5]. 70% of schools participate in PRiSE for multiple years, in spite of teacher turnover at 21% per year [5.2].

PRiSE has changed national outreach strategy and is being used internationally
PRiSE has won several awards [5.3], and been championed by leading UK outreach organisations:

SEPnet

SEPnet, a network of nine universities in south-east England, was directly influenced by PRiSE to change their Outreach and Public Engagement strategy. SEPnet Director of Outreach and Public Engagement, Olivia Keenan said, "the researchers involved in PRiSE have driven impressive impacts in school students' aspirations and skills, the uptake of STEM subjects in further and higher education, and the development of teaching practice. PRiSE has drawn on the specific research and expertise of researchers to drive these impacts in a way that would have not been possible without their involvement. The success of this research-based engagement with schools has prompted SEPnet to include a 'Research in Schools' theme for its Outreach and Public Engagement strategy for 2017-2024. This inclusion has been directly influenced by Archer's work in this area, with the PRiSE programme being explicitly highlighted in the strategy as a key example of good practice within SEPnet. This policy change will see the implementation of similar methods of using research and researcher expertise at UK universities. SEPnet will support this activity through in-kind contributions to programme development meetings and strategic planning and evaluation work, an estimated £27,000 over the next 3 years." [5.7]. Based on Archer's learning about how researchers can drive engagement with their research in new and effective ways, the University of Surrey received GBP2,000 of funding from SEPnet to develop a PRiSE-style astrophysics pilot project in consultation with Archer, which began in late 2019 [5.8].

The Ogden Trust

The Ogden Trust is a charitable trust aiming to increase physics uptake among underrepresented students. Chief Executive, Clare Harvey said, "We have highlighted PRiSE on our online resource area for Ogden Outreach Officers. The Ogden Trust is very happy to support the spread of this activity further, for example by committing to funding a best practice sharing workshop which contributes to the development of our national approach, resulting in the adoption of similar initiatives at more of our partner institutions. The opportunity to take part in authentic research and present findings to others, enables students to 'be' the scientist and develop that as part of who they are. Participating in research projects has a positive effect on

the uptake of physics by girls, and so this project can help address diversity problems in the subject" [5.9].

Internationally

Internationally, the success of PRiSE has led to the USA's National Oceanic and Atmospheric Administration making Archer's space science audio publicly available in 2018 and to the establishment in 2019 of a consortium of US institutions (UCLA, the Space Science Institute, and Virginia Tech). This consortium has developed a pilot programme to engage schools and the public similarly to Archer's PRiSE project. It has involved researchers and outreach professionals, leveraged the staff time of a programme manager and an undergraduate intern, and has also been used in undergraduate teaching at UCLA [5.10].

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

[5.1] MO Archer, J DeWitt & C Thorley (2020). Transforming school students' aspirations into destinations through extended interaction with cutting-edge research: 'Physics Research in School Environments'. *Geoscience Communication.* In review. doi:10.5194/gc-2020-35.

[5.2] MO Archer (2020). School students from all backgrounds can do physics research: On the accessibility and equity of the PRiSE approach to independent research projects. *Geoscience Communication.* In review. doi: 10.5194/gc-2020-37.

[5.3] Queen Mary University of London. (2017, March). *Physics Research in School Environments Programme*. http://www.qmul.ac.uk/spa/researchinschools. 19 October 2020.

[5.4] BBC Sounds. (18 October 2018). *Old Dogs and Physics in Space*. [Video]. BBC Inside Science. https://www.bbc.co.uk/sounds/play/m0000qpw.

[5.5] MO Archer & J DeWitt (2020). "Thanks for helping me find my enthusiasm for Physics!" The lasting impacts `research in schools' projects can have on students, teachers, and schools, *Geoscience Communication.* In review. doi: 10.5194/gc-2020-36.

[5.6] M Archer, J DeWitt, C Davenport, O Keenan, L Coghill, A Christodoulou, S Durbin, H Campbell, L Hou (2020). Going beyond the one-off: How can STEM engagement programmes with young people have real lasting impact? *Research for All*. In preparation. arXiv:2003.06162

[5.7] O Keenan. Director of Outreach and Public Engagement. *SEPnet* (testimonial letter, 21 April, 2020). [Corroborator 1]

[5.8] H Campbell. SEPNET/Ogden Public Engagement and Outreach Manager. *University of Surrey* (testimonial letter, 31 March, 2020). [Corroborator 2]

[5.9] C Harvey. Chief Executive. *Ogden Trust* (testimonial letter, 21 April, 2020). [Corroborator 3]

[5.10] M Hartinger. Research Scientist, Space Scientist Institute. *Virginia Polytechnic Institute and State University* (testimonial letter, 29 May, 2020). [Corroborator 4]