Teaching Maths Remotely – Video Conferencing for Lectures, Tutorials, and Computer Labs

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Abstract

An increasing amount of higher education institutions around the world offer lectures or even entire programmes to students remotely via audio–visual technology, as the necessary hardware and internet bandwidth become more affordable. This project presents the experience with this technology in the context of an MRes programme in "Mathematics of Planet Earth", taught jointly between Imperial College London and University of Reading. The effects of using this technology on the learning experience of the students are discussed, both in context with the intended learning outcomes of the programme as well as with mathematics teaching in general. The main problems encountered are reported, and practical recommendations are given for future users of this technology. Finally, suitable arrangements for future review of our teaching are discussed.

Contents

1 Introduction

The invention of writing and in particular the much later invention of printing made it possible to learn without being in direct contact with the teacher. There is a sense in which scientific journals, radio broadcastings, CD–sets with language courses, TV–lectures, video–conferencing and audio–visual lectures are essentially variations of the same idea. (One may add the distinction between "live" teaching, where teacher and student communicate remotely by means of some technology, and "recorded" teaching which can take place even after the teacher's death).

The decrease in cost of audio–visual technology and internet bandwidth in recent years has made it feasible to broadcast a reasonable part of the original classroom experience to audiences which are not in the same location as the teacher. The equipment is much more affordable when compared to high–end video conferencing technology, which became available in the 1990's, and the day–to–day running does not require specialist's knowledge. The ability to reach an audience which is in a remote location from the teacher is attractive, and it is clear that this allows for curriculum and programme arrangements which would otherwise be impossible.

In Summer 2013, the School of Mathematical and Physical Sciences at the University of Reading and the Mathematics Department at Imperial College London proposed to set up a Centre for Doctoral Training in "Mathematics of Planet Earth" (MPECDT), answering a call from EPSRC to apply for funding of doctoral training centres. The bid was successful and the CDT accepted it's first cohort of 12 students in autumn 2014. The programme consists of a 3–year PhD preceded by a 1–year MRes. The MRes has a taught element comprising three bespoke "core courses" which are taught in autumn. Each core course is accompanied by computer practicals and tutorials. Although the students are registered with both institutions, about half of the cohort resides at UoR and the other at IC. Further, staff from both institutions teach elements of the programme. To render this possible, high quality audio–visual (AV) equipment was installed at both institutions to enable remote delivery of the lectures. Our experience with this technology during the first term of this programme forms the basis of this project.

The project report is organised as follows. Section 2 details why the decision was made to use an AV link for this programme, in relation to the purpose and academic aims of the MRes and the wider objectives we have in terms of academic development of the students. In Section 3, I will briefly describe the installed AV equipment at both ends, along with the respective classroom environment. Experience from both students and teachers during the first term are lined out in Section 4, while Section 5 contrasts with our expectations. The effects of using this technology on the learning experience of the students are discussed, both in context with the intended learning outcomes of the programme as well as with mathematics teaching in general. Section 6 explores several possible approaches to deal with the encountered issues,

and Section 7 outlines an action plan along with arrangements for future review.

2 Why using an AV–link?

Mathematicians are not known for enthusiastically embracing new teaching and learning technology. "...and the 'value' of replacing blackboards with white-boards, smart-boards, overhead projectors, PowerPoint or whatever, we are well known for contesting such notions." (Kahn and Kyle, 2009). It was probably for this reason that we did not initially envisage the use of an AV–link in teaching. We had a vision of a joint programme with very strong cohort elements. There is strong evidence supporting the effectiveness of learning as a group in various ways, and having the opportunity of setting up a programme in which this could be exploited was the main driving force behind the proposal.

The EPSRC call for doctoral training centres has two stages, with outline proposals being submitted to the first stage and, upon successful review, full proposals being invited to the second stage. Our outline proposal still assumed that students would be travelling between Reading and London approximately twice per week during term time. From the reviewers' comments and through internal discussion however it became clear that this scheme was likely to overburden both students and staff to a degree that outweighed the benefits. It was also hard to justify from a financial point of view; we estimated travel costs to amount to about £40000 for the entire programme, just so that student could attend the lectures (assuming off–peak travel). The costs for installing the AV–link in Reading eventually amounted to the same, but there is of course considerable added value for the school and the university as a whole, who shared the financial burden.

The AV–link was thus in some sense a second choice, and I view it as a *means* rather than a *method*, an *enabling* rather than an *enhancing* technology. This general view informed our approach to using it for teaching. The vision was to bring in world leading experts from both institutions to teach on the programme and thus give the students a unique learning experience. Arguably, a teacher teaches best when she or he is given the freedom to lecture in the *way* she or he likes most, hence the equipment had to be as flexible as possible to accommodate different lecturing styles. To be able to share enthusiasm and passion for the subject with the students, the AV–link had to be as little of a barrier as possible. TV channels spend millions of pounds in technology, staff, training, and research to attract consumers to their programme and make watching the news enjoyable rather than tedious. We had to achieve something very similar but with a fraction of the budget. Even more, the AV–link had to allow for interactive learning and students taking part in the teaching.

