IATL Academic Fellowship Final Report

Science, Maths and Music

Gavin Bell

Overview

The project aimed to explore the relationships between music and science/mathematics with a focus on development of interdisciplinary teaching at this interface. The most important outcome of the project was that we obtained IATL approval for a new interdisciplinary module, *The Science of Music* (IL016, www.warwick.ac.uk/sciofmusic) which will run in the Spring term 2016.

From a personal perspective, the most remarkable aspect of the project has been the degree of enthusiasm for the topic shown by staff, students and external speakers. It quickly became clear that the overlap between science, mathematics and music is an interdisciplinary area which attracts a great deal of interest. This initial impression has been confirmed by the popularity of the IL016 Science of Music module for which we have recruited 27 students from across the University, unfortunately having had to turn down around 20 more for reasons of practicality. Eight staff from Physics contributed directly to the project, plus numerous colleagues from Warwick including the Coull Quartet, and several external scientists and musicians. Undergraduates have been involved throughout: participating in our one-day meeting, providing input into module development,

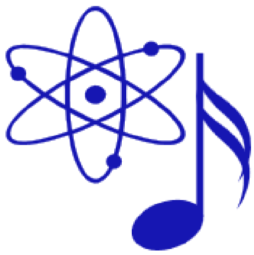
Project participants: Susan Burrows, John Halpin, Rachel Edwards, Oksana Trushkevych, Rudolf Roemer, Paul Harrison, Michael Pounds (Physics); Nicholas Roberts, Roger Coull (Quartet).

Activities

The project comprised four main activities: (1) Science of Music interdisciplinary module development, (2) a one-day meeting on the science / music interface bringing together scientists and musicians, (3) development of live and video-recorded demonstrations to help teach scientific concepts related to sound and music (e.g. waves, frequency, resonance, Doppler effect), and (4) a trial of peer assessment by students to underpin planned peer assessment activities in the Science of Music module.

We divided the project group into teams of two people (for one team, four) to lead each of these aspects. Typically, such activities work best when being led by one or two people and the group was certainly too large for everyone to have detailed input on every activity. Nonetheless, the whole group could contribute to the four activities. As well as bi-weekly face-to-face meetings we used the online collaborations tools based in Sitebuilder to facilitate the project (calendar, forum, fileshare, video, webgroup). This structure and approach proved effective, and much of the online record is available for viewing in the “Developers corner” link from www.warwick.ac.uk/sciofmusic. In the following four sections I hope to give some practical details of what we did as well as problems encountered and the motivation and background.

1. Module Development (Nick Roberts & Gavin Bell)



Prior to the application for an Academic Fellowship, a group of academics in Physics originally convened to discuss the possibility of a *Physics of Music* module within the department. Several other UK physics departments offer such a course and the idea had been floating around for a number of years. During our discussions it became apparent that another option, namely a fully interdisciplinary module, might allow us to explore the area in a more broad-based way rather than simply offering another topic-based Physics option module. Hence the first, and critical, decision to make once the Academic Fellowship was underway was whether we should proceed with a physics option module or an interdisciplinary module. Here, the enthusiastic response of our non-Physics colleagues in the interdisciplinary meetings organised during the Fellowship project gave impetus to the idea of an IL-coded rather than PX-coded module. The popularity of the Challenges of Climate Change module in its new interdisciplinary form (it was originally a Physics option module) gave support to the notion that this approach could succeed.

We were also careful to liaise with undergraduate students during the module development. In Physics this was principally through the Physics Society: we were very lucky that the president of the society at the time was fantastically helpful and very proactive in getting feedback to me during the course development. Valuable input also came from informal interactions through the student music societies (via the Quartet members) and from an "ideas box" as well as face to face conversations at the one-day meeting. I think that this input gave us greater confidence that the students would engage very positively with a more experimental module. It is probably fair to say that this was seen as a more risky approach within the department and certainly moved the project team out of our "comfort zone". Had we proceeded with a PX *Physics of Music* module, I suspect we would have quite easily put together a nice curriculum for, say, 3rd year Physics students. However, it was clear that the demands of an interdisciplinary module were much more stringent. For example, we could not assume anything about students' scientific or mathematical background post-16. Interdisciplinary modules are also significantly different from typical physics modules in terms of teaching style and student numbers; for example, I am teaching 175 students on my second year *Quantum Physics and its Applications* course with no small-group teaching at all, apart from Personal Tutors' support. The merits of an interdisciplinary module were discussed around the department and some persuasion was needed to bring everyone on board. For large STEM departments, relatively small modules are easily seen as "inefficient".

