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Rethinking The Nature Of Experimental Learning: Moving Beyond Conventional Laboratory Experiences

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RETHINKING THE NATURE OF EXPERIMENTAL LEARNING: MOVING BEYOND CONVENTIONAL LABORATORY EXPERIENCES

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ABSTRACT

Laboratory experimentation is an important educational tool across many disciplines, providing a mechanism for students to enhance their understanding of the relationships between theoretical models and physical reality. However, whilst laboratories are used extensively, the existing approaches to experimental learning have evolved little in the last 100 years, the intended learning outcomes are often poorly articulated and the connection between the learning outcomes and the student experiences is unclear. These limitations hasve meant that the development of laboratory experiences has tended to be driven by a combination of history, the capability of physical laboratory environments, and technological opportunity (e.g. the feasibility of rich simulations or remotely accessed laboratories) rather than pedagogic considerations or a deeper understanding of the role of experimentation within the educational process. Indeed many “new” laboratory innovations tend to only be technologically-enhanced versions of conventional experiences rather than leveraging the affordances of new technologies. In this paper we explore the nature of experimental learning and the extent to which we can achieve improved educational outcomes by a reconceptualization of the nature of this form of learning.

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1 INTRODUCTION

1.1 General Context

Laboratory experimentation has long been a distinctive characteristic of education within a range of disciplines, particularly those associated with the physical sciences (Hofstein & Lunetta 1982; Pickering 1993). The use of laboratory experimentation has become so embedded that the inclusion of laboratories experiences into the curricula is often mandated in many accreditation frameworks: e.g. from Engineers Australia accreditation criteria: "*3.2.4.5. Practical and 'Hands-On' Experience: There must be substantial hands-on practical experience manifested through specifically designed laboratory activities, investigatory assignments and project work….*" (Bradley 2008).

Despite their pervasiveness, there is however a lack of clarity regarding what defines experimental learning (not to be confused with experiential learning). Whilst predominantly focused on the active manipulation of a phenomena under study, most commonly it is discussed in terms of the physical laboratory experience of the student rather than by the underlying education purpose. This purpose is not inherently tied to activities within a physical laboratory setting, and yet we often treat it as though it were.

Over the last several decades we have seen technology used to construct laboratory activities that have begun to break the conventional model of a laboratory classroom. As two examples: remotely accessed laboratories (Ma and Nickerson 2006) enable students to access physical laboratories regardless of location and time; and simulations and virtual reality allow students to manipulate "experimental equipment" that might otherwise be too difficult (or too dangerous, or too expensive) to access. Despite the improved affordances offered by these new possibilities, the actual experimentation that is carried out has tended to adhere to the same underlying conceptual model. For example, most remotely accessible laboratories that have been developed tend to be remotely accessed versions of similar hands-on experiments, rather than an inherently new type of experimental activity.

In this paper we argue that this represents a missed opportunity. The emergence of new technologically-enabled laboratories should be providing a trigger for reconceptualising the nature of educational experimentation. We begin by considering the nature of existing experimentation, and then look at how these activities have begun to change. We then consider the core purpose of experimentation independently of the current physical implementations, and then what this might tell us about possible future models of experimental learning experiences.

1.2 Existing and Emerging Experimental Learning

Most current experimental experiences adhere to a relatively common model, based around laboratory activities. In a typical laboratory session, students will access, often only at designated times or for a relatively limited period, the laboratory apparatus. Within this time window they will conduct experiments (either individually or in groups) within a laboratory room using standardised equipment that provides a stylised or simplified version of a more complex real-world phenomenon. The experimental activity undertaken will exist somewhere on the spectrum between "cookbook" (i.e. with students following a set sequence of steps) and inquiry-based (i.e. with students given freedom to investigate a selected phenomenon).

To some extent this physical laboratory-based model of educational experimentation is a consequence of practical constraints: the need for physical access to (often expensive) equipment; the need to have a proximal relationship between a laboratory tutor and the students; the need to make the phenomenon under study evident and remove distractors; etc.

These constraints date back to the earliest examples of educational laboratories in the latter part of the 19th century[2] and since then the physical form of educational experimentation within a laboratory setting has remained largely unchanged (see, for example, Figure 1 illustrating an experimental laboratory from 100 years ago, which is quite similar to most contemporary teaching laboratories)!

