Institution: Royal Northern College of Music (RNCM)

Unit of Assessment: 33 - Music, Drama, Dance, Performing Arts, Film and Screen Studies

Title of case study: PRiSM – Creating innovative new music and software through the interdisciplinary collaboration of scientists, mathematicians and composers.

Period when the underpinning research was undertaken: 2011 - June 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:
Professor Emily Howard	Director PRiSM and Professor of Composition	Sept 2005 – present
Dr Sam Salem	PRiSM Lecturer in Composition	Nov 2019 – present
Dr Christopher Melen	PRiSM Research Software Engineer	Oct 2019 - present

Period when the claimed impact occurred: 2015 - December 2020

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

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

PRiSM, the RNCM Centre for Practice & Research in Science & Music, promotes a collaborative interdisciplinary approach to musical composition which has had a number of impacts on creativity, culture and society. Including scientists in the creative process of composition, through enduring partnerships with composers, stimulated reflection on their own research from a new perspective, leading to new insights. Innovative curation and programming of the resulting musical works attracted new audiences for mathematics, science and contemporary music, and changed a cultural organisation's approach to programming future events. Leading edge technology, developed and evolved in collaboration with composers, led to innovative new methods of composition.

2. Underpinning research (indicative maximum 500 words)

PRiSM was established as an interdisciplinary research centre at RNCM in 2017 by Emily Howard, RNCM Professor in Composition, Marcus du Sautoy, Simonyi Professor for the Public Understanding of Science and Professor of Mathematics at Oxford University, and David de Roure, Professor of e-Research at the University of Oxford. Dedicated to the creation of new work through collaboration between musicians, mathematicians and scientists, PRiSM was awarded £914,000 in 2019 from the Research England fund *Expanding Excellence in England* (E3).

Howard has been a composer and academic at RNCM since 2005. With a background in mathematics, her compositions are frequently informed by scientific and mathematical concepts. In 2015, she was appointed Leverhulme Trust 'Artist in Residence', in the Department of Mathematical Sciences (DMS) at the University of Liverpool (UoL), collaborating with researchers in contemporary mathematics. Howard subsequently composed ***Torus* (2016) [3.2],** part of her series *Orchestral Geometries* "transforming mathematical notions into musical ideas has become an important part of what I do".

Ada Lovelace (1815-1852) is of particular interest to the member of PRiSM. Lovelace worked with Charles Babbage on his proposal for a computing machine, the Analytical Engine, and proposed how the Engine could be used to create music. Howard's ***Ada sketches* [3.1]**, part of ***The Lovelace Trilogy* (2011)**, imagines the inner world of Lovelace as she explores a mathematical equation solved by the Analytical Engine. ***But then, what are these numbers?* (2019) [3.3]** was commissioned by the Barbican Centre for the event *Ada Lovelace: Imagining the Analytical Engine,* curated by Howard as Director of PRiSM. The piece is based upon a

setting of a letter by Lovelace to her mother. The text is dissected, randomised and reordered using algorithms from the earliest days of computing that form the foundations of modern Artificial Intelligence (AI).

PRiSM SampleRNN [3.5] is a computer-assisted compositional tool released in June 2020, PRiSM's first major contribution to the field of Machine Learning. It generates new audio outputs by 'learning' the characteristics of an existing corpus of sound or music. Changing parameters of the algorithm and how the dataset is organised significantly changes the output, making these choices part of the creative process. The audio generated can be used directly in a composition or to inform notated work to be played by an instrumentalist. The software was developed in response to work by Dr Sam Salem, PRiSM Lecturer in Composition. For his piece ***Midlands* (2019) [3.4]**, Salem made field recordings whilst walking 120km of the River Derwent. These materials were used to synthesize new sounds with Wavenet, a deep-learning algorithm, but the speed of the workflow made it difficult to explore the full possibilities of the technique. An alternative, SampleRNN, represented an opportunity to generate sound more quickly but the code was broken (documented in the PRiSM blog post *A Psychogeography of Latent Space* **[5.6]**). PRiSM Research Software Engineer Dr Christopher Melen, undertook a complete reimplementation of the SampleRNN code, fixing broken dependencies and upgrading it to work with the latest versions of Python and Tensorflow. It constitutes a completely new implementation of the SampleRNN architecture.

