Institution: University of Birmingham		
Unit of Assessment: UoA 9, Physics		
Title of case study: Enhancing public engagement, interest, understanding and awareness of physics through novel outreach activities		
Period when the underpinning research was undertaken: 2012–present		
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:**
Prof. Cristina Lazzeroni	Professor of Particle Physics	2007–present
Prof. William Chaplin	Professor of Astrophysics	1999–present
Prof. Andreas Freise	Professor of Experimental Physics	2005–2020
Prof. Kostas Nikolopoulos	Professor of Physics	2012–present
Prof. Amaury Triaud	Professor of Exoplanetology	2017–present
Period when the claimed impact occurred: 1 August 2013–31 July 2020		
Is this case study continued from a case study submitted in 2014? Yes		

1. Summary of the impact

Impact has been achieved by making high-profile physics accessible beyond academia through a multi-strand engagement strategy. Specifically, we have:

- **Enhanced physics teachers' professional practice** and influenced curricula change;
- **Improved the awareness of STEM subjects amongst schoolchildren**, leading to these subjects being chosen as career pathways;
- **Influenced artists' creative practice** to explain complex science;
- **Improved engagement and reach** with the public's understanding of physics.

2. Underpinning research

The University of Birmingham's world-leading research in Particle Physics and Astronomy sits at the heart of the School's public engagement strategy. The work of five researchers underpins the impact. They are investigating the fundamental building blocks of nature (**Particle Physics**: Lazzeroni, Nikolopoulos), opening a new window on the universe (**Gravitational Waves**: Freise) and illuminating the life cycles of stars and their planets (**Stars and Exoplanets**: Chaplin, Triaud).

Particle physics

Since the 1930s, physicists have largely explained the universe through the *Standard Model*. The final piece of this framework came with the discovery at CERN in 2012 of the Higgs boson particle, which attracted the Nobel Prize in Physics. Our physicists led key parts of the analysis that uncovered the Higgs (Nikolopoulos) and built part of the ATLAS experiment that detected it [R1]. The *Standard Model* cannot however explain everything that we know exists and we are in the forefront of efforts to search for new physics beyond it, using two major experiments at CERN, NA62 and LHCb [R2]. Lazzeroni leads the international NA62 collaboration. The overall portfolio underpins our programme of engagement on Particle Physics with schoolchildren (including workshop activities). Our experimental detector work underpins our programme deploying particle detectors in schools, which the children use to conduct their own research.

Gravitational Waves

Einstein's theory of gravity revolutionised our understanding of space and time. His theory predicted the existence of gravitational waves, created by massive objects such as colliding black holes. In 2015, the Laser Interferometer Gravitational Wave Observatory (LIGO), an international collaboration we are part of, detected gravitational waves for the first time [R3, R4]. This discovery launched a new era in astronomy, revealing previously unseen objects in far-away galaxies. We have led analyses in LIGO to reveal the astrophysical sources of measured signals. We are one of only three UK universities that built LIGO detector hardware (Freise) and this activity underpins work with an artist developing a musical synthesiser based on the detectors. Our development of the widely used gravitational wave detector design software FINESSE was critical in the construction of our gaming apps for mobile phones.

Stars and Exoplanets
Stars are the building blocks of the Galaxy and provide sources of energy for creating the conditions that may support life on the planets they may host. We are a world leader in using the natural, resonant oscillations of stars (Chaplin) — asteroseismology — to characterise and study thousands of stars in our local solar neighbourhood [R5]. We use data from our own telescopes and NASA missions to reveal the otherwise hidden interiors of the Sun and stars. The resonances are due to trapped sound waves, like those of a musical instrument, and the use and interpretation of stellar oscillations and the pictures they paint of stellar interiors underpins our work with artists. We are also involved in breakthrough discoveries and studies of exoplanet systems (Triaud) [R6]. Our work with artists uses data on the characteristics and orbits of these newly discovered planets.

3. References to the research

[R1] ATLAS Collaboration (including K. Nikolopoulos), "Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC", *Physics Letters B*, 716, 1 (2012); DOI: 10.1016/j.physletb.2012.08.020; **Particle Physics**: detection of the Higgs boson at the Large Hadron Collider, cited 7724 times.

