THE VIRTUAL LABORATORY AND INTERACTIVE SCREEN EXPERIMENTS

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INTRODUCTION

The concept of a virtual laboratory in the physical sciences is one with many ramifications. These may relate to the purpose a virtual laboratory is seeking to address, its mode of delivery, the scope of delivery, the experience of both students and tutors, and indeed the suitability of an activity for implementation in a virtual laboratory. The concept also excites opinion, both for and against, in many educational circles. In this article, we will explore these concepts, and others, in the context of a particular class of virtual laboratory, the interactive screen experiment. Before embarking on detailed discussions, we must first define for ourselves what we mean by a virtual laboratory, understand what value it can bring, and importantly what it cannot (and indeed must 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 which come to mind include a 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. We should distinguish the latter case from a computer-controlled experiment, where a student will directly control an apparatus in his or her vicinity via a computer interface (figure 1). This gives us a definition of a virtual laboratory – *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 “universe”). We will see however, that this need not be the case, and indeed as we shall see, the whole concept of the interactive screen experiment is to bring as close a connection to reality as possible, to as many students as possible, to the virtual laboratory.

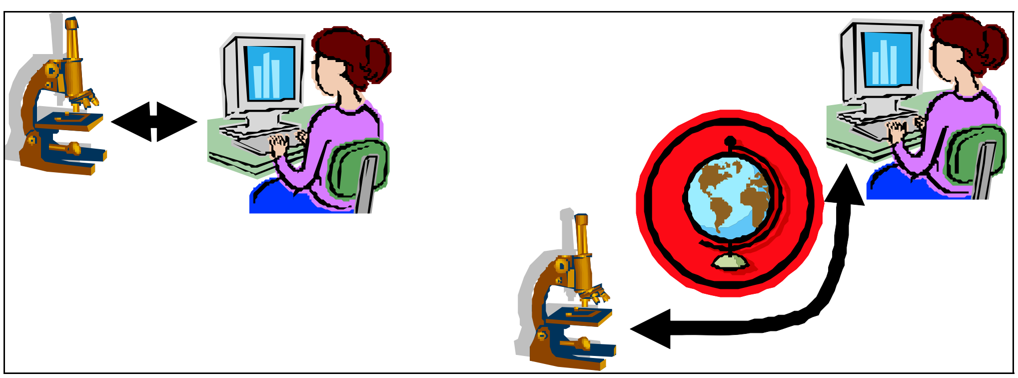

Figure 1. The distinction between (a) a computer-controlled experiment and (b) a remote controlled experiment. The latter case is an example of a virtual laboratory

Having established the concept of a virtual laboratory and examined the properties of interactive screen experiments, we will examine in detail the benefits such resources can bring. In summary, the key areas of benefit are; accessibility, training and augmentation. Some specific examples in each of these areas 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 is not a benefit at all. 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.