`More here on active learning`

3 AV provision at UoR and IC

To address the needs at hand, the AV technology has to be seen in context with the classroom environment. The teaching experience at the remote end can only be as good as the experience at the live end. The setup had to accommodate audiences of about 30 people at both ends. The AV–link had to be minimally invasive so as to disturb the learning experience at the live end as little as possible, while at the same time broadcast as much from the learning experience as possible to the remote end.

At both ends, a suitable classroom with capacity for about 40 people was identified. Both rooms comprised ample white-board space and a standard teaching PC. These rooms were equipped with the necessary technology. The room in Reading comprises two double column white-boards, with two high definition ceiling cameras capturing the two white-board columns. A third camera points at the lectern area capturing the lecturer, with a fourth wide angle camera mounted at the front end pointing back at the audience. A visualiser is mounted on the lectern; this is basically a camera mounted on a gooseneck and facing the surface of the lectern. The visualiser can be used to present printed material or handwriting. A computer monitor (called *feedback monitor*) is mounted on the ceiling facing the lectern. This allows the lecturer to monitor either the remote audience, herself or himself, parameters of the visimeet software, or instant text messages transmitted from other participants in the meeting. Instant messaging usually works even if everything else fails, so other members of the meeting can warn the lecturer of technical problems that she or he might be unaware of. Finally, two ceiling mounted projectors face screens which are mounted behind the white-board columns. This means that the white-boards have to be pulled down if the corresponding projector is in use. A schematic drawing of the setup is shown in Figure 1. The room in Reading features a set of ceiling microphones capturing both the lecturer and the audience, and there is no need for the lecturer to carry a microphone. This configuration though requires a sophisticated digital signal processing (DSP) unit which automatically "focusses" the microphone array onto whoever speaks, be it a member of the audience or the lecturer, by increasing the input gain at the relevant microphones while at the same time reducing the volume of other microphones.

The room at Imperial is comparatively simpler. The white-boards are fixed and can alternatively be used as screens. There are only two cameras, one facing the audience and a second one capturing one of the white-boards. This means that the amount of white-board space which can be transmitted is considerably smaller. However, there is an additional smart-board, the content of which can be transmitted, too. The room at Imperial is bigger than in Reading, in particular the total wall space that could potentially be used for projecting and mounting white-boards. Extending the video configuration at Imperial is thus possible, but

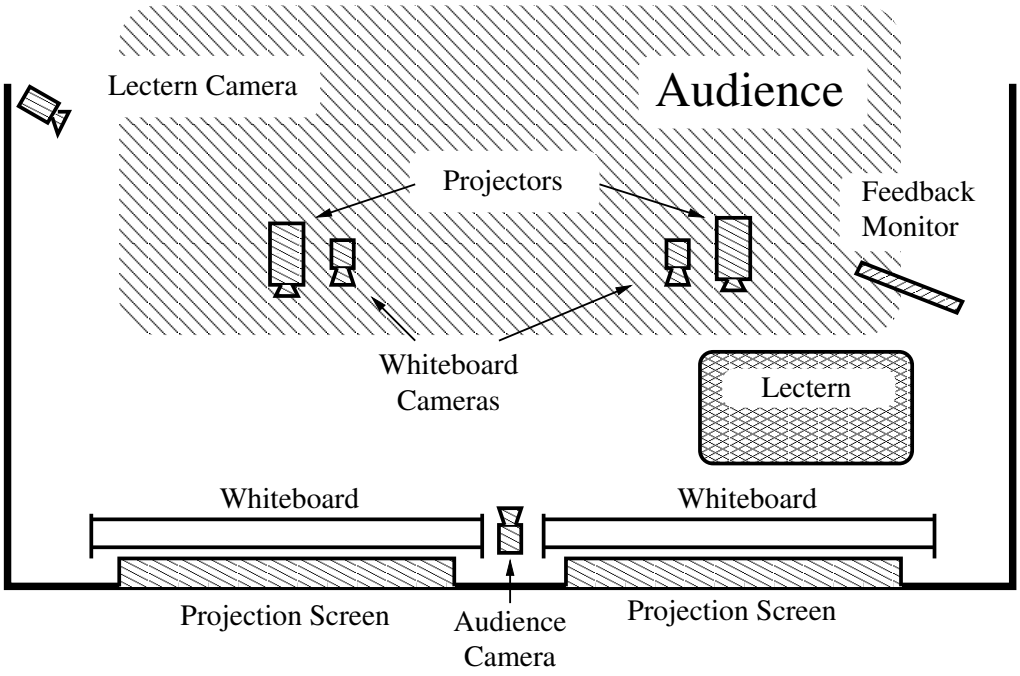

Figure 1: Schematic drawing of the AV room in Reading (Philip Lyle Building G74). The projectors, white–board cameras and the feedback monitor are ceiling mounted.

after our experiences in the first term this has low priority. The audio equipment at Imperial is solely based on mobile microphones. In particular, the lecturer has to wear a microphone, and the audience has to use microphones too in order to engage in discussion with the other end. Currently, lecturer microphones are worn around the neck on a lanyard, while the audience either passes around a hand-held mic or uses a tabletop room mic.