From a personal point of view, I began to favour the interdisciplinary approach at an early stage. Having delved into the literature, I felt that a purely *Physics of Music* module would still be a bit too narrow compared to a wide range of exciting topics which could still be coherently presented. The opportunity to broaden our own (Physics) students' skills would also be enhanced by an interdisciplinary approach. I had also lectured a popular physics option module (PX266 *Geophysics*) for many years, and while our topic-based options modules form a very important and popular part of the physics course, my feeling was that a *Physics of Music* course would, to some extent, be more of the same: we apply a purely physics approach to yet another topic. I think it is really important that some of our offering to students has a real "wow factor". Interdisciplinary modules could have a crucial role here, and I hope very strongly that *The Science of Music* can achieve this.

The next stage was to make some important practical decisions jointly with IATL colleagues on examination, assessment, CATS options, timetabling and teaching spaces. As a department, we are used to conventional lectures, examples classes, problem sheets, and so on for our core teaching, although we do use other methods such as hands-on learning (teaching labs) and group presentations (second year *Physics Skills*). It was therefore very stimulating to discuss with IATL and other non-Physics colleagues about approaches we could take. It quickly became clear that teaching slots longer than the usual 50 minutes in STEM subjects would be needed and also that a flexible venue was essential –certainly not a traditional lecture theatre. We quickly homed in on the Humanities Studio as the best available teaching space and ten 110 minute slots over one term as an appropriate and practical timetabling arrangement.

From the start I wanted to have the students involved proactively with defining the module experience. This prompted us to seek curriculum ideas during the one-day meeting as well as the informal engagement mentioned above. Furthermore, I proposed that the penultimate teaching slot should be an "open topic" to be decided on during the course by the students. Finally, I also proposed that peer assessment should be used for project work; we decided to investigate this in more detail via a trial on existing student work in physics (see section 4). Both of these ideas were accepted by the team and subsequently approved in the final module proposal.

The actual topics for the curriculum were decided by sharing ideas online and brainstorming in our face-to-face meetings, using suggestions from students, ideas from external speakers, and surveying the literature. The bibliography [1-7] gives some of the resources used in planning the curriculum; our intention is to use *Measured Tones: the interplay of physics and music* [1] as the core book for the course. With a relatively large number of people contributing to the module, one potential pitfall pointed out during discussions with IATL was that students may not experience the module as a coherent whole. Emphasising a single book should help here; furthermore, I intend to be present at all the sessions (if at all possible) to act as a consistent contact point for the students throughout the course. Module coherency is discussed further in the section on Implications.

Having arrived at a list of themes matched to available sessions, we again distributed the sessions among the academics in the project group as session leaders. This structure will allow us to focus on our individual sessions with the module convenor acting to provide continuity and consistency in approach. We plan to use a variety of teaching methods in each session:

- Traditional lectured material – students listen and take notes.
- Traditional demonstrations – session leader performs demonstrations to highlight important points. Examples include:
    - Using a vacuum jar to demonstrate sound propagation in air.
    - Using bass guitar to demonstrate nodes, antinodes, timbre, pitch relations, etc.
    - Demonstrating simple electronic sound generation.

- Guest speakers – students listen, take notes, ask questions and discuss.
- Group discussion – students talk about their prior reading around a topic in small groups then present their conclusions.
- Hands-on activities – students do some experiments in small groups then discuss and briefly present their conclusions. Examples of such activities are:
    - Using a monochord to find a string centre by eye or by ear (using the octave).
    - Pitch-following via group singing.
- Formal presentations – students give a short presentation on their project topic to be peer-assessed by the group.
- Using an alternative venue to demonstrate the importance of spaces' acoustic response.

I aim to be very clear with the students about the activities involved in the teaching of the module so that they will be better able to focus on the content rather than being surprised by the activity formats. The plan for session 1 is that students present up to 30 seconds of a music clip, or sing or play an instrument, then discuss why they chose that music in the context of the course topics. They have been asked to send in a description of what they will do and the, at the time of writing, some really fascinating pieces and justifications have been submitted. The high level of engagement at this early stage gives me confidence that the cohort will indeed be proactive and committed. This session 1 activity is planned to simultaneously act as an icebreaker, as an introduction to the non-traditional teaching methods to be used, and give an overview of the curriculum.