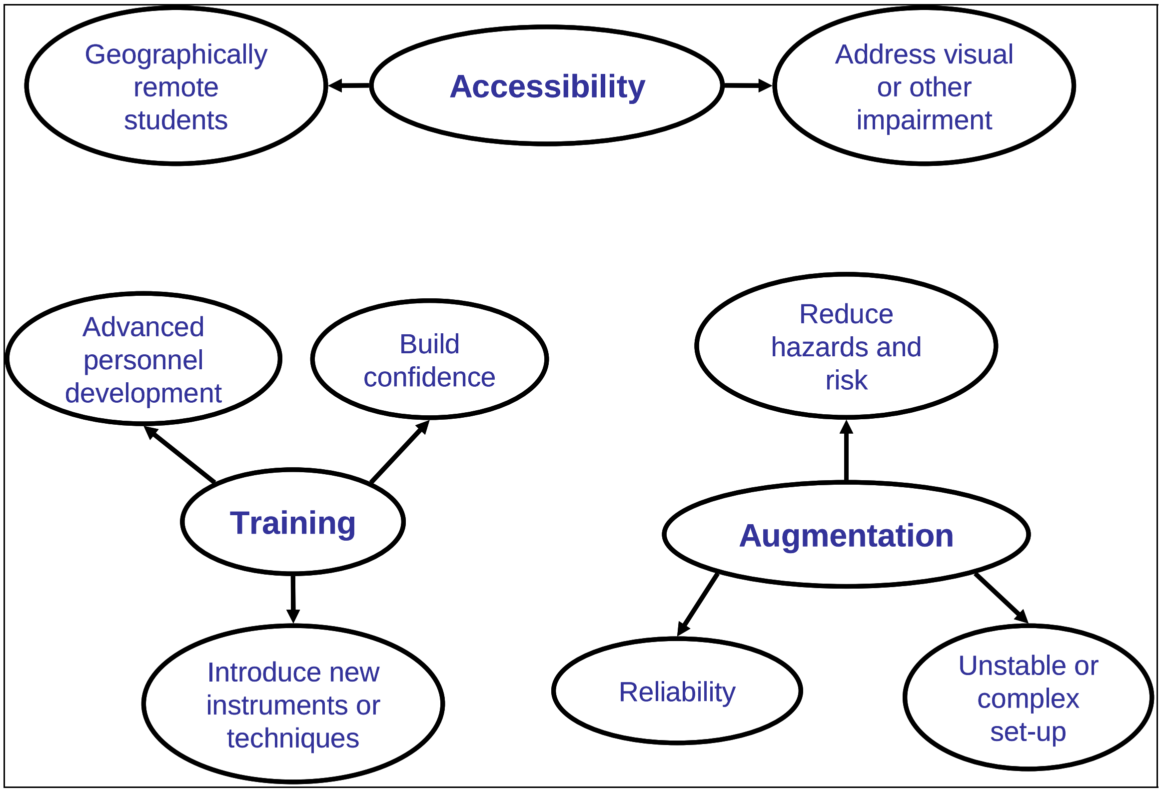

Figure 2. Some of the benefits of a virtual laboratory

THE INTERACTIVE SCREEN EXPERIMENT

In the introduction, we have discussed the definition of a virtual laboratory. It now falls to us to examine the concept of the interactive screen experiment in such a way as to distinguish it from other forms of virtual resource, and to understand the benefits interactive screen experiments can bring.

In its broadest sense, we can define an interactive screen experiment as a highly interactive movie of an experiment, filmed as that experiment was being performed. By highly interactive, we do not simply mean the movie is capable of being moved forward or backward at different rates – this is trivial interactivity, and would provide minimal educational benefit. It is better perhaps to take a specific example. Figure 3 shows a screen-shot of a simple interactive screen experiment illustrating the relationship between the extension of a spring and the tension in the spring.

Figure 3. An example of a simple interactive screen experiment.

In this example, the user "interacts" with the movie (the interactive screen experiment) by "clicking" as normal on the dial of the force-meter, and "turning" it by "dragging" it round using the computer mouse or other control device. The dial then 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. In the previous section, we distinguished interactive screen experiments from simulations. This example will serve to strengthen this distinction. In the case of a simulation, a programmer would code the behaviour of each element. For example, the spring might be given the behaviour of its extension being proportional to its tension – a straight-forward Hooke's Law case. 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 (the "turning of the dial") arises from coded behaviours governing how the movie switches between recorded frames as a result of user action. In consequence, the outcome of the interactive screen experiment illustrates the *real* physics of the phenomenon, rather than some idealised representation.

EDUCATIONAL BENEFIT OF INTERACTIVE SCREEN EXPERIMENTS

Interactive screen experiments contain within themselves significant technological interest. However, this is of no value if these resources deliver no educational benefit. In this section, we will explore in more detail the benefits identified in the introduction and figure 2.