The release of PRiSM SampleRNN was accompanied by a model developed by Salem using data from the RNCM's world-class archive of choral music. Since then, it has developed into one of PRiSM's major projects, bringing together practitioners across a diverse range of disciplines and fields of study, and illustrating PRiSM's core research concerns of collaborative and interdisciplinary effort. It is currently being used in projects by composers, musicians and technologists across the globe. A free and open-source project, the latest release can be downloaded from the software development platform *GitHub*. The software is readily available (open source) and the technique has been made explicit through a number of online resources and performances demonstrating this creative application of AI; informing technology researchers, other arts practitioners, educators and the general public.

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

[**3.1] Ada Sketches (2011)** Music by Emily Howard, text by Laura Tunbridge.
Commissioned by Soundings, Austrian Cultural Forum (ACF), London
World première: 12 May 2011 Soundings Ensemble, Austrian Cultural Forum, London
Published by Edition Peters [EP251982]
https://www.edition-peters.de/works/ada-sketches/251982

[3.2] Torus (2016) by Emily Howard.
BBC co-commission with the Royal Liverpool Philharmonic Orchestra
World première: BBC Proms 25 August 2016, Royal Liverpool Philharmonic Orchestra cond. Vasily Petrenko, Royal Albert Hall, London, UK. Broadcast live on BBC Radio 3.
Winner of a British Composer Award 2017 (Orchestral Category).
Published by Edition Peters [EP73341] https://www.editionpeters.com/product/torus/ep73341

[3.3] But then, what are these numbers? (2019) by Emily Howard
Commissioned by the Barbican Centre
World première: Britten Sinfonia. Milton Court Concert Hall, London 2 November 2019
Published by Edition Peters [EP73473]
https://www.editionpeters.com/product/but-then-what-are-these-numbers/ep73473

[3.4] Midlands (2019) by Sam Salem
Commissioned by and premiered at the Bludenzer Tage Zeitgemässer Musik Festival by the ensemble Distractfold. A video of the performance is available here:
http://www.osamahsalem.co.uk/?page_id=1556

[3.5] PRiSM SampleRNN (2020)
Full code and documentation available from Github https://github.com/rncm-prism/prism-samplernn and the Google Colab Notebook https://colab.research.google.com/gist/relativeflux/10573e9e1b10b1ff45e3a00099259741/prism-samplernn.ipynb
Funded by Research England, Expanding Excellence in England (E3), which awarded £914,000 to PRiSM in 2019, funding research for three years until July 2022.

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

PRiSM created innovative new music and software through the interdisciplinary collaboration of scientists, mathematicians and composers, leading to a number of impacts on creativity, culture and society. Innovative communication of science, mathematics and a government healthcare initiative engaged new audiences in contemporary music and changed a cultural organisation's approach to programming. Machine learning (ML) and artificial intelligence (AI) were applied to contemporary classical music in a new way, changing the practice of composers and demonstrating a novel application of the technology to the general public.

Collaborative development of new software changed creative practices
Dr Melen is the first computer scientist to hold the post of Research Software Engineer at RNCM. As well as developing the code for PRiSM SampleRNN **[3.5]**, he collaborated with RNCM and external composers, running the models that they designed together on the PRiSM Deep Learning Machine and exploring the effect of changing the parameters of the software on their specific audio data. As part of this iterative process, he found new ways to 'tune' the models in response to each composers' needs. The application of ML to contemporary classical orchestral music, rather than modern popular music, presents unique data challenges in terms of the characteristics of the music. "Nobody else has done this to my knowledge, to this extent, on this kind of music before". *Interview with Dr Christopher Melen* **[5.6]** Dr Melen also engaged with users exploring PRiSM SampleRNN through the platform where it is deployed (user *relativeflux* on GitHub). Comments from experienced followers of SampleRNN and non-experts alike, were positive ("Thanks for keeping Samplernn alive!"; "Best parameters for a layperson"; " I'm a musician and a teacher, and I needed a working and well documented RNN to introduce my students to") **[5.6]**. Melen's PRiSM blog post *A Short History of Neural Synthesis* (22 May 2020), outlines the history and development of the code. A PRiSM tweet sharing the post was the top tweet for May 2020 (6,884 impressions) **[5.7]**