[R2] NA62 Collaboration (including C. Lazzeroni), "First search for $K^+ \rightarrow \pi^+ \nu\nu$ using the decay-in-flight technique", *Physics Letters B*, 791, 156 (2019); DOI: 10.1016/j.physletb.2019.01.067; **Particle Physics**: test of the Standard Model at NA62, cited 93 times.

[R3] Abbott, P. B. et al. (including A. Freise), "Observation of gravitational waves from a binary black hole merger", *Physical Review Letters*, 116, 061102 (2016); DOI: 10.1103/PhysRevLett.116.061102; **Gravitational Waves**: first detection of gravitational waves, first detection of a pair of black holes, cited 5767 times.

[R4] Abbott, P. B. et al. (including A. Freise) "GW170817: Observation of gravitational waves from a binary neutron star inspiral", *Physical Review Letters*, 119, 161101 (2017); DOI: 10.1103/PhysRevLett.119.161101; **Gravitational Waves**: first detection of gravitational waves from binary neutron stars, cited 3923 times.

[R5] W. J. Chaplin et al., "Asteroseismic Fundamental Properties of Solar-type Stars Observed by the NASA Kepler Mission", *Astrophysical Journal Supplement*, 210, 1 (2014); DOI: 10.1088/0067-0049/210/1/1; **Stars and Exoplanets**: first asteroseismic catalogue of fundamental stellar properties from the NASA *Kepler* Mission, cited 257 times.

[R6] M. Gillon et al. (including A. Triaud) "Seven temperate terrestrial planets around the nearby ultracool dwarf star TRAPPIST-1", *Nature*, 542, 456 (2017); DOI: 10.1038/nature21360; **Stars and Exoplanets**: key paper on one of the most well-known exoplanet systems, cited 654 times.

4. Details of the impact

We have improved the confidence of school teachers to teach physics and provided them with tools to do so, and we have improved the perception of STEM subjects amongst schoolchildren (primary and secondary) and made these subjects more accessible. We have enabled under-represented cohorts to feel they can continue with STEM subjects in higher education, and we have enhanced public understanding of physics through collaborations with artists to facilitate improved communication of science.

(i) ***Enhancing physics teachers' professional practice and their capacity to teach physics***

The way school teachers deliver physics curricula and syllabi has changed as a result of them participating in our training programmes (Lazzeroni), which are underpinned by lessons and resources based our Particle Physics research [R1, R2]. Specifically:

Over 300 primary schoolteachers from the UK, Italy and Greece delivered our lessons and resources in their schools after we had trained them [A, E]. This exposed children to cutting-edge physics research for the first time and reached around 5,000 UK children at more than 10% of primary schools in the West Midlands. Two international pilots reached around 550 children in Italy and 750 in Greece [A, E]. It was our dissemination of best practice in the educational literature [H] that led to the Italian programme, in which we trained teachers from 20 schools in collaboration with the Italian National Institute for Physics and Nuclear Research (INFN) [A, E]. The programme is in the process of being formally adopted (from 2021/22) as part of the teachers' training programme at the University of Turin [E].

A key change which resulted from our programme was that teachers are more confident to deliver physics in lessons. A Head Teacher in Italy said: "one of the key aspects of the program, namely the training of teachers by scientists, has been crucial in enabling the teachers to acquire a confident knowledge of the subjects" [E]. As a proxy indicator, of the 50 UK and Greek teachers we trained through the CERN pilot project *Playing with Protons* [A, G] which includes our resources, 100% said they had become more creative in their teaching methods and 80% confirmed that their confidence to deliver lessons had increased [C].

Our programmes have also changed how educators approach their everyday practice. Of 900 UK secondary schoolteachers who undertook our training, around half of those surveyed said there would be visible changes in their daily teaching delivery, and 78% said they would use our resources [C]. This equates to changing practice at one in ten of UK secondary schools, and the majority of those in the West Midlands.