The installation and testing of the equipment at the Reading end was carried out by Snelling Business Systems Ltd. and overseen by Tobias Kuna (Dept. of Mathematics) and myself, along with Dan Bretherton and Pawel Stasiak from IT services. From the very beginning, we encountered a multitude of problems both at the Reading end itself as well as with the connection to Imperial. Unfortunately, the critical phase coincided with a major restructuring of UoR IT services, which was not precisely helpful. The support we received from Dan Bretherton and Pawel Stasiak can hardly be overrated, and they provided it outside of their normal duties an put in uncounted extra hours to get the system to work. This project report is dedicated to both in recognition of their efforts.

There are several companies offering commercial software for remote lecturing. For reasons of compatibility, we choose *visimeet*, marketed by IOCOM. The user interface of the software very much resembles the well known internet communication software *skype*. Every user has a unique identification in the visimeet community. Upon launching the software, the user can invite any of his contacts to a meeting. During a meeting, each party can choose to transmit any number of windows from her or his desktop. These could be windows showing camera output, but also windows showing electronic documents, for example PowerPoint or pdf presentations. The windows are transmitted to the other participants in the meeting who can then decide how to present them given the local setup.

Since this is a pedagogical project, there is no need to consider all of the many technical issues we encountered in detail here. However, inasmuch as they affected the teaching, they will be discussed in the next section.

4 Experiences from the first term

The MRes in Mathematics of Planet Earth (MPE MRes) commenced in 2014 with the first cohort of students, and about so far about 120hrs worth of teaching have been transmitted between UoR and IC as part of this programme. The AV–room was used for remote teaching (both as live end and as remote end) on a number of other occasions. Students on the MPE MRes resident in Reading used the AV–room to attend lectures of the MAGIC consortium, a national EPSRC–funded consortium providing postgraduate–level lecture courses in mathematics using video conferencing technology. Further, we hosted the launch lecture for 2014 of the MAGIC consortium, given by Elizabeth Mansfield (University of Kent). This demonstrates the

added value this facility brings to the University.

Our resumé from the first term is that by and large, the AV–link in the present configuration serves our needs, and that the decision to use an AV–link was justified. We also see no need for changing the fundamental layout. However, a large number of issues came up during the term which had to be resolved or still need resolving. Some are of technical nature but with a strong impact on the teaching, while others are directly of pedagogical nature and caused by the constraints set by the equipment. Further, we misjudged to some extent what would be feasible in terms of teaching approaches via an audiovisual link, putting elements of our programme in need of revision.

We used the AV–link for standard lecturing, tutorial style interactive classes, and computer laboratories. In all three cases, students participated at both the live and the remote end, usually about 6–8. In order to get a detailed picture of the students' experience, I asked them for detailed feedback in the form of a questionnaire (see Appendix I). The questionnaire asks for feedback in relation to one core course (MAMCDU which I taught), but this was mainly because I thought it inappropriate to publish student feedback on lectures that weren't mine. Most of the questions ask for experience in the context of remote lecturing. In the remainder of this document, I will cite feedback from these questionnaires. I have labelled the students A to J, and a reference (student A, Q2.2) means student A's answer to question 2.2. The full set of questionnaires can be found in my reflective portfolio (EOFXXX). What I only realised later is that to interpret the answers it is important to know whether the student was based at Reading or at Imperial. This might not be directly obvious from the anonymised questionnaires, but fortunately, more often than not the students let us know whether their answers are from a Reading or Imperial perspective.

General issues The issues and problems which inevitably emerge when using a new and complicated technology, when added to the burden on teachers and students present in any learning situation, can easily be overwhelming and put all participants under enormous stress. A general problem is reliability. There are many components to the AV–link, and failure of any individual one can render teaching impossible. In our case, the lack of proper IT support exacerbated the situation. Lectures had to start late or even postponed as technical problems had to be resolved. Fortunately, the timetable of our programme was reasonably flexible to accommodate this, but it put everyone involved under considerable stress and required a lot of ad–hoc reorganisation and improvisation.

Even when working reliably, remote lecturing implies a considerable overhead. The equipment has to be switched on, warm up, and the software has to establish the link. This requires about 10 to 15 minutes preparation time if all goes well. All too often, a problem lies at the remote end and is identified only after the class has

already started, causing further delays. Inexperience with the technology again add to frustration and delay.

