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# Interactive screen experiments—innovative virtual laboratories for distance learners

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## Abstract

The desirability and value of laboratory work for physics students is a well-established principle and issues arise where students are inherently remote from their host institution, as is the case for the UK's Open University. In this paper, we present developments from the Physics Innovations Centre for Excellence in Teaching and Learning (piCETL) in the production and technology of the virtual laboratory resources, interactive screen experiments, and the benefits and drawbacks of such resources. We also explore the motivations behind current implementation of interactive screen experiments and examine evaluation strategies and outcomes through a series of case studies.

## 1. Introduction

The concept and implementation of virtual laboratory resources in the physical sciences has many consequences. These relate to the purpose a virtual laboratory is seeking to address, the experience of both students and tutors, and the suitability of an activity. In this paper, we explore these concepts in the context of a particular class of virtual laboratory, the interactive screen experiment (ISE), pioneered by Kirstein [1, 2] and Schumacher [3], introduced to the UK as the reality viewer by Bacon [4, 5] and now being developed at the UK Open University (OU) in partnership with the University of Reading through the HEFCE funded Physics Innovations Centre for Excellence in Teaching and Learning (piCETL) initiative [6]. Additionally, we will examine how, and for what purpose, these resources have been incorporated into OU courses, and summarize evaluation in a selection of case studies.

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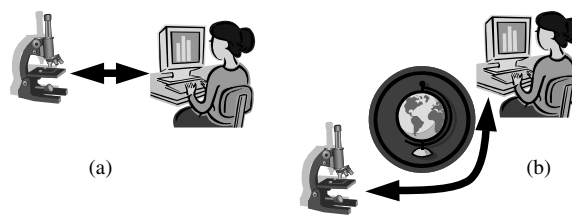
The OU was established in 1969 to provide degree programmes by distance learning. There are no formal entrance requirements for undergraduate courses and most students are adults, usually in employment or with other significant responsibilities. Their study is therefore part-time and opportunities for face-to-face contact with personal tutors are limited. The situation in the sciences for practical work is very challenging. In the OU context, practical work is taught at week long residential schools hosted by traditional universities and staffed by OU tutors, and by home experiments (some apparatus supplied by OU, with students supplying common household items). However, such a strategy, whilst effective, cannot address all issues. Particular points include the following:

- distance/lack of access (the OU has students all over the world, some in very remote locations; others may not have full access to resources, perhaps because they are in prison or hospital);
- employment responsibilities or other commitments (especially caring responsibilities) mean that some students simply cannot attend conventional laboratory sessions;
- students may have declared disabilities or be just slightly lacking in dexterity or aspects of visual acuity, such as accommodation or depth of field;
- the OU, by definition, is open to all; students may never have done laboratory work before or may be particularly lacking in confidence.

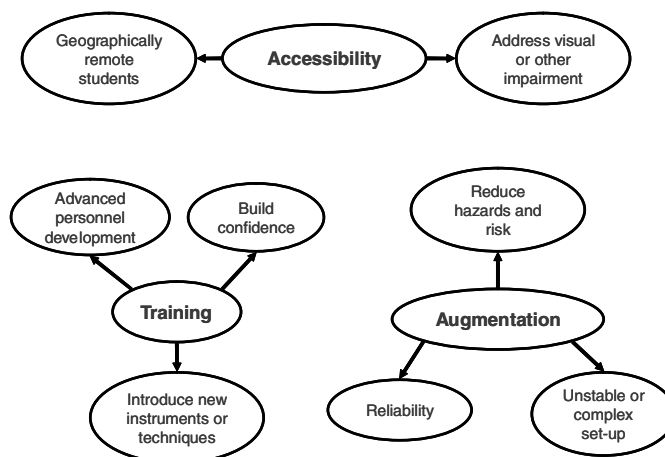
Given the above constraints on the teaching and learning of practical skills in the OU environment, a means of engaging students with practical work outside the laboratory (or indeed without equipment) is necessary to supplement and enhance the effectiveness of the real practical work, or (where unavoidable) to act as a replacement.

