Institution: University of Exeter

Unit of Assessment: UoA 9 Physics

Title of case study: Inspiring the next generation of STEM students through novel and immersive engagement.

Period when the underpinning research was undertaken: 2013-2020

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:
Nathan Mayne	Associate Professor	2011-Present
Justin Dillon	Professor (Graduate School of Education)	2017-Present
Eric Hèbrard	Senior Lecturer	2016-Present
David Sing	Associate Professor	2010-2018
Sasha Hinkley	Associate Professor	2014-Present
Hugo Lambert	Associate Professor (Mathematics)	2010-Present
James Manners	Lecturer (Mathematics)	2019-Present

Period when the claimed impact occurred: 2014-2020

Is this case study continued from a case study submitted in 2014? N

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

Finding effective ways to communicate science, technology, engineering, mathematics and medicine (STEMM) research to the public and students in deprived areas can be challenging, but is critical for encouraging the uptake of STEMM studies and careers. Prof. Mayne, working with local SMEs, pioneered the use of virtual reality (VR) in the communication of cutting-edge exoplanet research, developing an innovative and immersive VR Exoplanet Tour **[5.1]**. This unique resource has reached a huge worldwide audience; attracting over 12 million views and over 5,000 comments, making it **the most viewed science-based VR resource on the entire YouTube platform**, while also winning a prestigious Lovie award.

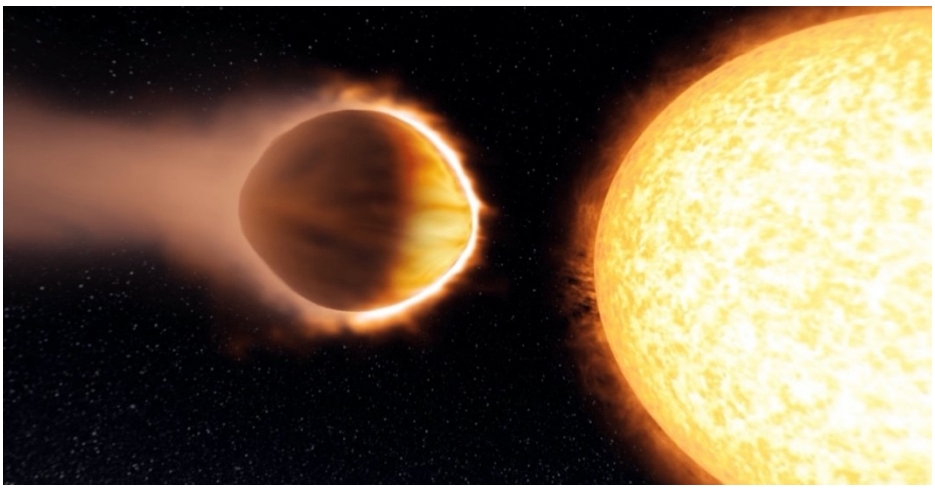

*Fig 1 Visualisation of the evaporating Wasp-121b captured from **[5.1]***

The VR Exoplanet Tour, has since been screened to over 18,000 people through international exhibitions and over 1,000 students across Devon and Cornwall. Feedback indicated that, in response to the VR Tour, **97% of students were inclined towards STEM based subjects**, and >50% stated they were inspired to work in science or technology. We estimate that our work has positively influenced millions of people around the world towards STEM. The project has also **supported our partners' economic growth and success,** increasing their turnover, staffing, external investment, products and business portfolios.

2. Underpinning research (indicative maximum 500 words)

The Astrophysics Group at the University of Exeter (UoE) is one of the largest groups in the UK studying stars and planets, with a wide-ranging research programme at the forefront of astrophysical observation and modelling. One of the main areas of expertise is in exoplanet research: finding and characterising planets orbiting distant stars. This research covers both observational studies using large-scale ground and space-based facilities, led by Prof. D. Sing and Prof. S. Hinkley, and state-of-the-art theoretical modelling aimed at understanding the potential climates of these distant worlds, led by Prof. N. Mayne, Dr E. Hèbrard and Prof. Hugo Lambert (Mathematics).