2. *One Day Meeting (Rudolf Roemer, Roger Coull) – Music and Science*

As part of the Academic Fellowship project we felt it was very important to have a flagship event to bring together people from different disciplines. Meeting organisation can be an onerous task and we wanted to be able focus on the programme and speakers rather than the organisational details. Therefore we chose to use an existing structure, that of our one-day "Physics Day" meetings. Dedicated clerical support for this meeting was provided by the department, with the other expenses (venue, catering, external speakers' travel, etc.) covered by the Academic Fellowship and Quartet budgets. The meeting was a great success, with strong positive feedback from all the participants and speakers. Full details of the meeting can be found at:

http://www2.warwick.ac.uk/fac/sci/physics/news/physicsdays/events/musicandscience/

With more than 50 participants, this was the best-attended of all 18 Physics Days run so far in the department. We think this is clear evidence of the broad appeal of this interdisciplinary interface.

One of the problems we encountered was that of high fidelity audio provision. Not all teaching spaces in the University boast good quality audio systems, and the Helen Martin studio chosen as the venue has none. Hiring costs for such equipment can be very high. We managed to borrow a set of good speakers and an amplifier from a colleague in Physics which solved the problem. For the module, I have purchased a pair of Yamaha powered monitor speakers which provide very high quality, accurate reproduction without the need for additional amplifiers. All of the Physics Day talks were filmed: some stills from these videos are shown overleaf with commentary to illustrate the breadth of the meeting.

Science and Music **Physics Day, 6th May 2015**

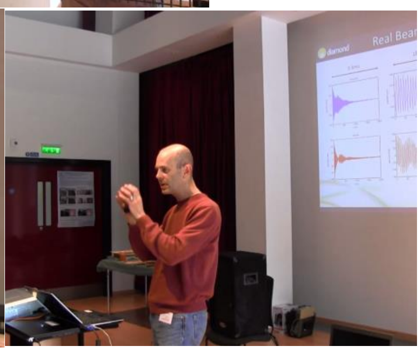
The Coull Quartet participated both in the organisation and during the meeting, playing and demonstrating to help the speakers illustrate their points.

Bruno Guastalla, left, instrument maker and restorer, spoke on "Around Violin Making" and the amazing complexity of the violin. http://brunoguastalla.net

Dr. Richard Gratwick, right, Warwick Mathematics, dispelled some clichés in his entertaining talk on "The Mathematics of Music", playing his own violin during the lecture.

Dr. Malik Refaat, pictured centre, Warwick Psychology, spoke on "Auditory Perception", including some fun and fascinating audience participation around note-following and rhythmic coordination.

Professor Alan Wing, School of Psychology, University of Birmingham. Alan and his team talked about "Music Ensemble Timing Skill" – how do real groups of musicians keep time? They measured the Coull Quartet live using their recording hardware and analysis software, who showed outstanding accuracy as well as a high degree of "democracy" in the ensemble's timing.



Chris Gayford, left, conductor, spoke about "Feeling Sound" and Dr. Guenther Rehm of Diamond Light Source described "Using sound to understand the electron beam behaviour in a synchrotron", tiny oscillations of the beam in a 543m circumference electron storage ring.

3. *Demonstrations (Rachel Edwards, Oksana Trushkevych, Paul Harrison, John Halpin)*

Demonstrations developed in this strand of the project aim to help explain complex physical concepts in a non-mathematical way that is accessible for students from all disciplines. We are extending some excellent demonstrations already developed for Physics outreach activities; moreover, several new visual aids have been developed for the interdisciplinary module. Several of the most relevant and exciting demonstrations have been selected for "live" use in the teaching space (e.g. throwing around a Doppler Effect ball) and/or to prepare video content. These include explaining waves using a Rubens tube, visualising resonance using tuning forks and Chladni plates, and causing a wine glass to resonate with sound to explore energy transfer.

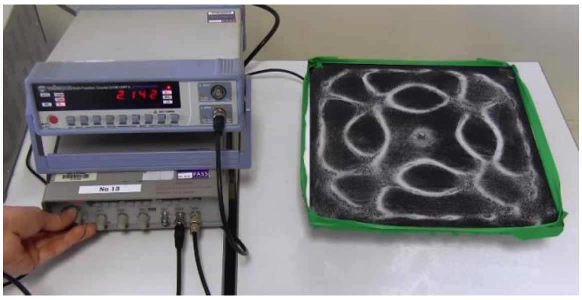
Filming of the demonstrations ran from March through April using IATL's equipment. One problem we found is that the sound fidelity of standard video camera built-in microphones is not very good at higher sound pressure levels (loudness). We will need to re-record some of the material with better sound quality using an external microphone to overcome problems of distortion.

