Remote Operation, Immersive 3D Virtual Environments and Interactive Screen Experiments for Teaching Practical Science On-Line

One of the biggest challenges facing the Open University and other providers of distance education courses in Science is the provision of practical work for students. In Physics and Astronomy, subject benchmarks and professional bodies each stress the importance of such experience for students:

> "Physics curricula should give students experience of the practical nature of physics. They should provide students with the skills necessary to plan investigations and collect and analyse data (including estimation of inherent uncertainties). These skills may be acquired as part of a course in a laboratory or by a range of alternatives including computer simulations. Practical work should thus be a vital and challenging part of a physics degree, and all graduates in physics should have some appreciation of natural phenomena in an experimental context." *Physics & Astronomy Subject Benchmark statement, Quality Assurance Agency for Higher Education* (http://www.qaa.ac.uk/academicinfrastructure/benchmark/honours/physics.pdf)

> "All graduates of an accredited degree programme should have some appreciation of physics as an experimental science. They should have an understanding of the elements of experiment and observation and should therefore be able to plan an experimental investigation; use apparatus to acquire experimental data; analyse data using appropriate techniques; determine and interpret the measurement uncertainties (both systematic and random) in a measurement or observation; report the results of an investigation and understand how regulatory issues such as health and safety influence scientific experimentation and observation. For many degree programmes, experimental work in a conventional laboratory course will be a vital and challenging part and will provide students with the skills necessary to plan an investigation and collect and analyse data. However, these required skills may also be acquired through computer simulation, paper exercises with appropriate data, or case studies using real experimental data from a published source." *Graduate Skills Base and the Core of Physics, Institute of Physics*, http://www.iop.org/activity/policy/Degree_Accreditation/file_26578.pdf

Work in the piCETL has explored the use of a number of approaches to teaching practical Physics and Astronomy that provide an alternative experience to a conventional laboratory-based curriculum. These approaches are more readily applicable to teaching students at a distance, on a global scale, and may broadly be divided into three categories:

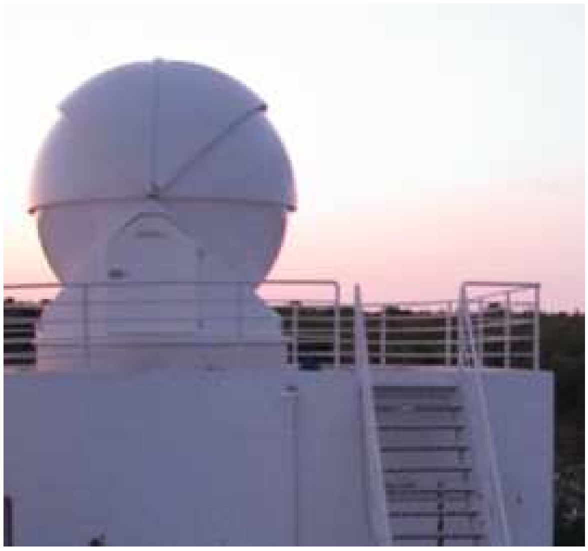
1. remote operation of equipment
2. immersive 3D virtual environments
3. interactive screen experiments

All three types of experience will likely find a place in the planned Level 2 *Advanced Scientific Investigations* module which will be a compulsory component of the new BSc Natural Science qualification that is currently being developed by the OU Science Faculty. For many students, spending a few days or a week away from home to carry out practical work at a 'traditional' OU residential school is something they are not able, or not willing, to do. These remote, virtual, and on-line alternatives offer such students a far greater choice and enable access to be provided to groups of students who have previously been denied an experience of practical science. They also mean that, for the first time, OU practical science modules can be offered globally.

Remote Operation of Equipment : PIRATE

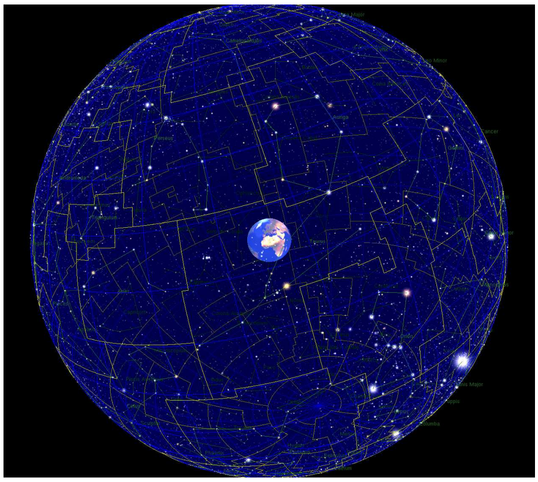
PIRATE (the Physics Innovations Robotic Astronomical TElescope) is a remote-controlled 40cm telescope on a robotic mount in an automated 3.5m dome. Students connect to PIRATE via a web interface and submit commands to: remotely open or close the dome, point the telescope, and acquire images of the night sky. Observers download images to their own PC for analysis with commercial CCD image manipulation software. Expert users have full access to the PIRATE control PC for system maintenance, development and more advanced applications.

Small student groups have shared simultaneous access to PIRATE via the automated observatory control software ACP. Larger groups of students will be able to monitor PIRATE's real-time use with an animated 3D model of the telescope under a simulated sky. The animation runs locally on the students' PC but obtains live information on the status of PIRATE from a web server. When used alongside live conferencing software, interactive, live observations with a mass audience are feasible.