Firstly, we will examine accessibility, which may manifest itself in two ways – either students may have reduced dexterity or other attributes which limit their ability to carry through a real experiment, or they may be physically unable (due either to mobility issues or geographic location) to attend a laboratory class. The benefit of an interactive screen experiment in the second case is clear. The experiment is effectively “delivered” to the student in his or her own environment, and using equipment familiar to the student. The first case is less clear, until one realises that in producing the interactive screen experiment, one is at liberty to include non-standard means of controlling the virtual apparatus. Returning to the spring example in figure 3, we have discussed its control in terms of “grabbing” and “turning” the force dial using a mouse or similar pointer control device. However, we may include a keyboard control, whereby a student may turn the dial simply by key presses. One can conceive of other input and control methods such as voice input or custom interfaces. Clearly, these may not be a “default” component of an interactive screen experiment, as individual requirements vary widely. Accessibility is not limited to input, but extends to output. In the spring example, it is evident that a student with a visual impairment may have difficulty reading the extension or force scales (indeed, many students with good eyesight may have similar difficulty). In a real experiment, the obvious solution would be to improve the lighting and provide magnification. Again, this is straightforward to implement via enhanced resolution or magnified images in the interactive screen experiment as appropriate.

In the context of geographical location and/or mobility issues, the use of an interactive screen experiment may provide a substitution for a real experiment. This may seem like using the idea to replace real laboratories, and indeed this is true to a limited extent. We should recognise though that for the student unable to attend a real laboratory for whatever valid reason, a well-designed interactive screen experiment can provide an appropriate substitute.

Moving on, a common experience of students, especially those new to experimental science, is that of entering a laboratory and being faced with the intimidatingly unfamiliar. Although we may try to prepare students with instruction manuals and preparatory work, these approaches cannot address the fundamental “newness” of the laboratory experience. Closely focused interactive screen experiments can yield significant benefit here through providing training and practice in the use of instrumentation, apparatus and techniques. For example, prior to a laboratory class, part of the preparatory work might be to conduct an interactive screen experiment based on a new piece of equipment the students would be expected to use, or indeed based on the entire experiment, allowing a “preview” to gain familiarity. Consequently, students would enter the laboratory with enhanced skills, improving their ability to achieve the intended outcomes of the class.

The impression might be taken from the above that the training aspect of interactive screen experiments applies only to the “novice”. However, all practitioners in science have recourse to the unfamiliar at times (indeed, this is a defining characteristic of the scientific researcher). It is quite within the scope of the interactive screen experiment concept to provide advanced training.

Finally, we arrive at the concept of augmentation as a third benefit of interactive screen experiments. This concept covers a range of sub-topics, illustrating enhanced applicability, as shown in figure 2.

The benefits in the case of hazardous experiments need not be stressed. This also provides a case where an interactive screen experiment can justifiably replace a real experiment.

Another case where replacement is justified is in experiments with unstable or complex set-ups. Here, the student may focus on the learning outcomes of the resource without distraction from procedures or activities beyond the students’ abilities or outside of the learning context of the experiment. Allied with this class are experiments relating to rare events, such as solar or lunar eclipses. Again, a resource may be created enabling the student to experience and investigate the event in a timely manner.

As a final example of augmentation, we come to the use of interactive screen experiments in post-experiment learning. Students quickly discover that real experiments do not always work in the way they expect – either through mistakes or lack of experience on the students' part or on malfunction of equipment. In such cases, a student may re-visit the experiment via an interactive screen experiment, in order to reinforce his or her experience either by gaining additional data or simply to observe expected behaviours.

WHAT MAKES A GOOD INTERACTIVE SCREEN EXPERIMENT?

The question of what makes a good interactive screen experiment is not one with a simple answer. However, we may generate a number of criteria an interactive screen experiment should have in order to provide an effective learning experience.