Before discussing the ISE concept in detail, it is necessary to define what is meant by a virtual laboratory, understand what value it can bring and, importantly, what it cannot (and indeed ideally should not) do. 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. The latter case is distinguished from a computer-controlled experiment, where a student will directly control an apparatus in his or her vicinity via a computer interface (figure 1). For the purpose of this paper therefore, a *virtual laboratory is one where the student interacts with an experiment or activity which is intrinsically remote from the student or which has no immediate physical reality*. The latter part of this definition may seem to imply that a virtual laboratory 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 [7]. Within the Open University context these include accessibility, training and augmentation; some specific examples are given in figure 2. It is of particular note that one frequently perceived benefit—that of *replacing* real laboratories—is missing. This is simply because it should not normally be regarded as a benefit. Nothing can replace the experience of working hands-on with apparatus and equipment, hence, although better than no experience, the virtual laboratory should not be perceived as providing a full experience, unless such replacement is unavoidable.



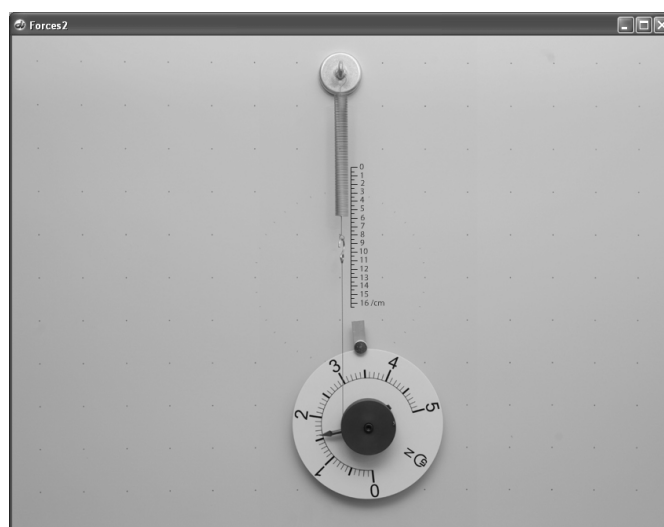
**Figure 1.** The distinction between (a) a computer-controlled experiment and (b) a remote-controlled experiment. The latter case is an example of a virtual laboratory.



**Figure 2.** Some of the benefits of a virtual laboratory.

## 2. The ISE concept

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. Figure 3 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 straightforward 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



**Figure 3.** An example of a simple interactive screen experiment (contained in [8] as forces2.exe).

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 idealized representation and it will inherently include nonlinear effects. The example shown in figure 3 may be downloaded, together with a portfolio of other ISEs presented at the Physics Higher Education Conference 2008 [8]. The ISEs are in stand-alone Windows executable format, requiring no installation or special procedures.

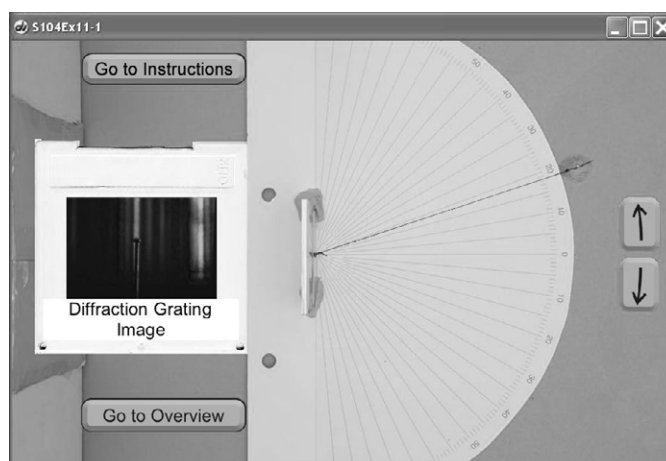
### 3. Using and evaluating ISEs

ISEs can be put to a variety of uses depending on the requirements and context of the learners and of the learning outcomes of the courses in which they are included. In this section three uses of ISEs in Open University courses will be examined through case studies.

For each ISE designed for Open University use, evaluation needs to address the following questions:

- Are students able to use the ISE effectively and efficiently?
- Are any instructions provided appropriate and easy to use, or is it appropriate that the ISE has no instructions?
- Are there any bugs or other flaws in the software?
- How do students perceive and react to the ISE?
- Does the ISE achieve its intended aim, for example enabling the student to complete assessment tasks associated with the activity the ISE is supporting?