This impact case study focuses on science communication and public engagement activities designed to inform and inspire a wide range of audiences about the potential environments and climates of distant worlds underpinned by the group's research findings. By combining theoretical models with the observational data, the group were able to determine quantities such as the temperature, pressure, composition and wind speeds in exoplanet atmospheres. These results, in turn, were then used to generate scientifically accurate simulated environments. Immersive virtual reality (VR) animations, the first of their kind, were created through extensive, iterative, design processes involving close communication between the researchers and visual effects programmers. As a specific example, a landmark study demonstrated the transition from clear, to cloudy, to hazy atmospheres for a subset of exoplanets termed hot Jupiters (Jovian planets in close orbit to their parent star) **[3.1]**. These observational data, combined with 3D numerical climate simulations of the planets **[3.2, 3.3]** provided the required insight to develop realistic scenes within the animation of the planets Wasp-121b and HD189733b (Osiris).

Observations and modelling of another class of exoplanets, young Jupiter like planets **[3.4]**, was also used to develop the visualisation of the planet LkCa 15b. For terrestrial or Earth-like planets, sophisticated climate modelling performed at UoE provided the first insights into the potential water-based cloud cycle for potentially habitable exoplanets **[3.5]**. This research informed development of the scenes featuring Kepler-62e, 55 Cancri e and Trappist 1e. The individual animations were combined into a `VR Exoplanet Tour'.

Finally, and more recently, research exploring the impact of dust in the climate of potentially habitable exoplanets **[3.6]** has been converted into a format accessible to students. These resources were then incorporated into engagement sessions, performed online and in person.

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

[3.1] Sing, DK, Fortney JJ, Nikolov N, Wakeford HR, Kataria T, Evans TM, Aigrain S, Ballester, GE, Burrows AS, Deming D, Désert J-M, Gibson NP, Henry GW, Huitson CM, Knutson HA, Lecavelier Des Etangs A, Pont F, Showman AP, Vidal-Madjar A, Williamson MH, Wilson PA. *"A continuum from clear to cloudy hot-Jupiter exoplanets without primordial water depletion"*. Nature, 529:59–62. (2016). DOI: 10.1038/nature16068

[3.2] Amundsen DS, **Mayne NJ**, Baraffe I, Manners J, Tremblin P, Drummond B, Smith C, Acreman DM, Homeier D. *"The UK Met Office global circulation model with a sophisticated radiation scheme applied to the hot Jupiter HD 209458b*". Astronomy and Astrophysics, 595:A36. (2016) DOI: 10.1051/0004-6361/201629183

[3.3] Lines S, **Mayne NJ**, Boutle IA, Manners J, Lee, GKH, Helling CH, Drummond B, Amundsen DS, Goyal J, Acreman DM, Tremblin P, Kerslake M. *"Simulating the cloudy atmospheres of HD 209458 b and HD 189733 b with the 3D Met Office Unified Model"*. Astronomy and Astrophysics, 615:A97. (2018) DOI: 10.1051/0004-6361/201732278

[3.4] Hinkley S, Kraus AL, Ireland MJ, Cheetham A, Carpenter JM, Tuthill P, Lacour S, Evans TM, Haubois X. *"Discovery of seven companions to intermediate-mass stars with extreme mass ratios in the Scorpius-Centaurus association"*. Astrophysical Journal, 806:L9. (2015) DOI: 10.1088/2041-8205/806/1/L9

[3.5] Boutle IA, **Mayne NJ**, Drummond B, Manners J, Jayesh G, **Lambert FH**, Acreman DM, Earnshaw PD. *"Exploring the climate of Proxima Centauri B with the Met Office Unified Model"*. Astronomy and Astrophysics, 601:A120. (2017) DOI: 10.1051/0004-6361/201630020

[3.6] Boutle IA, Joshi M, **Lambert FH**, **Mayne NJ**, Duncan L, **Manners J,** Ridgway R, Kohary K. *"Mineral dust increases the habitability of terrestrial planets but confounds biomarker detection"*. Nature Communications, 11, 2731 (2020). DOI: 10.1038/s41467-020-16543-8