All of the videos are available on the Science of Music web site.

- Four videos comparing flute and clarinet (by mathematics undergraduates).
- Twelve videos of our Rubens Tube responding to cello, voice, and classical and pop music.
- Four videos using bass guitars to demonstrate feedback, timbre and string vibration.
- Four videos using physical objects to illustrate wave motion and resonance (string, our sticks-on-a-string wave motion demonstrator, Chladni plates, a wine glass).

Two stills from the videos are shown here to illustrate the activities recorded.

Nick Roberts, Coull Quartet, demonstrating the Rubens tube by playing notes from an A-major scale. The tube (bottom right) burns gas through holes in the top. Speakers feed the sound in to the tube, and at certain pitches a clear "standing wave" is set up in the tube. This can be seen directly in the pattern of the flames.



Oksana Trushkevych demonstrating a Chladni plate (right). A speaker beneath the plate causes it to vibrate like a drum skin. Patterns of sand on the plate form because there are "nodes" in the plate's vibration where the strength of the vibration is nearly zero.

4. *Peer Assessment Trial (Susan Burrows, Michael Pounds)*

A trial of peer assessment took place in the summer term. We discussed extensively within the department what form the peer assessment trial might take and several options were examined. In particular the trial needs to be associated with accessible academic content while also respecting students' privacy and avoiding a burden of extra pressure during assessment. A solution was found by focusing on web-based *group* project work. The trial consisted of individual assessment by 20 students of web pages designed by second year student groups (typically 6 students) as part of their 2nd year *Physics Skills* module. These web pages are currently on the Physics Skills module website with restricted viewing permission. After assessing using the same format as the academic assessment, which was completed the previous autumn term, a group discussion took place among assessors and academics. A comparison was made with the actual marks (quantitative) and comments (qualitative) from academics given earlier in the year.

Participants were offered £20 in the form of either Amazon vouchers or a Warwick Card top up, to incentivise around one hour's work for the assessment and a further one hour for the group discussion. The number of webpages assessed was 18, with academic marks (on the 17 point scale) ranging from 11 to 15.

The full report by Sue Burrows and Michael Pounds is appended as an outcome of the project. Their conclusions are reproduced here:

- Group work may lessen any potential bias and even out any imbalance in scores.
- If peer assessment is to go ahead, it should be a pillar of the module.
- Credit should be given for doing the assessment.
- The assessment should be done in a timetabled session.
- Students should be involved with setting marking criteria.
- For student to gain a benefit, peer assessment should be done at an interim stage with feedback given, so they can learn from the process before submitting a final piece of work.

For the forthcoming IL016 module, we will certainly be able to apply lessons from this study. Necessarily, the project presentations will take place in week 10 so it will not be possible to use the peer assessment in a directly formative way: for the project presenters it will be a summative assessment. Of course, all the students will be involved in doing the peer assessment (credit will be given in lieu of the weekly assessed questions) and the experience of *doing* assessment should be a formative one. We have not set detailed marking criteria yet for the project work – this can be discussed with the students during the course. In the study, some students felt that they did not have the expertise to mark fairly, and especially in the interdisciplinary context we will have to make sure that students feel prepared and confident to assess. We can devote some of session 9 to this if the cohort feels a need to do so. It would also be good to get the students' input or marker anonymity, an issue which was clearly unresolved in the peer assessment study. One aspect of the project presentations which the students ought to be able to assess *better* than the academics is the broad criterion of "how well is the presentation understandable by your peers?" and we will discuss this as part of a thorough student preparation for peer assessment.

Outcomes and Implications

We did not write formal evaluation criteria for the project but I believe that all four strands have been very successful. The **peer assessment trial** has given us valuable insight into students' views in a Physics context and suggested specific actions to be implemented for the *Science of Music* module. We have developed **demonstrations** for use in both the module and elsewhere (see below) which are well-integrated with the planned curriculum. The *Science and Music* **Physics Day** was the best-attended Physics Day ever, with excellent feedback and cementing valuable external contacts. We also got useful student (and other) input into the curriculum development for the module via the ideas box at this meeting. The key outcome is our successful development of the **IL016 Science of Music module** which will run from January 2016. High levels of student engagement bode well and the whole team is looking forward to participating in an excellent experience for the cohort.

