Institution: University of Bradford

Unit of Assessment: B8 Chemistry

Title of case study: 'Molecular Music' and the Sound of Chemistry: Bridging arts and science to move students and the public beyond a traditional separation of discipline fields

Period when the underpinning research was undertaken: Nov 2017 – July 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 Anaïs Pitto-Barry (APB)	Assistant Professor of Chemistry	2017 - present
Dr Louise Comerford Boyes (LCB),	Associate Professor of Psychology	2002 - present
Dr William Martin (WM)	Associate Professor of Chemistry	2009 – present
Prof. Nicolas P. E. Barry (NB)	Professor of Chemistry	2016 – current

Period when the claimed impact occurred: Nov 2017 – March 2020

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

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

Molecular Music is an interdisciplinary scientific and artistic project creating pedagogic and science/arts 'literacy in the public' impacts specifically in chemical education. Initially a local collaboration between the University of Bradford (UoB) and Ilkley Grammar School, we have achieved regional and national impacts, such as transformation of teaching methods at Sixth Form level, influence on career path choices for students and demonstrated effect of increased understanding of spectroscopy and physical chemistry in the general public. High-profile engagement and dissemination (e.g., flagship public events and wide-reaching media outputs) have achieved tangible change for a diversity of key stakeholders.

2. Underpinning research (indicative maximum 500 words)

Molecular Music is a project based on translating the vibrations of molecular bonds into the audible range in order to produce, from their infrared (IR) spectrum, a unique set of musical notes for any molecule or material [R1]. NB and APB arrived at UoB in 2016 and 2017 and were inspired by the strong history of spectroscopy at Bradford [e.g. R2].

Institutional excellence in spectroscopy is one starting point for this project, another being the chemistry education interventions and impact research that WM and LCB previously developed together at Bradford [R3]. LCB brings to the project a track record of impactful research into hybrid arts-sciences education projects, as exemplified by her long engagement with Arts Council England's/UK government's flagship creative learning programme '*Creative Partnerships'* 2002-2011 [R4]. This work focused on exploring the advantages to be gained by crossing discipline boundaries and introducing creativity and the traditional arts (e.g. music, fine art, dance, drama) as an engaging means of optimising access to and learning outcomes in a broad range of disciplines including Life Sciences [R5,R6]. This prior research provides a sound starting point for the present collaboration. Molecular Music exemplifies true interdisciplinarity and was made possible by a Partnership Grant from The Royal Society. We developed this project out of existing traditions, expertise and successful previous collaborations to further innovate and facilitate the learning of spectroscopy by non HEI students, as well as to increase scientific literacy in the public. We have worked with a lead chemistry teacher from Ilkley

Grammar School, who was enthusiastic about the idea and understood its potential as a novel and effective learning method for his students.

The research outcomes and impacts attributable to Molecular Music and presented in this case study evidence Kolb's theory of experiential learning: the foundation of chemistry learning through laboratory experiences. Here, we pushed the boundaries of Kolb's theory by taking chemistry pedagogy beyond the laboratory and engaging participants in music-making to explain, explore and ultimately make more accessible complex chemistry concepts. An illustrative example is as follows: one key aspect of the project was working with 35 Sixth Form students tasked with synthesising five molecules, whose syntheses offered an interesting range of laboratory techniques from a learning point of view (e.g., trans-dibenzalacetone – used in sunscreens). The students used IR spectroscopy to characterise these molecules at the university's specialised STEM Centre for Outreach. For each molecule, the key absorption bands were listed in a table. An arbitrarily chosen divisor (kept constant for all molecules) was then applied to convert these frequencies into the audible range and compared to the equal-tempered scale, to associate each IR frequency to a musical note. The unique characteristic set of IR absorbances for each molecule was translated to a unique set of musical notes. The final step was to compose music for each molecule, using its range of notes; this aspect of the project now involving music students at the same school.

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

[R1]. N. Garrido, et al. (2020) The Sound of Chemistry: Translating Infrared Wavenumbers into Musical Notes, *Journal of Chemical Education*: 9*:* 703-709. http://dx.doi.org/10.1021/acs.jchemed.9b00775.

[R2]. J. Jehlička, and HGM Edwards (2014) Raman spectroscopy meets extremophiles on Earth and Mars: studies for successful search of life, *Philosophical Transactions of the Royal Society A*: *372:* 20140207. http://dx.doi.org/10.1098/rsta.2014.0207.

[R3]. B. Lucas et al. (2014) Greening STEM: The Big Green Lab Project, *Education in Chemistry*: 26-29. https://edu.rsc.org/feature/the-big-green-lab-project/2000119.article.

[R4]. S. Hayton et al. (2010) Creative Labs: Exploring Creative Knowledge Transfer in schools-based projects with artists**,** UNESCO World Conference on Arts Education. http://www.unesco.org/culture/en/artseducation/pdf/abstract306suehayton.pdf.

[R5]. K. Pahl, L. et al. (2010) Artists, Art and Artefacts Boundary Crossings, Art and Anthropology, *Creative Approaches to Research*: 3: 82-101. https://doi.org/10.3316/CAR0301082.

[R6]. L. Comerford Boyes, and I. Reid (2005), What are the benefits for pupils participating in arts activities?, *Research in Education*: 73: 1-14. https://doi.org/10.7227/RIE.73.1.