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

In 2014, as one of >50 engagement events delivered over the last 6 years by Prof. Mayne, the BBC's annual astrophysics programme, **'Stargazing Live!'**, included a filmed segment on the research of the UoE's Astrophysics group **[3.1-3.3]**. The programme reached 2.78M viewers and achieved the second highest unique website views for the entire BBC **[5.2]**. Executive Producer, Helen Thomas referred to Mayne's involvement as "*a good example of how complex and potentially difficult to understand science can be articulated for a wide audience.*" **[5.2]**. During the episode, a visualisation featuring exoplanet research outcomes, created by Prof. Mayne and Prof. Sing with BBC visual artist Dave Storr, was used. This visualisation inspired a local SME, Engine House VFX (EHVFX), to approach Prof. Mayne to form a collaboration aimed at developing new, innovative and inspiring, research-led media. Working with EHVFX and Bristol-based science communication centre, We The Curious (WTC), the UoE researchers created the first fully immersive VR experience of exoplanet environments. During production, the Astrophysics Group produced simulations of exoplanet climates and predicted realistic atmospheric conditions of exoplanets. These simulations were then recreated to be viewed during an immersive VR Exoplanet Tour.

Enhancing global public understanding of STEMM and Exoplanets: Since its launch in 2017, the VR Exoplanet Tour has reached a colossal worldwide audience, attracting over 12 million views and more than 5,000 comments on YouTube since 2017 **[5.1]**. For context: the number of views is an order of magnitude greater than the entire online catalogue of WTC. It is easily the most viewed exoplanet related contribution, and the most viewed science-based VR resource on the entire YouTube platform **[5.1**]. The rate of views is sustained at >3.5 million views/year, compared to videos on comparable popular physics channels which typically achieve a few hundred thousand views/year **[5.3]***. The final production was also used as part of a VR exhibit at the National Space Centre (NSC) **[5.4]** and screened to around 8,000 people at the WTC planetarium, while also generating a fourfold increase in subscriptions to the WTC's YouTube channel **[5.5]**. Additionally, the VR animation was used as part of an exhibition in France (with alternative commentary), reaching a total of around 10,000 people **[5.6]**. The production went on to achieve further international recognition: in 2018, it won a Bronze award and the 'People's Choice Award' in the 'Internet Video' category at the European creative industry Lovie Awards **[5.7]**.

The impact this immersive experience has had on people is evident from the comments on YouTube. For example:

"When you learn more in a YouTube video than a whole school year…"
"It was like a trip to the planetarium. Love It. I'm an educator and I will definitely be including these VR videos in my classroom."
"If science class were as awesome as this."

Videos on the US-based Minute Physics, the largest and most popular physics channel on YouTube, typically receive hundreds of thousands of views per year, while its most popular ever video averages 2 million views/year. For the UK based and highly acclaimed Sixty Symbols channel, the most viewed video ever receives an average of 240,000 views/year. Data from YouTube channel pages **[5.3].*

*Fig 2 Visualisation of Trappist-1 from the surface of Trappist-1e captured from **[5.1]***

***Increasing student aspiration in STEMM studies and careers**:* Building on the Astrophysics Group's research and outreach, Prof. Mayne and Prof. Dillon set up the Exoplanet Outreach Programme in 2018. An investment in VR headsets has allowed students to view the VR animation as part of a wider engagement session. Due to the impact of COVID-19, these sessions have now moved online, enabled by the creation of an online exoplanet project. As of the REF submission date, this outreach programme has reached over 1,000 students across a network of schools in the Southwest, covering several regions with very low rates of progression to higher education and areas ranking high for `Indices of Multiple Deprivation'. In addition, we have adapted our Nature Communications article **[3.6]** for the "Science Journal for Kids", providing an articulation of our research particularly aimed at school children. All of these resources can be accessed through Prof. Mayne's group website **[5.8]**

Feedback questionnaires obtained from a sample of 378 students who participated in our outreach programme has allowed us to quantitatively assess the impact of our VR media on attitudes towards science. In short: our VR experiences have a very positive impact, with 97% of the students reporting that their feelings towards STEM based subjects had changed positively, and >50% stating they were inspired to work in a science or technology job in future **[5.9]**.

Our outreach programme was also featured in a regional news broadcast (BBC Spotlight **[5.9]**), including interviews with staff and students at Pool Academy. Claire Meakin, Principal at Pool Academy stated: "*The students were captivated during the session, and since we have noticed an increase in their interest in science*." **[5.9]**. Meanwhile, Marcus Corrie, Science Teacher at Woodrofe School commented: *"An excellent and engaging experience for our A level physicists, a perfect complement to their studies... linking real research to a tangible experience for the pupils, which fuelled enquiry and debate about the nature of these worlds…I strongly believe that it has inspired a number of our students to consider studying physics beyond GCSE*." **[5.9]**. This evidence gives an indication of the impact of the online immersive animation on science engagement. Combined with the global reach of our YouTube resources, our findings suggest millions of people around the world will view STEM subjects and STEM careers more positively.