Wherever possible the evaluation is objective—recording and observing what students actually did, not what they say they did. Since it may only be possible to observe a small number of students in a controlled environment, it is frequently appropriate to make use of qualitative research methodologies.



**Figure 4.** An ISE representation of the S104 diffraction experiment (contained in [8] as OUDIFF12.exe).

### 3.1. Case study 1: S104 Exploring Science

S104 Exploring Science is the OU's new flagship level one course, delivered for the first time in 2008, providing an introduction to the physical, life and earth sciences. Students study at a distance using provided course materials (books, DVDs, etc) as well as on-line support and assessment. One aspect of the course is the inclusion of experiments performed at home by students, using both readily available household items and more specialist items provided by the OU.

One experiment, completed approximately one third of the way through the 9 month 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). Most students find the experiment useful and enjoyable, with the following comments being typical of many:

- 'I really enjoyed this experiment. I was surprised at how interesting and successful it was. I even got my parents to observe the difference in the spectrums of the bulbs, and was able to explain to them how the energy-efficient bulbs work. It was good because I was able to share my new knowledge.' (S104 student)
- '(students) are normally quite blown away that you can look inside the atom with just day to day equipment . . . ' (S104 tutor)

However, the experiment requires some skill and dexterity to set up and requires moderately high visual acuity; in particular, high accommodation and good depth of field. Some students are therefore 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 (figure 4) for download from a hidden part of the course website or as an executable file on CD-ROM. Students who are unable to perform the real experiment for themselves are advised to contact their tutor, who will arrange access. Other students are not told that the ISE exists, since it is preferable that students perform the real experiment wherever possible.

**Table 1.** Feedback from students using an ISE in S104 Exploring Science.

Student	Reason for requiring access to ISE	Version of ISE used	(a) Instructions downloaded? (b) Magnifier used?	Method used to move the 'pin' on the screen
A	Could not obtain the equipment (student abroad)	Web link	(a) Yes (b) no	Dragged using mouse
B	Could not set up the experiment—too fiddly; could not bend down to view the spectrum	Web link	(a) No (b) no	Dragged using mouse; used arrows on screen
C	Could not bend down to view the spectrum	Web link	(a) Yes (b) no	Used arrows on screen
D	Other: 'I only have the use of one arm at present'	Web link	(a) Yes (b) no	Dragged using mouse; used arrows on screen
E	Could not obtain the equipment (student in prison)	CD-ROM	(a) No (b) yes	Dragged using mouse; used arrows on screen; used arrows on keyboard

Students need to use the ISE by themselves, without direct supervision from a tutor, so a set of brief instructions has been produced. However students 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). Tutors are given guidance on how to support students in using the ISE should they have any queries and they are also given guidance on how to mark any assignments where the student's report is based on their use of the ISE.

**3.1.1. Evaluation methodologies.** Evaluation of the S104 ISE was via two methodologies; monitoring of use and observation in the OU's Institute for educational technology (IET) Usability Laboratory.

For the presentation of S104, which started in October 2008, the students' performance of the diffraction grating experiment was assessed in a tutor-marked assignment. Of the 1600 students studying this presentation of the course, only around 20 needed to use the ISE. Feedback from these students and their tutors has indicated that the students were able to interact successfully with the ISE and to complete the related assessment tasks as successfully as those who performed the real experiment. Detailed feedback from five of the students who used the ISE is shown in table 1, and indicates their reasons for using the ISE and their interaction with it.

It needs to be noted that the current use of ISEs in S104 is for the purpose of addressing accessibility issues. Hence, a comparison with students doing the real experiment would not be informative in this case. However, study of table 1 shows the categories of students whom the ISE assisted, and also reveals the manner of accessing and interacting with the ISE. It is noticeable that the trend was for students to use mouse interactions, but not exclusively. Indeed, some students used more than one method to interact—a revealing outcome in itself as this provides feedback to future ISE control design.