Grants

PI: Nicolas P. E. Barry; Grant Title: What is the sound of chemistry?; Sponsor: The Royal Society; Period of Grant: Oct 2017 – July 2019; Grant Value: GBP2,675.

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

At the local level: The underpinning research directly impacted the teaching methods used at Ilkley Grammar School: Molecular Music is now routinely used in the classrooms to teach spectroscopy and as the basis for the school's first science-based practical Extended Project Qualification [A].

Senior management of the school also cite demonstrable impact on less able pupils [A]: '*Engagement with the subject material has improved, and the link to music has helped students*

grasp the concept more easily. This is especially noticeable with those students with predicted A-Level grade C-E; students who typically find making links to abstract concepts more challenging, and where the ideas developed in the project of using art to make science more accessible have really resonated.'

The Chemistry teacher also explained how the project broadened student's experiences: *'This project offered my students chances to experience science outside of the current scheme of work and allowed us to extend our provision beyond the curriculum. We were also able to offer opportunities for students to meet real researchers and learn about their specific interests which again would not have been possible without this support.'* [B].

As part of this project, chemistry students were engaged in exploring and understanding aesthetic and artistic interpretations of the molecule in the compositions created by their music student peers and learnt about the software the musicians used. Musicians learnt about spectroscopy and IR peaks from their chemistry peers, as well as what chemicals are used for. Described by some participants as not only enjoyable but 'unique', the project's effect on these students is evident in impact data generated by a mixed-methods questionnaire [R1]. 100% (*n* = 15) of respondents said they would recommend the activity to a friend on account of it being variously fun, interesting, educational and challenging. The most frequently cited project impacts include: that the project improved students' knowledge, understanding and skills with regard to both chemistry and doing research; that it increased their interest in chemistry and gave them an insight into doing chemistry at a higher level and as a profession; that the interdisciplinary nature of the project was important, and that they had learnt valuable dissemination skills in terms of being able to speak about the science to audiences [R1]. In terms of impact on pupils' understanding of scientific concepts and skills acquisition, 73% saw themselves as having a better understanding of the science because of the activity. Specifically, 87% reported feeling more confident with regard to understanding and using the IR spectrometer, and 73% reported a positive change in their understanding of infrared energy causing chemical bonds to stretch and bend [R1].

The qualitative data also shows that impacts extended beyond music/chemistry learning. Some pupils reflected that the project developed their skills and confidence in explaining, disseminating and presenting to an audience. Others began to exhibit a deeper understanding of the importance of societal scientific literacy [R1]: that it was '*important to bring the arts and sciences together to keep minds open, important to make the public interested and appeal to everyone*.'
'*This was a great project, I'm so glad I had the opportunity as it has developed my creativity, people skills and knowledge of chemistry.*'
'*Just a fantastic project that I'm going to remember for the rest of my life, thank you for the opportunity.*'
'*It was a really enjoyable experience that allowed me to meet and talk to some very important people in a situation where I felt equal.*'

At the national level (scientific literacy in the public): The project has been showcased and team members interviewed on local community radio station, BCB Radio, (38,000 listeners per week), BBC Radio 4 (Inside Science), The Economist podcast (listened to 14,000 times on Twitter alone) and at several public engagement events: Royal Society Summer Science Exhibition 2019, Bradford Science Festival 2019, Otley Science Festival 2019, Bradford National Science and Media Museums half term event 2020 (February). In 2020, planned events were cancelled because of the pandemic.

12,653 members of the public visited the Royal Society Summer Science Exhibition 2019 including 1,518 students and 187 teachers. Audience feedback on our exhibit was collected by The Royal Society [C], this feedback evidences that Molecular Music was a very effective methodology for teaching chemistry to people with limited knowledge of the subject. Changes to visitors' knowledge of chemistry is evidenced by data such as:
"*Very impressed with the explanations, given my limited chemistry knowledge. Really accessible and engaging*"

"*Explained it at different academic levels so I could easily understand, plus learn more*"

The Ilkley Grammar School students who participated in the Exhibition experienced additional positive impacts, as illustrated by the email from one of the mothers of such students [D]: "*Lily has certainly grown up in her time away, both being given the independence to explore London, and also talking to such wide range of people at the exhibition. This has boosted her self-confidence massively! She announced when she came home 'Mum; I'm now ready to go to University!'. I think she has also developed a sense of pride at being to work at such a high academic level that your project was based at.*"

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

A. Testimonial Letter from Ilkley Grammar School
For the school, a major impact attributable to the project is the development that we are now delivering science practical-based Extended Project Qualifications (EPQ) for the first time. These allow students to explore a research topic in-depth and are highly regarded by university admissions tutors. Having their own project to work on has increased the engagement of these students. Working with research professionals from UoB on the RS project increased the confidence of staff to deliver these projects, which coupled with the practical skills developed by the staff and the laboratory equipment purchased through the partnership, has helped catalyse the start of a research culture amongst the A-level student body. We envisage the delivery of research-led teaching to be a continuing part of our offer at IGS

B. Testimonial Letter, Chemistry Teacher, Ilkley Grammar School

C. Summary of Feedback from The Royal Society Public Engagement Team
Further feedback from the event:
"*They knew how to explain things at my level*";
"*All interactive activities worked and were really cool! The research mixed science with something relatable to most (music)*";
"*The music was wacky but this made it exciting and really contributes to the diversity of the science on show. The applications for blind people to learn about chemistry here is fantastic*".

D. Email from a student's mother.