Another phenomenon to be considered is what has been called *techno–stress* (Boddison, 2010, p.56), after Mason (2013). This term describes the widely observed phenomenon that in remote lecturing, the audience's attention declines much more rapidly than during normal lecturing. A study by Jacobs and Rodgers (1997) reported that teachers as well exhibited unusual signs of stress when lecturing remotely, and our experience confirms this. The study suggest that the difficulties in handling the students simultaneously with the (unpredictable) technology may be the reason for this (p.294). But they go on to explain that "the need for techniques which would not normally be employed in a traditional setting is doubtless to some degree responsible for the regularly reported fatigue of the teachers as also of the students, at the end of every session". I will argue in Section 5, based on the findings of Jacobs and Rodgers, our own experience, and feedback from the students, that techno–stress is mainly an instance of stress caused by communication over poor channels, which leads me to recommendations how to deal with it.

Lectures Lectures, for the purpose of this document, refers to a situation in which a teacher delivers material to the students through speaking in combination with visual media (computer presentations, boardwork, visualiser). Somewhat to our surprise, this classroom setting worked best, in comparison to the other two (tutorials and computer labs). The students' comments confirm this without exception. Although they mention several things which can be improved, nobody thought that classical lectures are unsuitable for remote lecturing or under-use the potential of this technology. A few observations from students and staff warrant a closer look. Using the white-boards generally worked fine (a heartwarming message for all mathematicians), as long as the capturing cameras are of sufficiently high definition. The same is true for the visualiser (I used the visualiser to capture what I was writing on paper, basically as a replacement for the white-boards as they were installed only later). Some students even preferred this over the white-board (student H, Q.3). Slides work fine as well, but in addition to the usual reservations against slides, lecturers need to be aware that remote students might not be able to see what the lecturer is pointing at (student E, Q.3, Q.4). More generally, in comparison to the white-board, computer presentations have the disadvantage that the lecturer appears on a different screen than the slide, which makes following the lecturers body language more difficult; I will come back to this point later.

Tutorials A tutorial, for the purpose of this document, refers to a situation in which set problems are discussed between the students and the teacher. Students may have tackled the problems prior to the session to a varying degree, that is a tutorial might encompass everything from comparing and discussing the solutions

to actually solving them in class. My definition of a good tutorial is a tutorial that allows the teacher to provide the students with a maximum of formative feedback as well as feedback from peers. So by definition, a tutorial requires strong interaction between students and teacher and between students themselves.

We conducted relatively few tutorials (for the course on "Partial Differential Equations") via the audiovisual link, as our general model was that tutorials would be provided separately at both ends. The reason for this decision will be discussed in Section 5 below. Although our experience is limited, it suggests that tutorials via an AV–link require a different approach than live tutorials. The simple reason is that symmetric interaction between two groups of people on both sides is very difficult, and an individual student might too easily get detached from what is happening. A problem that is relevant here and which is widely discussed in the literature is that establishing direct eye contact via the remote link is difficult (see e.g. Boddison (2010), p.171, Jacobs and Rodgers (1997), p.297, Acker and Levitt (1987) in the context of video-conferencing). The reason is simply that to look into the eyes of the remote communication parter, one has to look onto the screen, while the communication partner's eyes are the camera which comes from a different angle. Technical solutions to this problem exist but they are expensive. In any event, students who are physically in the same place as the teacher will naturally have an advantage which can be unfair.

In hindsight, our decision to use the AV–link for tutorials only as a makeshift solution was justified. There might, however, be room for using the AV–link for a tutorial arrangement in which more junior teachers (e.g. PhD students) are conducting the tutorials at both ends but are supported by a more experienced member of staff "on call" via the AV–link (see Sec. 6).

Computer labs An important element of our programme which we did look forward to teach via the AV–link were computer laboratories. In computer laboratories, students work on set problems which involve writing large pieces of computer code. Students were supposed to have a theoretical understanding of the problem as well as some basis in the computer language to be used. The role of the teacher is mainly to help the students with translating the mathematical problem into a coding problem and provide guidance with regards to the implementation. Students with little experience in programming lack the trained eye to spot errors in their code, errors which have nothing to do with the underlying problem (or the student's understanding of it) and only lead to frustration.

There is a lot of literature which suggest that computer laboratories as we envisaged them are perfect for remote teaching. "Through these initial experiences I came to the view that the best use of video-conferencing with students is likely to be in small group work, where interaction is a vital part of the session. In video-conferencing it is of the essence to get students conversing with each other. Possible

activities could be student presentations, problem solving exercises sharing computer applications, or student feedback debates on relevant topics." (Pitcher, 1999). Experience of our staff does not support this at all, and we received pretty negative feedback from the students, which contained loads of interesting suggestions as to what the problem was and how to improve the situation (realising how mature and constructive our students are was heartwarming after all this frustration). Before looking at this feedback more closely, I should say that it is mostly concerned with the computer labs for my course. The labs were taught by a colleague from Imperial College, but I would like to stress that the responsibility for the problems with this element of the programme lay with me rather than anyone else.