The IET Laboratory was used to investigate the ISE's usability in a controlled setting. Quesenbery [9] identifies the five dimensions of usability as effectiveness (the completeness and accuracy with which users achieve their goals), efficiency (the speed with which users can accurately complete their tasks), engagement (the degree to which the product is pleasant and satisfying to use), error tolerance (how well the design prevents errors or helps with recovery



**Figure 5.** A screen-shot of a recorded IET Usability Laboratory session.

from those that do occur) and ease of learning (how well the product supports initial orientation and subsequent use).

Following accepted practice for usability laboratory evaluation (see for example [10] and [11]), participants interacted with the ISE without assistance other than an initial briefing. They were however provided with printed guidance notes. The participants' interaction with the ISE was observed live and recorded for subsequent analysis (figure 5). A verbal think-aloud protocol was used, whereby the participants were asked to talk about what they were doing or trying to do. After the evaluation session itself, each participant was asked to comment retrospectively on the reasons for their actions and on their reaction to the ISE.

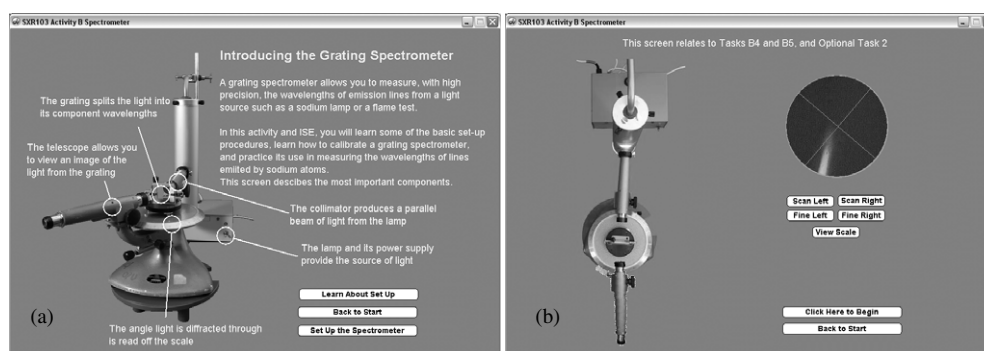
**3.1.2. Early findings from the IET Usability Laboratory.** Six volunteer participants (two students taking S104 at the time of the study, and four tutors) were observed as they attempted the ISE, under the protocol described above. The outcomes will be presented in fuller form in a future paper, and are discussed here in summary.

Observations from the IET Usability Laboratory and from interviews revealed students and tutors found the ISE easy to use, and made comparisons with the real experiment, noting a connection between the ISE and reality. On the whole, participants found the ISE and instructions clear and accessible (a cosmetic issue surrounding accessing the ISE via a web browser was identified and addressed). An issue arose because two blue spectral lines were visible in the grating images in the ISE, whereas the course text described just one such line. The source of this discrepancy was traced to the spectral response and sensitivity of the camera used in imaging the spectrum, which differed significantly from that of the human eye in the blue region. Hence, lines which are distinctly blue and violet to the eye both appear blue in the images. This issue is now explained and clarified in the ISE instructions to avoid confusion but other aspects are deliberately not explained, to enable students to pursue their own investigation as they would if doing the real experiment.

### 3.2. Case study 2: SXR103 Practising Science

SXR103 Practising Science is a 1 week level 1 residential school course. The primary aims of the course are to





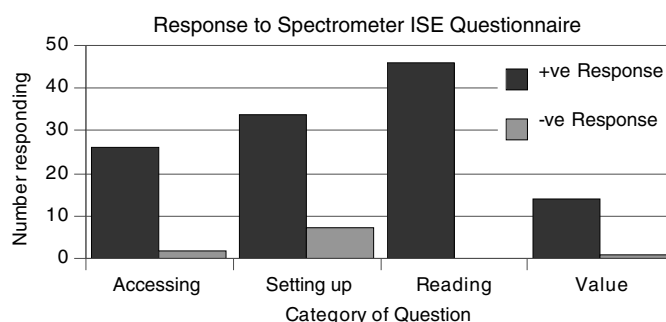
**Figure 6.** An ISE illustrating the setting up and use of a simple grating spectrometer. (a) An introductory screen allowing familiarization with components. (b) Taking measurements with the spectrometer ISE, showing the presence of flares (contained in [8] as *sxr103 spectrometer.exe*).