PRiSM invited American trombonist Weston Olencki to RNCM in December 2019 where Dr Salem captured over 2,000 individual sound recordings of solo trombone performance. Salem trained PRiSM SampleRNN code on the corpus of Olencki's extended techniques to generate material for use in composition (*Psychogeography of Latent Space* **[5.6]).** On 26 September 2020, composer, performer and vocalist Jennifer Walshe gave the world premiere of *Ireland: A Dataset*, live streamed from the National Concert Hall in Dublin. A dataset of recordings of Irish traditional songs were analysed using PRiSM SampleRNN to generate AI-generated versions which were then incorporated into the performance. Music Critic Alex Ross wrote "The results are at once nonsensical and oddly charming: Walshe seems to be suggesting that randomization can restore mystery to traditional material." (*Jennifer Walshe's Sublime Chaos*, The New Yorker, October 19, 2020 **[5.6]).**

Enduring partnerships between scientists and composers led to new research insights
Howard's work with Lasse Rempe (Professor of Pure Mathematics) during her Leverhulme Residency in 2015 had a profound and long-lasting effect on interaction between the UoL Department of Mathematical Science (DMS) and other departments such as Physics, Chemistry and English with the Department of Music, and led to new interdisciplinary collaborations. "There is no question that hosting Emily contributed immensely to the intellectual environment in our department" Professor Lasse Rempe, DMS **[5.1]**. The relationship between these departments and RNCM also endured. *8 Cubed 2020,* paired 8 RNCM and UoL composition students with 8 UoL scientists to create music on topics ranging from airport noise and animal behaviour to

biomechanics. Rachel Bearon, Professor of Mathematical Biology, UoL said of her collaboration with RNCM student Anna Appleby on *Uptake* (2020) "It was thrilling to see how scientific concepts were translated into a musical score, and also to gain insight of the creative process. The conversations provided us the opportunity to explore our modelling philosophy from a new perspective, and has provided the strengthening of ties across a diverse range of departments at the University of Liverpool, from Music to Eye and Vision Science." **[5.3]**

Scientists from Manchester Metropolitan University (MMU) took part in the first iteration of 8 cubed in 2018. Whilst working on *Hive (2018)* with RNCM composer Robert Oswell Smith, Dr Jenny Rowntree, Senior Lecturer in Ecological Genetics and Applied Conservation (MMU) discovered that the sounds of a hive could be used as an indicator of colony health. **[5.2]**

Several composers and scientists that met through the two iterations of 8 cubed have continued to work together on new projects. For example, PRiSM Doctoral Researcher Bofan Ma's collaboration with Professor Keeley Crockett, Professor in Computational Intelligence (MMU), *offset iii* based on Crockett's research project 'Silent Talker'; a camera-assisted, lie detecting AI system that analyses non-verbal behaviour. She saw the collaboration as an opportunity to encourage people to look at AI technology more positively. "This partnership has brought a new dimension to my research and it has been an enriching experience to work with Bofan – such a creative and talented composer. The pieces provided me with a unique window to see how AI is interpreted by others who are not in the field, in novel and interesting ways. The reconfiguration of performance gestures was fascinating and made me focus more on how AI is perceived, interpreted and understood by the general public. The idea that there needs to be much better communication and education of AI has led to a number of new avenues, one of which is work on Place Based Ethical AI in Greater Manchester, which was undertaken with Policy Connect and the All-Party Parliamentary Group on Data Analytics (Report Launch October 2020)." **[5.2]**

PRiSM Doctoral Researcher Zakiya Leeming first met Mathias Brust, UoL Professor of Chemistry during Howard's Leverhulme residency and they have continued a dialogue on music and science. Leeming's audiovisual piece [U]nusual [m]etals (2020) examined the concept of wave-particle duality from discussions with Brust, who said "Having seen how, through the lens of a composer, a physical phenomenon can be expressed artistically in sound (and pictures)…this can give us a new perspective that can yield new insight." **[5.3]**

Engaging new audiences for mathematics, science and contemporary music in new ways
PRiSM research has enabled music to connect and engage audiences with unlikely topics for musical expression. PRiSM Doctoral Researcher Zakiya Leeming led four RNCM doctoral researchers in a collaboration with *Connected Health Cities* (CHC), a government-funded programme communicating the benefits of sharing health data across the North of England. RNCM composers were paired with managers of CHC research projects. Five new pieces were premiered by Festivo Winds at a sold-out event *#MusicSaysDataSavesLives* at Manchester Museum (September 2019). "For a long time, we have been exploring new ways to reach out and have conversations about health data. Communication through music has expanded our #DataSavesLives message by bringing together two complementary worlds," Dr Amanda Lamb, CHC Deputy Director & Chief Operating Officer **[5.8]**. "I never thought you could build a creative relationship between music and data...It was brilliant," Audience feedback card **[5.8]**. The five performances were shared for the first time in December 2020 via the PRiSM website. The Tweet from @RNCMPRiSM announcing the new material was the top Tweet that month, with 8,020 impressions **[5.7]**.