Immersive 3D environments : the PIRATE Simulator & Celestial E-Sphere

We have developed several 3D graphics applications to support our teaching. Some of these applications create virtual environments. In particular a telescope simulator has been used to introduce students to the controls of a particular telescope that they will then subsequently use at an observatory**.** Most students have never used a telescope before and find controlling one rather challenging. This results in significant wasted observing time at the observatory. The developed application simulates the sky, the telescope, and the hand-controller. They sky is rendered in a familiar planetarium style. The telescope is a 3-D, fully-animated and textured graphical entity that gives the user the look and feel of the real telescope. The hand-controller works identically to the actual one except within the application it is clicked on with a mouse. This enables the students to gain a familiarity with aligning the telescope before commencing the course. It also allows them to gain a working knowledge of using celestial coordinates and the night sky.



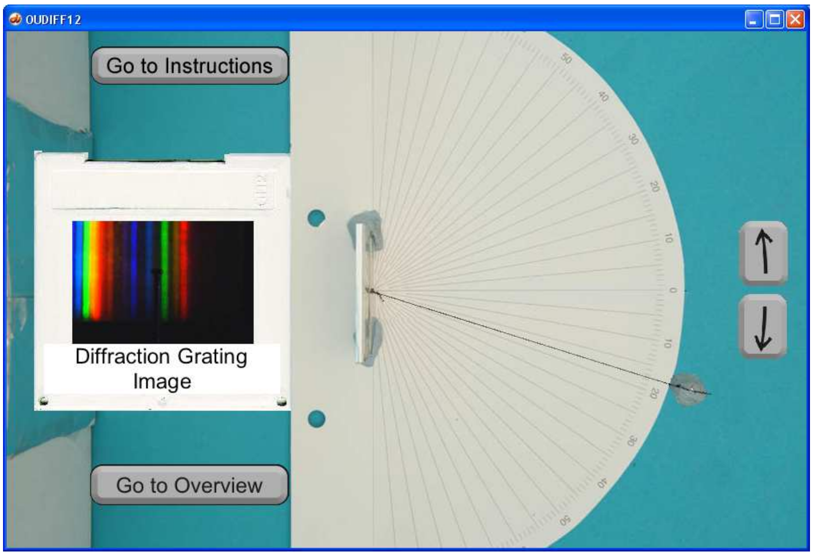
The Celestial E-Sphere allows students to explore an interactive ‘map’ of the night sky that can be viewed from the inside (looking out) or outside (looking in). It presents a very striking animation that is aesthetically pleasing whilst being of obvious educational value. Features have been incorporated that correspond to a typical planetarium demonstration so allowing its use in e-tutorials.

Interactive Screen Experiments

In the most general terms, a virtual laboratory is a computer-based activity where students interact with an experimental apparatus or other activity via a computer interface. Typical examples include a computer-coded simulation of an experiment, whereby a student interacts with programmed-in behaviours, and a remote-controlled experiment where a student interacts with real apparatus via a computer link, yet the student is remote from that apparatus. For our purposes, we refer to Interactive Screen Experiments as something distinct from either of these alternatives. ISEs constitute a virtual laboratory where the student interacts with an experiment or activity which has no immediate physical reality. This definition may seem to imply that such virtual laboratories can have no physical reality behind it at all. For example, in a simulation of gravity we might code for behaviour different to the familiar inverse square law (if only to explore the consequences of such a simulated universe). However, this disconnection with reality need not be the case; the whole concept of the ISE is to provide as close a connection to reality as possible within a virtual laboratory environment.

It is important to understand the benefits that resources such as ISEs can bring to the learning experience. Within the Open University context these include accessibility, training and augmentation. In its broadest sense, an ISE can be defined as a highly interactive movie of an experiment, filmed as that experiment was being performed. By highly interactive, it is not meant that the movie is simply capable of being moved forward or backward at different rates; this limited interactivity, whilst valuable, would curtail the range of experiments possible. A specific example can be used to illustrate the point.

The picture shows a screen-shot of a simple ISE demonstrating Hooke's Law. In this example, the user interacts with the movie (the interactive screen experiment) by using the computer mouse to manipulate the on-screen representation of the dial. The dial rotates as would the real example, with the spring extending or contracting depending on the direction of rotation. Simultaneously, the force indicated (equivalent to the tension in the spring) is shown by the pointer. Moving the dial controls the frame-to-frame motion of the movie, with each frame being a snapshot of the experiment as it was being performed. This example also serves to strengthen the distinction between ISEs and coded simulations. In the simplest case the behaviour of the spring might be programmed using a straight-forward Hooke's Law case with no element of nonlinearity. In the case of the interactive screen experiment though, the images presented on the screen are taken from a *real* experiment, recorded as it was being performed. The interactivity (turning the dial) governs how the movie switches between recorded frames as a result of user action. In consequence, the interactive screen experiment illustrates the *real* physics of the phenomenon rather than an idealised representation and it will inherently include nonlinear effects.



An experiment in the Level 1 Introductory Science course requires students to set up a simple spectrometer for themselves, using a diffraction grating that is provided, a paper protractor that can be downloaded from the course website and various household items (e.g. light bulbs, cardboard, drawing pin, pin, cotton). The experiment requires some skill and dexterity to set up and requires moderately high visual acuity, and as a result some students are unable to perform it. In addition, students in prison may be forbidden access to some of the required household items. Therefore an ISE version of the experiment has been produced (shown above) for these students, who are advised that in general they should just follow the instructions given to all students in the course text (because they are, after all, doing the same experiment, and keeping the experience as close to reality as possible is desirable).

Conclusions

Work carried out in the piCETL over the last few years has demonstrated the possibility of creating immersive 3D virtual environments and interactive screen experiments, as well as remote operate of physical equipment, as a viable means of providing valuable practical physics and astronomy experiences to students studying at a distance. Moreover, student engagement with these new tools has been positive throughout and demonstrates the utility of these resources in a wider context. It is fully anticipated that the new faculty-wide practical science course will draw heavily on these lessons and experiences as it builds a new practical science experience for OU students in the 21st century.

Andrew Norton, Physical Science Awards Director, April 2010