- introduce the nature of practical work in the laboratory and in the field, and the skills of recording, reporting and interpreting data;
- develop confidence in working with a variety of laboratory and field equipment and techniques;
- introduce literature and web-based research;
- develop team working, problem solving and oral communication skills.

In many ways, SXR103 is the experimental partner to S104, in that the physical, life and Earth sciences are addressed in a way which emphasizes the unity of science. For example, the school does not comprise pure physics, chemistry, biology and earth science laboratories, but rather takes a more integrated approach. In particular, one activity involves measuring low levels of radioactivity in rocks, combining skills in physics and earth science; another involves the use of spectroscopy in environmental analysis.

For most students, SXR103 represents their first encounter with experimental science, an encounter which for some can prove daunting. A particular concern is the students' lack of familiarity and confidence with experimental equipment; it is such an issue that ISEs are designed to address. To examine the effectiveness of ISEs in developing confidence and competence at residential school, an ISE based on the setting up and calibration of a simple grating spectrometer was created to assist students in the environmental analysis laboratory (figure 6(a)). The ISE is highly structured, taking its cue from the workbook students are provided with for the environmental analysis laboratory. The first steps are to set up the spectrometer by focusing the telescope and collimator. The advantage to students at this point in the ISE is a visualization of what 'in focus' means in the spectrometer context; to ensure this, the ISE is structured to give constructive feedback, and to require correct set-up before the student can proceed to the calibration section. As in the real activity, calibration uses an intense sodium discharge lamp. A consequence of the intensity is the presence of flares in the spectrometer view (figure 6(b)) which, to the inexperienced eye, may be mistaken for true spectral lines. Since ISEs are based on images from real experiments such imperfections are automatically present. Students can therefore gain intangible experience, which is often difficult to describe without examples, before encountering the real spectrometer.

**3.2.1. Evaluation methodology.** A typical residential school day comprises laboratory or field trip activities during the day, and tutorials and workshops in the early evening. The



**Figure 7.** Outcomes of the SXR103 Practising Science ISE survey.

spectrometer ISE was made available as an optional workshop activity over several evenings (limited to five students per session), to which students about to perform in the environmental analysis laboratory were encouraged to come. Students were observed as they were working through the ISE and encouraged to complete a short survey concerning the usability and the benefits of the ISE.

Observations and responses from students were of value, but the ultimate test of the value of ISEs in developing confidence and competence is in the real laboratory. To this end, students who participated in the ISE workshop were followed up in the environmental analysis laboratory and their response to the real spectrometer in the light of the ISE experience evaluated through brief interviews. As with the S104 study, numbers were insufficient for a statistically significant analysis, hence the outcomes should be viewed as qualitative.

**3.2.2. Evaluation outcomes.** The survey was structured as a series of objective questions in four categories, each category containing four to six questions. The categories were: starting the spectrometer ISE, setting up the spectrometer, taking measurements and the value of the ISE. The outcomes are presented in bar-chart form in figure 7. The total responses in each category represent the total positive and negative responses to all the questions in that category. In each of the four categories, the responses were overwhelmingly positive. Students were able to access the ISE, using both on-screen and printed guidance. It was interesting to note that a number of students needed to perform the setting up more than once to get a satisfactory result—illustrating the connection to a real experiment. This outcome is contained in the negative responses to the ‘accessing’ category, and informed improvements to the setting up instructions. However, the ability to make a mistake in this way illustrates the value of an ISE over a simple instructional manual in that making mistakes at the familiarization stage means that the likelihood of students repeating the error in the real experiment is reduced. This outcome was emphasized in the final section of the survey, where students reported both an improvement in confidence for the forthcoming laboratory, and that they had data taken by themselves from the ISE to check against the real experiment.

When students were interviewed following their experience in the laboratory, the value of the ISE was borne out through comments such as: ‘I knew what I was looking for (when using the spectrometer)’. These comments addressed the use of the equipment (students were familiar with the various components of a spectrometer), taking measurements (measuring angles using a Vernier scale had been introduced) and observation of spectral lines (students were aware of the difference between real spectral lines and optical artefacts).