The PRiSM Perception App was developed by PRiSM and Oxford e-Research Centre in collaboration with the EPRSC 'Fusing Audio and Semantic Technologies' project. It was launched at the PRiSM event "*The Music of Proof: What does Maths Sound like?*" held at RNCM in conjunction with Manchester Science Festival in October 2017. Data was collected from 249 of 600 audience members using the App at a performance of *The Ligeti Fanfares* (1985), to investigate how people perceive musical segmentation whilst listening to contemporary classical music. At another event "*Music and Maths*", attended by over 800 people, 500 members of the

audience used the App to indicate where they perceived palindromes in a performance of Haydn's Symphony No. 47 in G major 'The Palindrome' by the Oxford Philharmonic at the Sheldonion Theatre, Oxford in Jan 2018. This research has implications for contemporary composers, performers, and audiences and how they engage with new music in particular **[5.5]**.

In November 2019, Howard curated the event '*Ada Lovelace: Imagining the Analytical Engine*', commissioned by the Barbican Centre as part of their programme 'Life Rewired'. Four works were premiered including Howard's *But then, what are these numbers?* (2019) [**3.3]** and *Alter* (2019) by the PRiSM team, led by Robert Laidlow. *Alter* is about, and utilises, AI, and features a new musical instrument, *The Lovelace Engine*, modelled on Babbage's Analytical Engine. *The Lovelace Engine* was realised by Mechanical Engineer Jonathan Morris (Cambridge Design Partnership) in collaboration with Laidlow **[5.9]** to great acclaim. "The piece created by Robert Laidlow and the PRiSM team brought whimsy and creativity to their commission, Alter, visually representing the Analytical Engine with a digitally printed instrument that was part of the music itself." Sarah Hickling, Classical Music Programming, Barbican Centre **[5.10])**. "Alter…had a gratifying sense of theatrics, using an analytical engine replica as a percussion instrument" (The Guardian 3 November 2019 **[5.4])**. The Tweet by @RNCMPRiSM, sharing performances from the event was the top Tweet in March, with 11,300 impressions **[5.7]**. The online recording of *Alter* has been viewed over 600 times (https://youtu.be/L1mQGaNmfUM).

Impact on Cultural Organisations

The Classical Music Programming Team at The Barbican praised the PRiSM team's use of national media **[5.4]** to promote the event, which "reached outside of the usual classical music outlets [and] meant that we welcomed a more cross-arts audience… who greatly enjoyed the lively discussion and engaging music." Working with Howard as a curator changed the team's approach to programming future events. "We are exploring using the role of expert curator more frequently across our programme, challenging the knowledge and experience of our in house team by bringing in expertise from outside our four walls". "The involvement of PRiSM opened up new opportunities for us in terms of access to expertise and resources, something we would hope to replicate for future projects in our work with other organisations and institutions." **[5.10]**

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

[5.1] Leverhulme Trust Artist in Residence final report, ref. No. 2014-AIR-054
[5.2] PRiSM 8 Cubed Documentation
[5.3] [U]nusual [m]etals Documention
[5.4] Media Reviews and References. A list of links to relevant media reviews and interviews.
[5.5] *What Determines the Perception of Segmentation in Contemporary Music?* Phillips, M. et al. (2020) Front. Psychol. 11:1001. https://doi.org/10.3389/fpsyg.2020.01001
[5.6] PRiSMSampleRNN documentation from the PRiSM Web Pages
[5.7] RNCM PRiSM Twitter full year analytics 2020
[5.8] Connected Health Cities PRiSM blog post
[5.9] *Ada Lovelace: Imagining the Analytical Engine* extracts from the PRiSM Web Pages
[5.10] Letter of support: Sarah Hickling, Classical Programming Coordinator, Barbican Centre