I asked the students (Question 4 on the questionnaire) *to give their opinion on whether the design of the computer laboratories was particularly suitable or unsuitable for remote lecturing and why. Please highlight advantages and disadvantages of the employed media.* Student opinions from the remote side were extremely consistent in their criticism: "Computer laboratories were not suitable for remote learning because computer sessions need an individual support that is quite hard to give remotely" (student B, Q.4). Other students' comments were very similar: "The main issue with the numerical labs was the almost impossibility to discuss with the professor when he or she was on the other side. This situation made the usual problems in understanding the tasks greater and even more complicated, sometimes creating new problems" (student C, Q.4), "Generally, remote teaching is not really suitable for the tutorial style of the computer labs" (student E, Q.4), "I believe 'tutorials' that involve dialogue between lecturer and student are less suited to remote learning." (student J, Q.4). It is also evident from these comments that the students very clearly understood how we had the tutorials envisaged. I have to stress that the teacher changed the delivery about halfway into term and from the responses to Q.4, it is clear that the situation improved. This will be discussed in Section 6, along with the interesting suggestions for further improvement in the students' responses to Q.4.

5 Implications on teaching and learning

In this section, I would like to discuss the wider implications of using an AV–link for teaching. First, I will focus on the general issues identified in Section 4, more specifically on the problem of techno–stress. Then I want to sketch briefly the implications of using an AV–link on the programme as a whole, and on teaching and learning in general.

In Section 4, I identified techno–stress as an issue when teaching via and AV–link. This strongly impinges on the teaching experience and thus warrants a more general discussion. I believe that techno–stress is not directly related to the fact that the teaching takes place via high level technology as such (and hence, techno–

stress is a misnomer). Rather, given the findings of Jacobs and Rodgers as well as our experience, techno–stress seems to be just an instance of stress or rapid exhaustion caused by distorted communication. Other instances are having to talk over a crackling telephone line, in a noisy environment, or in a foreign language, or having to listen to a lecturer with poor presentation skills.

The underlying problem is that a lot of mental capacity is spent on compensating for the disturbances (be they technical or psychological), drawing the attention away from the actual content of the communication. I will refer to this phenomenon as exhaustion from tedious communication (ETC). In a very interesting paper, Kosslyn et al. (2012) analyse flaws in PowerPoint presentations from a psychological point of view. Despite the focus of the paper, it contains a number of quite general messages. Firstly, the authors point out that "remarkably little research provides direct guidelines for designing presentations". What they mean is that although there is a vast number of resources on how to improve presentations, little research seems to have been undertaken to relate what we perceive as good or bad presentation skills to our understanding of human perception. This is probably the reason why, although remote teaching via AV–links is a very common phenomenon nowadays and various case studies are available, I found many of the practical recommendations to be at variance with what I would recommend based on our experience. The authors of Kosslyn et al. (2012) though demonstrate how our understanding of human information processing could be used to formulate guidelines for designing PowerPoint slides. The same should be possible for standard presentations and also for presentations via an AV–link. More generally, it would be desirable to develop an etiquette for all participants in remote teaching, with the ultimate aim of minimising ETC.

I will now discuss a couple of observations which will form the basis of a few recommendations for our future teaching. Firstly, we completely underestimated the role of audio. The absolute must in remote teaching is a rock solid audio link. The following thought experiment might illustrate this. Suppose You (the reader) are asked to lecture about a subject of your choice either via the radio or through a silent film. Unless the subject is very special, I believe that most lecturers would prefer the radio, especially if there is the chance to make up for the missing visual information, for instance by providing the audience with lecture notes in advance of the lecture. Secondly, any kind of communication uses a number of different channels at the same time (verbal, visual, non–verbal etc), but their relative weighting becomes greatly distorted via the AV–link. Visual information, in particular from slides, is usually transmitted very well and projected onto a big screen and might therefore attract unduly large attention. Body language appears to be amplified[1] which can be distracting, which is exacerbated by the fact that quality of moving images is often

[1] Actors in film use a very much down-toned body language when compared to their colleagues on stage

poor. For the same reason, lip movements of the lecturer cannot be seen clearly, which makes understanding much harder than one might think. A third problem is that it is much more difficult for the lecturer to guide the remote audience's attention back and forth between the different media she or he uses, e.g. between the slides and herself or himself. This was mentioned already in Section 4 and noted by the students. Providing this guidance however is absolutely vital; leaving the audience guessing as to whether they are supposed to look at the slides, the presenter, the white-board or whatever medium the lecturer is using is likely to tire them down very quickly.