### 3.3. Case study 3: SXR207 Physics by Experiment

SXR207 Physics by Experiment is a one week residential physics course in which participants carry out a variety of laboratory activities appropriate for second level physics students. The primary aim of the course is to develop practical laboratory and data handling skills. To this end, SXR207 is centred around four separate laboratory experiments, which are supported by lectures, workshops and tutorials. Students spend a total of six hours in each of the four practical experiment sessions. Subjects covered include magnetic fields and forces, electrical oscillations, the Compton effect and a variety of short experiments based mainly on wave phenomena.

Because time in the laboratory sessions is limited, the use of ISEs was considered as a means of preparing students for the laboratory work. Of the four experiments, the Electrical Oscillations Laboratory was chosen for this trial because it involves the most complex measuring equipment. This work revolves around measurements made on inductors and resonant circuits using a standard analogue oscilloscope. The large array of controls on a typical oscilloscope can be very daunting to an inexperienced student; a large percentage of students will not have previously used such an instrument. Based on past experience, such students tend to spend a significant proportion of their time learning how to operate the oscilloscopes. This can take a significant fraction of laboratory time. A typical comment from experienced tutors is that in many cases, the measuring equipment was getting in the way of the students being able to work on the actual learning objectives of the experiment. The objective of the trial was therefore to prepare the students for the measurements that they would be required to make with the oscilloscope, thus allowing them to concentrate on the physics and maximizing their use of laboratory time.

Another advantage of choosing this experiment was that a suitable software package was readily available. The Virtual Oscilloscope [12] is an online package developed by the Technical University of Berlin. This is based on a typical oscilloscope very similar to the model used in the SXR207 Electrical Oscillations Laboratory and is made available for non-commercial purposes.

The Virtual Oscilloscope package includes an online tutorial, but experience from a limited trial in the previous year indicated that students needed additional guidance relating specifically to the laboratory work that they were about to carry out. A scripted activity based around the skills and measurements specifically required for the oscillations experiment was therefore developed for use with the Virtual Oscilloscope. This activity involved the students making various measurements on signals provided within the software package, and was intended to take approximately 30 min.

**3.3.1. Evaluation methodology.** In the week of evaluation, the Virtual Oscilloscope activity was offered to students in parallel with an existing computer workshop. Of the 65 students registered on the course, 28 elected to take part in the trial. Most stated that they chose the activity because they had little or no previous experience of using an oscilloscope. All students who took part did the online activity before the actual practical laboratory.

Evaluation has been based mainly on the comments of two experienced tutors who have run this laboratory on a number of occasions in previous years, and who were therefore very familiar with the usual timings and rates of progress through the laboratory. These tutors were asked to comment on the students' progress compared to other years.

**3.3.2. Evaluation outcomes.** Both tutors commented that the students appeared more confident in using the oscilloscope than usual. They also stated that there was a marked

decrease in the number of students asking for help or guidance. Tutors teaching this laboratory would normally give introductory demonstrations on how to use the oscilloscopes. However, because the students had grasped the basic principles from the online activity, these demonstrations were not required this time and the students were able to get on straight away with the actual laboratory work and measurements.

In this respect, the use of the Virtual Oscilloscope has succeeded in its objectives of training the students in the use of the measuring equipment and allowing them to concentrate on the physics content of the laboratory work. Based on this experience, the activity will be formally incorporated into future presentations of SXR207.

#### 4. Conclusions

ISEs have been presented as an innovative solution to developing and enhancing laboratory practice and access for distance learners, and as a means of providing training and experience for teaching laboratories. We have presented outcomes and data for two case studies (S104 and SXR103), and observations from a third (SXR207) using a variety of methodologies. The purpose for ISE inclusion was different in each case, and this is reflected in the evaluation methodologies employed and in the outcomes of the studies. In all cases, the studies provide evidence showing the ISEs fulfilled their purpose, supporting accessibility or providing additional experience.

The overall success of the studies has been such that the reported ISEs have been formally included in the S104, SXR103 and SXR207 courses to ensure that their benefits are felt by future cohorts of students.

#### Acknowledgments

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