The peer assessment study is available online: other faculties or departments may wish to compare their practice or student experience with the findings presented. One of the demonstrations we developed was used in lectures by Dr. Neil Wilson in teaching the *Physics Foundations* first year module (190 students). Neil said the videos we produced were "very useful in planning the waves part of the module" and has sent us a valuable link to online material which we will use in the second session of the IL106 module. We also plan to host another science / music one-day meeting to build on the success of the *Science and Music* Physics Day.

The total numbers of undergraduate students directly engaged, so far, by the project can be estimated as follows (though there will be some overlap, of course): approximately 30 attendees at the Physics Day, 27 registered students on the IL016 module, around 20 more interested in the module (some able to take it next year), 16 students took part in the peer assessment study, 190 first year students saw one of our demonstrations.

What changes might we embed in the department as a result of this project? I think it likely that our experience of the interdisciplinary approach will inform our regular teaching and with six teaching staff from Physics involved in delivering the I016 module, including the Director of Student Experience and Undergraduate Laboratory Manager, positive experience and good practice have every chance to spread within the department. This will be a second-order outcome of the project itself, since we need to deliver and reflect on the module itself. Beyond teaching, there are clear links to outreach activity. John Halpin, on the Demonstrations project team, has been closely involved with Physics outreach activities for a number of years, especially with schools. There is strong overlap between our demonstrations and those used in departmental outreach activities such as schools liaison, open days and public events. I have discussed our project work with Ally Caldecote, the Outreach Officer for Physics. There is strong overlap between the use of demonstrations in interdisciplinary teaching and in outreach, helped by the immediacy of the visual and aural experience. "The Chladni plates make beautiful patterns which really show up the beauty of physics", as Ally says. "A child might not think they are interested in physics, but they *are* interested in guitars, so making that connection can help break down a barrier," she continues. Therefore we are planning a schools outreach activity themed on science and music (after the module is complete). A further exciting possibility is a Christmas Lecture to enhance the current popular and successful series. As a major UK scientific facility, Diamond Light Source has a very active outreach programme. I am a regular user of the facility and we are keen to build on Guenther Rehm's presentation at our Physics

Day. One possibility is a summer undergraduate project following up on algorithmic music generation.

Can we produce research and/or creative outputs? I hope that the student projects associated with the IL016 module could produce original work of high quality. Such work may be publishable, for example in *Reinvention*, or may lead to a URSS project application. I have championed undergraduate research for many years, including algorithmic music projects (www.warwick.ac.uk/sonify) and other URSS, Royal Society, Nuffield Foundation and GRP-funded work. These can lead to published outputs, such as references [8] and [9], software and creative outputs (e.g. the sonification project), or leverage additional funding (e.g. my 2015 summer project results leveraged experimental time at Diamond Light Source in 2016 worth around £50k). I am also a member of the URSS assessment panel. We want to strongly encourage students on the module (and more broadly) to consider the possibilities of summer research projects and creative work (independently or with the student music societies). Might students compose or perform some scientifically or mathematically-inspired music?

Are there broader institutional issues? One issue which cropped up during the development and advertising of the IL016 module is scientific and mathematical confidence. It will be challenging, but certainly possible, to teach the concepts required without resorting to mathematical shorthand all the time, but it became clear that this was a significant worry for some students thinking about taking the module. During the project I attended a workshop on *Developing Mathematical Resilience*, led by Sue Johnston-Wilder. While the focus was more on younger students, similar issues were discussed. We will have the opportunity to reflect on our teaching (and examining) of mathematically rigorous topics without losing students with less mathematical background. It may be interesting to compare experiences with e.g. colleagues in social sciences where statistical methods are important but students have a wide range of mathematical backgrounds. It will also be interesting to see if there are any confidence issues in the opposite directions, e.g. with mathematics or physics students writing project work, referencing and preparing and delivering presentations.

Summary of Resources

- Web sites
  - Science of Music module site
  - Physics Day meeting site
- Videos
  - 24 demonstration videos (some to be re-recorded with better sound)
  - 6 talks recorded from Science and Music Physics Day (not presently available for public viewing but can be shared internally)
- Written material
  - Peer Assessment Study in Physics
  - IL016 Module Proposal
- Demonstrations and equipment
  - "String" and "sticks on a string" wave demonstrators
  - Chladni plates
  - Rubens tube
  - Tuning forks and instruments (flute, violin, bass guitar, etc.) for demonstrations
  - 7 copies of *Measured Tones* [1] for sessions leaders' reference and planning
  - Dedicated laptop and high quality speakers for in-session audio work
  - Donated equipment from physics labs for in-session audio work: signal generators, oscilloscope, etc.

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