A related problem that in the context of teaching and learning cannot be overrated is the difficulty for the remote audience to attract the speaker's attention. It is clear that if putting in a question or participating in any sort of discussion requires serious efforts, any form of interactive learning is impossible. This was a major problem with the tutorials and in particular the computer classes. In relation to this, in any AV configuration careful thought should be given to where to project the image of remote audience.

For the remainder of this section, I want to discuss the role of remote teaching in the context of wider teaching aims (both of academia in general and of our MRes programme in particular). As said already, we employ the AV–link as an enabling technology, not as a method. We use it because it allows students and lecturer to be in different places, which is what makes our joint MRes possible. The only two extra benefits in using this technology is that firstly, we can have management meetings between the two institutions without the need for travel, and secondly, the students can participate in lectures of the MAGIC consortium. It must be said however that there are other rooms at UoR where these lectures can be received.

A central problem for anyone involved in teaching is to create an effective learning environment, encouraging active learning, for instance through group work but also other means. As Kahn and Kyle (2002), p.207, argue, "in order to learn mathematics effectively students need to engage in a process that leads to the construction of their own mathematical understanding. (...) There are a whole range of ways in which students can avoid genuine engagement with mathematical content." From our experience, I believe that the opportunities to avoid engagement are even greater in remote lectures than in live lectures, and we certainly have no evidence that an AV–link in itself somehow encourages active learning. The lecturer has much less psychological control over the remote audience, and it is much harder to transfer emotions such as enthusiasm or serenity, and the potential for misunderstandings, either factual or emotional, is much greater. In the wider context of an MRes or undergraduate programme, this needs to be taken into account.

Remote teaching might not only have implications on individual students but also on the group as a whole, especially in our configuration where the cohort is split between two institutions. A core aim of the MPECDT MRes programme was

to create a strong cohesion between the students, or in other words, to create a cohort. The students had to realise that they are part of a very interesting and varied community, and taking active part in it would greatly enhance their learning experience. Given our experience I very much doubt that this could have been achieved solely using an AV–link. This coincides with my experience as a researcher that despite the many options of modern communication, personal meetings with research collaborators are still by far the most effective way to generate progress. To compensate for the fact that students are split between two campuses, we use our MPE Wednesday as a weekly meeting of the CDT (alternating between Reading and Imperial). The MPE Wednesday usually sees student presentations, workshops in transferable skills as well as the CDT seminar with external speakers.

6 Approaches to the issues

In this section, I want to discuss approaches to deal with what I see as the main issues that came up when we used the AV–link for our teaching, or with issues that are likely to come up with remote teaching in general.

Unfamiliarity with the technology It might seem that a simple solution to this problem is sufficient training for everyone involved in teaching via the AV–link, but this might be infeasible for several reasons. One of them relevant in the context of our MRes is that several staff give only few lectures or even only a single presentation (e.g. potential PhD supervisors presenting a project, or external speakers). We had good experience however with giving the students an introduction to the software so that they could start and use the system, assisting lecturers who were unfamiliar with the technology. It might be useful to designate a student at both ends to arrive 15 minutes prior to the lecture to boot the system and initialise the meeting (similar to the good olden days were students were responsible for wiping the boards).

Avoiding exhaustion through tedious communication (ETC) As argued earlier, the problem of ETC, especially in remote teaching, probably requires further research, but a few recommendations can be given. It goes without saying that good presentation skills are extremely important in remote teaching. Poor presentation skills are likely to be amplified when teaching via a remote link and, as discussed earlier, the remote audience will get exhausted the quicker the more attention is required to decipher the information coming from the lecturer. But in addition to the usual recommendations for presentations, which are still valid for remote teaching, the lecturer has to take extra care when guiding the remote audience through the presentation. She or he has to be aware of the fact that the remote audience will find it more difficult to connect the various channels of communication, i.e. visual, verbal,

and non–verbal, as discussed earlier. For this reason, it seems advisable, more even than for live lecturing, to keep the presentation simple. Only one medium should be used at any one time, in addition to speaking. When using a medium for the first time during a lecture, the lecturer should ask the remote audience whether it is transmitted clearly ("Can you hear me?", "Can you read this?", "You should see slide X now.") If the white-board is used, the lecturer should make sure to be captured by the camera while material on the board is explained. In particular, she should turn towards the audience while speaking so as to make lip movements visible. Pointing needs to be done slowly to make sure it is captured well.

When using slides, the lecturer has to be aware that the remote audience will struggle to see what she or he is pointing at. If the slides are captured with the camera rather than transmitted directly, the lecturer can point at it with a stick or her hands, but laser pointers cannot be used even in this situation as they are essentially invisible to the camera. If the slides are transmitted directly, the only way the lecturer can point is with the mouse pointer, but any delay in the transmission makes it imperative to do this slowly and with forethought. More generally, we found that in live lecturing, the lecturer turning his face towards the slide and moving his hands to handle the pointer is already a significant cue to the audience that attention should now be shifted to the slide content (and even more so if the stick is used), but this essentially disappears on the remote end. It is therefore good practice to provide this guidance verbally by saying this as "If we now look at equation X ..." or "Figure Y on the slide shows that X ...".