(ii) ***Improved the awareness of, and attitudes towards, STEM subjects among primary and secondary school pupils***

Perceptions of science have been positively changed for those cohorts of **primary and secondary schoolchildren in the UK and Italy who** engaged in our programmes. Specifically:

Understanding, attitude and interest towards physics was promoted amongst schoolchildren though our *World of Particles*, *Particle Physics through Visual Art* and *Particle Dance* programmes, which used activities based around play, drawing and sculpture to teach Particle Physics and our latest results at CERN [R1, R2]. This is bridging the gap between making science physically accessible, and understandable and relevant, which is essential to capturing students' interest during their education. These engagements improved levels of understanding of physics, shown by the fact that of 595 primary schoolchildren at 17 UK schools who participated in *World of Particles*, 90% reported that they had spoken to their family about what they had learnt and 95% were able to correctly recall information taught on the programme over a month later [C]. *World of Particles* was developed with the Ogden Trust, supported by a prestigious STFC Public Engagement Fellowship (Lazzeroni). This impact was recognised through the award of the 2019 Institute of Physics *Lise Meitner Medal and Prize* to Lazzeroni for "her exceptional innovation and leadership in making contemporary Particle Physics accessible to a large and diverse audience."

The programmes have **made physics a more accessible subject** [H], with more than three quarters of the 200 children who took part in the *Particle Physics through Visual Art* and *Particle Dance* workshops confirming this. Nikolopoulos won the inaugural *ERC Public Engagement with Research Award* (2020) for this "impact on people that are not the regular audience for frontier science." Children's interest in science has also improved through their participation in the programme, with 93% of the 595 UK children and 75% of the 550 Italian children who took part reporting that they were more interested in science than before [A, C, E].

We have made studying STEM subjects at university and pursuing a career in science more attractive for secondary school students, especially for women and for those from disadvantaged groups. We did this through our student-led research programme [A, C, E, G] where schoolchildren used particle detectors [R1, R2] from the European HiSPARC Project to perform their own research. We engaged 1,650 children in 13 regional schools. 90% of the 2015 cohort who were surveyed in detail decided to pursue science in Higher Education compared to fewer than 10% considering this before [C, E]. Half of the schools are from deprived areas, with a quarter in the most deprived decile [A]. Ensuring that students from these backgrounds, who tend to lack science capital, have opportunities to engage further in this area is important in terms of its contribution to diversification in STEM subjects. Around half of this cohort were female students, who are also less likely to study a STEM subject at university or enter a STEM career than their male counterparts; enhancing their understanding and enthusiasm for science subjects is vital to ensuring that the field is more inclusive. To give an example, one HiSPARC year-group from Bordesley Green Girls School in an under-privileged area of Birmingham presented their work at a Royal Society Summer Exhibition. Their teacher said "some were mistaken for undergraduates and offered jobs!" [E]. This change in attitudes was also seen among those on the *Particle Physics through Visual Art* workshops, of which 33% reported being more likely to study physics at university than they were before the activity [H].

(iii) Influencing artists' creative practice to explain complex science and improve their audience reach

New ways of thinking among artists have been generated through our co-production of exhibitions, performances and events [A, E]. Working with artists who employ sound, dance, opera, photography, film and technology, our PHYART@UoB programme produced **new forms of artistic expression** — inspired by and incorporating all areas of the underpinning research (Chaplin [lead], Triaud, Nikolopoulos and Freise) [R1–R6] — and ultimately **enabled the artists to reach audiences in new settings** [A, C]. One artist said that working together had "fostered new relationships and platforms to share the work", while another stated that "sharing ideas with direct feedback and applying them directly afterwards allowed for richer and creative compositions" [E]. Key examples of this extended audience reach are the presence of our collaborative work at science museums (Thinktank, Birmingham; We The Curious, Bristol) and science festivals (e.g. Oxford IF) with a combined audience of almost 14,000 [A] who otherwise may not have engaged with this novel interconnection of art and science.

These collaborations, which benefit both science and the arts, have been **identified as exemplars of best practice** in the National Coordinating Centre for Public Engagement's (NCCPE) consultation and report on how researchers and artists can work together to engage the public with research [G]; and in the Arts and Humanities Research Council (AHRC) *Cultural Value Project*, which looked at why the arts and culture matter and how we capture the effects that they have [G]. That this has enhanced creativity within the STEM field is evident through *Wire* music magazine's review of our work with artist Devine, which stated it "reminds you that it's still possible to factor in human imagination and physical presence into our understanding of the universe, something that's missing from so many other big data projects" [F].