Supporting economic growth and success: The development and use of the immersive VR in science communication has also had a significant and positive impact on our partner SMEs' economic growth and stability. EHVFX's Business Development Manager, Julia Le Gallo commented: *"Involvement with this project created an opportunity for us to develop areas of our work not previously considered, and in turn to pioneer a new approach to CGI and 360 immersive environments".* She further stated that: *"We have experienced an increase in enquiries from other companies - from the space sector especially. The Exoplanet Explorers project has been a great asset to apply to space-related content tenders, such as for Aerospace Cornwall, where we created eight short animations about the Cornish space and aerospace sectors. We are part of the Cornish space cluster as content providers in 2D, 3D and VR, which has led to further enquiries… We definitely learnt a lot from this project, and afterwards we find ourselves at the*

forefront of immersive content development in the UK." **[5.10]**. Further, according to Julia Le Gallo, *"Engine House has grown steadily thanks to our involvement on the Exoplanet Explorers project, with a turnover around £200K. We were also able to grow up to five people – two more staff added to the original team of three"* **[5.10]**. Additionally, alongside the fourfold increase in subscribers to WTC's YouTube channel, WTC also secured an STFC Public Engagement Spark Award to develop space-themed digital content, working with Prof. Mayne and members of the UoE Astrophysics group **[5.5]**.

Building on our successful partnership, a second immersive VR experience has been created with EHVFX, which in 2020 entered final production stages. It adopts a more cinematic approach, with research outcomes presented in a less explicit way (i.e. a 'stealth learning' approach). This animation will also serve as an introduction to a pedagogical web-based game, funded by a recent STFC Nucleus award. The game is currently being co-developed with Fish in A Bottle (an award-winning digital agency), and a Young Persons Advisory Panel (YPAP). The co-development process itself has had a positive impact on the young people involved. Frances Britton – a student at the Exeter School of Mathematics, commented that *"taking part in YPAP … left me with far more enthusiasm towards astrophysics"* **[5.11]**. Once completed, the new VR resource and game will be released worldwide through WTC's web platform, and will also feature in both UoE's outreach programme and a mobile exhibit developed by the National Space Centre. The release of these new resources has been delayed due to the ongoing pandemic (target April 2021).

Summary statement: This impact case centres on the development of an entirely novel and unique VR resource that has changed the attitude of a wide audience towards careers in STEM. It demonstrates the power of connecting leading academic research with industry partners to develop new ways of communicating science to the public. Our immersive VR animation, which brings to life world-leading research into the climates of exoplanets, has reached millions of people worldwide and received a European award for creative content. In addition, through a focused programme of engagement events, students across the South West, a region with historically low uptake of higher education, have been inspired to engage with STEM-based research. Finally, our partner SMEs have benefited from the collaboration with academic researchers, raising their profiles, increasing their turnover and staffing, stimulating external investment, creating new products and considerably enhancing their business portfolios.

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

5.1 VR Exoplanet Tour: Available at www.youtube.com/watch?v=qhLExhpXX0E. Stats report and viewer analytics available on request. Viewing comparison data found using YouTube's own search by combining "VR" and "science" queries:
www.youtube.com/results?search_query=VR+science&sp=CAM%253D
5.2 BBC Stargazing Live! Available at www.bbc.co.uk/programmes/b03pn83c. Available on request: (a) Evidence report, containing context, audience and viewer numbers and social media mentions.(b) Testimonial by Helen Thomas (Executive Producer, BBC).
5.3 Data available from channel home pages:
www.youtube.com/user/minutephysics/videos?view=0&sort=p&flow=grid
www.youtube.com/user/sixtysymbols/videos?view=0&sort=p&flow=grid
5.4 Testimonial. Space Communications Manager, National Space Centre.
5.5 Testimonial CEO, We The Curious.
5.6 Testimonial & report from Florian Delcourt S[cube].
5.7 Lovie Award Winners List 2018 - screenshot, context and links.
5.8 Engagement materials available at: http://exoclimatology.com/#outreach
5.9 Sample of school-based outreach evidence; testimonials from teachers and media coverage of the programme.
5.10 Testimonial. Business Development Manager, EngineHouse VFX.
5.11 Game co-development evidence and student testimony.