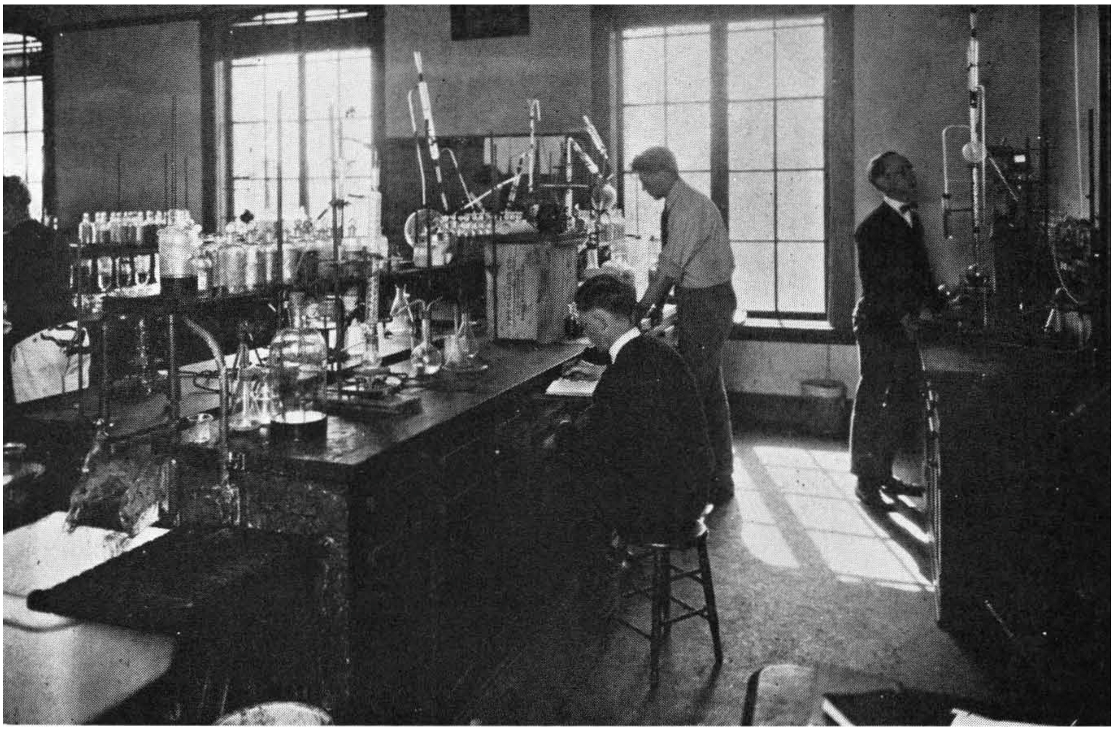

Fig. 1. The Caltech Chemical Laboratory c. 1923. (Image in the public domain: obtained from https://commons.wikimedia.org/wiki/File:Caltech_chemical_laboratory_1923.png)

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[2] An excellent discussion of the development of the Cavendish Laboratory by James Clerk Maxwell in the 1870's is given at https://www.phy.cam.ac.uk/history/old_maxwell

The ubiquity (and longevity) of this physical laboratory-based model of experimental learning has often led to experimentation as being defined by this model, rather than by the underlying education purpose. For example, consider the following definition:

"Laboratory learning is *learning that takes place in a space where students can observe, practice, and experiment* *with objects, materials, phenomena, and ideas either individually or in groups."* (Seel 2012)

The result of having experimental learning commonly conceptualised as an activity