(iv) Improving the public's engagement and understanding of physics and extending its reach

Public audiences' perceptions of physics have changed through their engagement with our research [R1–R6; C, E], especially around how art and science can intersect to better communicate science. This has enabled members of the public to make new connections between physics and the world around them (90% of those surveyed [C]) and changed their views on how artists and scientists can work together to communicate science (>90% [C]). Audiences we interviewed at our public events said they had learned new ideas (98% [C]) and more than 80% wanted to find out more and would continue to talk and think about the event they attended. These changed perceptions help citizens appreciate and value the relevance of STEM science to their everyday lives, which is important given the vital contribution of STEM to the prosperity of society.

Our work with artists has been picked up in the mainstream media, which enabled this change in perception to reach millions more people. This includes popular Channel 4 programme *Gogglebox* featuring a BBC news segment on our asteroseismology research [R5] — including turning stellar oscillations data into sound, which underpins our work with artists Devine and Robson — that reached millions of people [B], as well as multiple BBC radio programmes featuring our work [B]. One presenter stated "what a totally astounding, amazing project."

We used a range of approaches to achieve this and extend the reach to alternative audiences, including:

- Co-productions with artists as part of our PHYART@UoB programme [A, E], which engaged 15,000 people at live performances and exhibitions [A];
- Developing and making available gaming apps for mobile phones, based on gravitational wave detectors [R3, R4], which have been downloaded by the public almost 40,000 times and one game completed more than 15,000 times [D]. Freise was awarded the 2017 *Education and Outreach Award* by the LIGO collaboration in recognition of his pioneering efforts in creating LIGO-oriented interactive educational applications;
- Traditional forms of engagement, demonstrating particle and gravitational waves detectors [R1–R4] at Royal Society Summer Exhibitions (2014–2017) and other national science festivals, to a total audience of over 130,000 [A].

5. Sources to corroborate the impact

[A] *Events and Audience Figures*: numerous events and engagement activities, including at schools, to public audiences; includes deprivation data for schools.

[B] *Media Coverage* demonstrating reach: 5 Minute Oscillations of the Sun, BBC World Service Sounds of Space, June 2015; sounding stars coverage, BBC TV and Radio news and *Gogglebox*, Channel 4, May 2018; *Late Junction*, BBC Radio 3, May 2018; Digital Planet's 18th birthday show, BBC World Service, September 2019.

[C] *Questionnaires and Surveys*: from activities engaging primary school and secondary school students, and training of teachers; of attendees and participants from festivals, events, workshops, performances, exhibitions.

[D] *Online Access Data*: downloads and online score tables for gaming apps.

[E] *Testimonials*: from Dr Andrea Quadri, Head teacher, K-12 School Carvico, Italy (dated 28 December 2020), and Dr Sandra Malvezzi, Lead Scientist of Italian National Institute for Physics and Nuclear Research (dated 12 January 2021), both on engagement in Italian schools; from schoolchildren and teachers; Ogden Trust; from attendees and participants at events, workshops, performances, exhibitions; of artists in *PHYART@UoB* project.

[F] *Reviews*: of *Poetics of Outer Space*, *Wire* magazine, Issue 376, June 2015.

[G] *Reports*: A. Alexopoulos, M. Pavlidou, S Cherouvis, "Playing with Protons: a training course for primary school teachers at CERN", *Physics Education*, 54, 015013 (2019), DOI: 10.1088/1361-6552/aae7a4K; article in *Young Scientists Journal* by schoolchildren at King Edward VI High School for Girls on their HiSPARC research; excerpts from AHRC *Cultural Value Project* final report; and National Coordinating Centre for Public Engagement (NCCPE) report "What Works: Art Research Collaboration".

[H] *Academic Papers* (containing school engagement figures and testimonials): M. Pavlidou, C. Lazzeroni, "Particle physics for primary schools—enthusing future physicists," *Physics Education*, 51, 054003 (2016), DOI: 10.1088/0031-9120/51/5/054003; I. Andrews, K. Nikolopoulos, "Introducing particle physics concepts through visual art," *Physics Education*, 53, 054001 (2018), DOI: 10.1088/1361-6552/aad276/meta; Nikolopoulos, M. Pardalaki, "Particle dance: particle physics in the dance studio," *Physics Education*, 55, 025018 (2020), DOI: 10.1088/1361-6552/ab6952; L. Carbone et al., "Computer-games for gravitational wave science outreach: Black Hole Pong and Space Time Quest," *Journal of Physics: Conference Series*, 363, 012057 (2012), DOI: 10.1088/1742-6596/363/1/012057.