One criterion is that of number of adjustable parameters. The concept that an interactive screen experiment should provide as close an experience to reality as possible is only effectively realisable in cases with relatively few variable parameters. This is evident when one recalls that the interactive screen experiment is composed of a set of images, each being a point in the experiment's “parameter space” with interaction between images controlled via software. In the case of the spring experiment in figure 3, there is only one parameter; hence the parameter space is simply a one-dimensional array of images. In the case of two parameters, the space is two-dimensional and so on. Clearly, the number of images can grow rapidly, with implications for production and delivery, which will be discussed later. The solutions are to limit the number of parameters, or to choose a restricted parameter set which although does not include the full range of states at least includes those states relevant to the experiment in hand. In many respects, this latter case is not generally restrictive, since we can cover the parameters typically encountered in a real experiment. However, it would exclude “pathological” situations such as driving an experiment to destruction!

In many physics-related experiments, a normal outcome is that one particular set of parameters always produces the same result. That is, the experiment is deterministically reproducible. Such a situation makes for an excellent interactive screen experiment, although at first sight it would appear to exclude experiments with significant statistical variation such as radioactivity or extension to life sciences. This is not though the case, and strategies for tackling such experiments will be discussed in the next section.

So far, we have dealt with issues of applicability and usability of interactive screen experiments. However, we must not lose sight of the fact that these resources must first be delivered to the student! The first criterion here is that the interactive screen experiment must be platform independent. That is, it must work on all computer systems, be they owned by the student or by the institute they are studying with. This can be achieved by ensuring standard, readily available and easily (and legally) installable support software is used and, where necessary, ensuring versions appropriate to different platforms are produced. Ensuring the platform independence of an interactive screen experiment is clearly an issue of quality control and testing.

Given that an interactive screen experiment is platform independent, it is still necessary to deliver it. In the context of an educational institution, this is trivial since the resource can readily be made available on the institute's own systems. The situation is not so clear for independent or distance learning students, who will typically be remote from central resources and will most likely be using their own or public (e.g., library) computing. The main limitations here are ones of data transfer rate and resource file size. Assuming an internet-based delivery method, the time taken to acquire a resource is evidently limited by the student's connection speed. This speed varies widely between countries, and indeed within a country, especially between urban and rural areas. Related to this is the resource file size. A large, many parameter and image-intensive interactive screen experiment will not only take a significant time to acquire, but may also stretch the resources available on the student's computer (this may be especially true in a public computing area). A good interactive screen experiment is therefore one which can be easily accessed and placed on the student's computer within a reasonable time and which does not over-stretch the student's computer.

All of the above criteria are addressed at the design and development stage. The parameter space issue requires a consideration of the learning outcomes and ultimate resource size and delivery methods need to be considered in the context of the target audience. Evidently, a resource aimed at training and education in the developing world, where internet connection speeds may be limited or absent and high computing power may not be widespread must take greater account of delivery than one aimed at a developed world clientèle.

THE FUTURE FOR INTERACTIVE SCREEN EXPERIMENTS

The discussion so far has revolved around physics-based experiments which are deterministic in nature (that is, a given set of parameter values produce a well-defined outcome). As indicated in the previous section, not all experiments or experiences follow this pattern. For example, observing radioactive count rates in absorption or decay experiments frequently results in statistical variation of counts about some mean value, with the departures from the mean reflecting normal statistical behaviour. It may seem that such an experiment cannot be implemented as an interactive screen experiment, but this would be a wrong assessment. Classically, an interactive screen experiment is an array of behaviour-linked images, as discussed previously, with each image taken from a real state of the experiment. Similarly, each reading of a rate meter or similar instrument may be regarded as an individual state of the experiment. A statistical experiment may therefore be implemented by providing a sufficiently large database of readings which may be accessed randomly by the visual elements of the experiment.

So, statistical variation can be addressed. By realising this, the door is opened for a widening of the use of interactive screen experiments into topics beyond physics, and indeed science. With such fundamental barriers down, the application of interactive screen experiments will be boundless, limited only by technological aspects of creation and delivery, and the imagination of their creators. One can easily imagine experiments created for the physical, life and geological sciences, but in addition, one can conceive of "experiments" (or perhaps they should now be called "experiences") targeted at traditionally non-science topics. How about an on-screen archaeological dig? A virtual examination and restoration of a work of art? Or an interactive social sciences study? All are possible with the right motivation and input.

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