There is of course always the possibility to provide the students with handouts of the lecture notes. These can be a very valuable source of information in general, and if used wisely, can be very helpful during remote teaching in particular. If technical problems with the AV–link are encountered, such as white-board work being illegible at the remote end, the lecturer still has the notes as a last resort to continue with the lecture. Providing the students with lecture notes is not without problems and should be thought about carefully in general (see Tao (2006) for a reflection on this by an eminent mathematician who favours giving out lecture notes).

In Pitcher (1999), the delivery of a keynote lecture via an AV–link is described. Some of the arrangements employed in that experiment could be adapted to address some of the issues mentioned above in order to enhance the learning experience at the remote end. Basically, in Pitcher (1999), so–called "enablers" are present at the remote end who can help with the delivery. The enablers could emphasise the relevant part of the presentation by, for instance, projecting a large image of the lecturer at times when the slides are not relevant, present the footage of the lecturer adjacent to the transmitted slides, or in general make sure that only the relevant material is shown. In more sophisticated AV settings, the enablers might even remotely control the cameras. The caveat though is that to employ enablers to maximum effect, meticulous planning and even rehearsal is necessary. In the

experiment described in Pitcher (1999) "Both presenters (i.e. enablers) prepared thoroughly, to the extent of working to a pre-written script and an agreed agenda.", and the authors advise that "...far more preparation is needed for a successful video-conference session than for a conventional lecture. Preparation needs to give meticulous attention to detail, even to the point of writing a script and planning camera shots." It is clear that due to time constraints, a normal lecture course cannot rely on enablers to the same extent as the keynote lecture described by Pitcher (1999).

Interactive teaching and promoting active learning Our experience with tutorials and computer laboratories is consistent with what it described in Jacobs and Rodgers (1997), namely that "Real time video-conferencing can supply virtual face–to–face interactivity, but is subject to more obstacles than its physical equivalent". In other words, it is much more difficult to establish an interactive learning environment via the AV–link than in reality. This strongly affects our efforts to promote active learning by getting the students engage in the learning process and take it, to some extent, into their own hands, as a key point here is clearly that communication between students themselves and with the teacher meets with as few obstacles as possible. Redesigning our approach to remote tutorials and in particular computer laboratories is thus a pressing need in the MPECDT MRes.

In terms of tutorials, we will certainly continue with our approach to have these separately at both ends in conventional style, as we had good experience with this. In other words, the general recommendation is that to achieve active learning, remote lecturing has to be supplemented with live and interactive tutorials (in fact, I would like to think of the tutorials being at the centre of the learning process and say that they are supplemented with remote lectures). A problem we encountered is the variation in quality of the tutorials at both ends. This has little to do with remote teaching as such, but the programme management has to ensure that tutorial provision on both ends meets the same standards. This was not always the case in the first year of the MRes, and the students very rightly complained about this (see e.g. student I, Q.5). Of course, more tutorials require dedicated teaching staff, but as one student aptly put it "Of course, this will not be an issue next year; one of us will serve as the assistant for these lab sessions next year." (student G, Q.4). Indeed, we plan to recruit among our more experienced students for helping with the tutorials. But there is still a way we might put the AV–link to use here. The tutorials might run at the same time in the AV–room at both ends but essentially independently. Nonetheless, a more experienced teacher might be available "on call" via the remote link, being able to assist with questions when needed. There is a free version of the visimeet–software which can be installed on standard home PC's (this version has some inessential features disabled). Thereby, the experienced teacher "on call" can remotely take part in the tutorials from his office PC.

The core problem with the computer laboratories is that, on top of the issues with interactivity as mentioned above, the students and the teacher need to share computer code. As said previously, the instructor has to help students with finding errors in their code in order that the students can focus on the actual programming tasks. A solution that has been suggested in Boddison (2010), p.142, is to have a hand-held camera at the remote end that students can point at their screens, but this brings about technical problems as the frame rates of camera and computer screen have to match as otherwise the image is blurry (as already mentioned in Boddison (2010)).

Halfway through the term, with the students' (and instructor's) dissatisfaction with the computer labs mounting, the instructor teaching the computer labs tried the following approach: After explaining the tasks and clarifying initial questions via the AV–link, he left the room and engaged in a virtual chat room meeting with all students. Thereby, all students could share problematic pieces of code with the instructor and engage in a discussion, but of course within the limits imposed by a simple internet chat room, that is, only by writing short snippets of text. This was only a makeshift solution and far from optimal. The benefit was merely that now all students were on the same level in terms of getting the instructor's attention. In fact, this enraged some students at the live end as their teaching experience deteriorated (student I, Q.4).

A related but probably much better option would be that all students install the video-conferencing on their individual computers and engage in a meeting with the teacher using the free version of the visimeet–software mentioned before, rather than through an internet chat-room. We have not tried this, but there are a large number of technical issues one can think of with this approach.

7 Recommendations and arrangements for review

This section I will present somewhat of an action plan to address the issues identified above in the context of the MPECDT MRes and in particular of my teaching. Plans for evaluation and potential future review will also be discussed.

Lecturers who are unfamiliar with the AV technology will always be an issue in the context of our MRes. Our core teaching staff have, by now, acquired sufficient knowledge of the technology to be able to run their lectures without the need for outside help. But we will continue to welcome new staff teaching elements of the course, and guest speakers will continue to play an important part in our programme. As said, we already have good experience with employing the students as helpers with the technology. An introduction to the software is now envisaged as part of our introductory residential course, the *Kick–Off camp*, to be held in September 2015. We will further designate a student at either end to take responsibility for booting the system and initialise the meeting.

Improving presentation skills should be high on the agenda of every teacher's CPD, and this is particularly true for the remote teaching skills for staff on our programme. Given the students' feedback, this does not seem to be a pressing issue with the current staff, but we should all be open to improvement and use the opportunities available to enhance our remote teaching skills. I envisage that we more actively offer peer observation while remote teaching to all staff. Given the present situation though, there seems to be no need to make this mandatory or to add any element of compulsion. Another option we have is to record the lectures. The software we employ does offer this functionality, but unfortunately we encountered technical problems which we were unable to resolve during the first term. Further, it must be kept in mind that recording a lecture using the AV software does not faithfully reproduce the learning experience at the remote end. It simply records the transmitted windows, but fails to reveal any issues connected to the rendering at the remote end, such as problems with the sound output, the projectors, or how the transmitted windows are arranged.

We have also decided to provide the students with lecture notes, well in advance of the programme's start. There are a number of reasons for this decision, but one of them is clearly the potential unreliability of the AV–link.

With respect to tutorial provision, I will recommend that we stick with the model of separate tutorials at both ends being the norm. Coordination between the tutorials though needs to be improved. This will be less of an issue as our students from the 2014 cohort who share the same past experience will help, and hence we expect to have more coherence among the teaching staff in the first place. Nonetheless, at least for my course I will more closely monitor tutorial provision by asking the students for more specific feedback at an earlier stage. Strategic monitoring of unassessed homework is another mechanism of checking whether tutorial provision has the desired effect, and I plan to introduce this (or expand this) for a number of other reasons as well.

How to deal with our computer labs is a more difficult issue as essentially the entire CDT management is involved in the decision making process. Currently, we are discussing two options. Firstly, to keep the computer labs as an add–on element to the core course (essentially as they are now) but make sure we have tutors (or enablers) present at both ends, probably even two enablers at both ends, as our current students actually suggested. The instructor would act more in the background, being "on call" to help when problems emerge. What plays a role here is that we plan to expand the initial training in programming, to ensure that students are more familiar with coding and fewer problems in relation to that are expected to arise.

The second model is that the computer labs are scrapped and replaced by a dedicated course on numerical mathematics. This model is advocated by the current instructor, and there are additional reasons for this which have nothing to do with

the AV–link. This model would still require running computer labs, but these are envisaged as a residential course with all students being in the same location for a few days. There is no question that this model has the potential to provide the better learning experience, but it puts strong constraints on the timetable, the budget, and staff availability.

8 Conclusions

Experience with remote teaching via audio–visual technology was discussed in the context of an MRes programme in "Mathematics of Planet Earth", taught jointly between Imperial College London and University of Reading. We used the technology mainly as a tool to enable the teaching of this joint programme without having to travel, rather than as a method to enhance the teaching experience beyond what would be possible through standard teaching. In fact, it is questionable whether audio–visual technology actually has the potential to do so, at least without substantially increasing the required amount of preparation.

The effects of using this technology on the learning experience of the students are discussed, both in context with the intended learning outcomes of the programme as well as with mathematics teaching in general. A number of issues were identified. Most importantly, we found that the potential for interaction between participants is very much limited when compared to live lecturing and in particular tutorials. The high level of interaction which is absolutely essential for active learning in mathematics is, as we found, much more difficult to maintain, in contrast to what is sometimes stipulated in the literature. The implications this had on our programme were discussed, along with potential future improvements and arrangements for review. Further, we found that although standard lecturing via the AV–link works relatively well, great attention needs to be paid to presentation skills and delivery. The lecturer has much less control over the audience at the remote end, and it is easy to quickly exhaust the attention at the remote end by failing to take the limitations of the technology into account. Finally, the wider implications on the MRes programme and teaching and learning in general were discussed. As a major aim of the MRes is to build a strong cohort across the two campuses, further arrangements to ensure this are necessary. The AV–link alone will not provide enough cohesive forces to form a strong bond between the students on the programme.

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