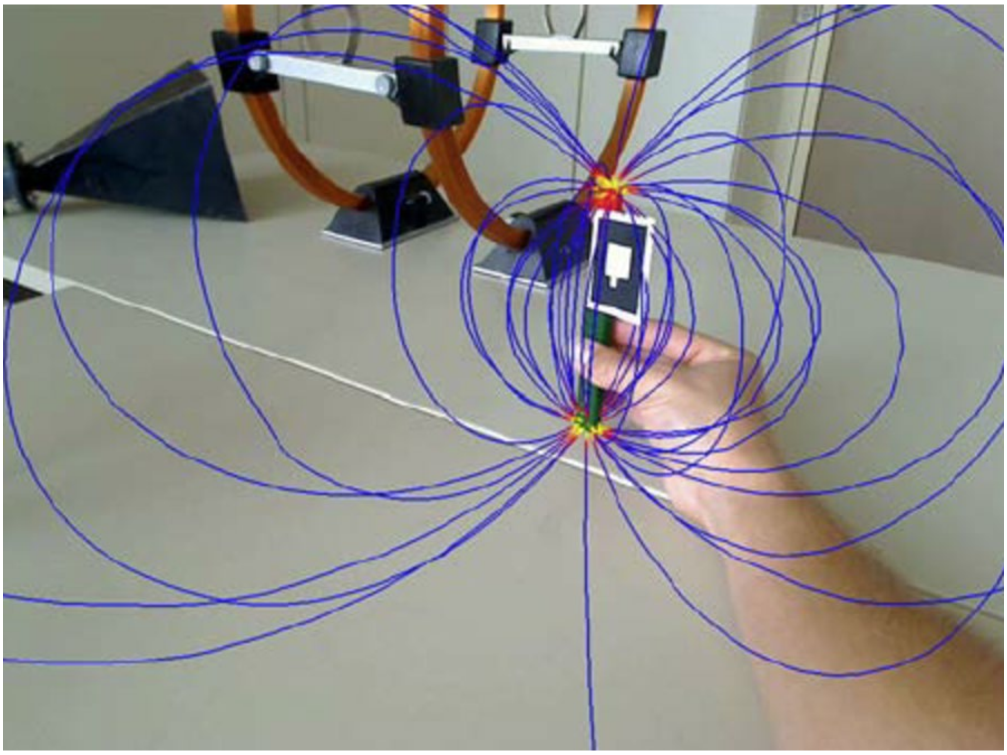


Fig. 2. The A magnetics experiment, where Augmented Reality is used to supplement the students view to show an "invisible" magnetic field. From (Buchau et al., 2009)

that occurs within a physical laboratory is that the nature of most experimental learning experiences has been relatively narrow, involving local manipulation of laboratory equipment and associated observation of the resultant behaviours.

Technology is however beginning to drive some changes to this model. Computational modelling tools have enabled simulations that allow students to manipulate the "experiment" in much richer ways than is often feasible with hands-on equipment. Networking technology has allowed physical labs to be instrumented and then controlled remotely (Corter et al., 2007), enabling enhanced access and the ability to share equipment between multiple institutions. Virtual reality has enabled a more immersive engagement with experiments. And most recently, Augmented Reality has begun to allow students to perceive elements of a laboratory phenomenon which were previously only indirectly sensed. As an example of this latter case, consider Figure 2 where AR allows a student to "see" a magnetic field.

These examples of the use of technology demonstrate experimental learning that is starting to diverge away from experiments based on “sit at a laboratory bench and manipulate the apparatus”. Nevertheless, the majority of extant examples are still based on adaptations of previous conventional laboratory activities and have used the technology primarily to enhance or supplement those activities rather than to create fundamentally new learning experiences.

This suggests the possibility of a missed opportunity. It is worth asking the question about whether there are new forms of experimental experiences that transcend the constraints implied by physical laboratory settings. Prior to considering this however it is worthwhile looking at what we know about the purpose of experimental learning.

2 CORE PURPOSE

The origins of laboratories within teaching programs dates back at least 150 years. Laboratories had existed well before then, but were originally established for the purposes of research. Their use in teaching was originally limited to providing demonstrations accompanying lectures rather than enabling student experimentation:

> *“In the catalogue for 1851-52 the statement is made that 'the chemical laboratory is amply furnished with apparatus and chemicals <u>for illustration of lectures in that department</u>*” (Whitman 1898) (emphasis in original).

Progressively though students became more actively involved in experimentation and by the beginning of the twentieth century it was well established. Debates did however continue over the relative benefits of the “Demonstration Method” versus the “Laboratory Method”, with the purpose of the latter being well described by Knox (1927) as:

> “*The laboratory method has been justified by advocates of this method on the ground that the manipulation of materials with proper directions develops a scientific attitude and a comprehension of acceptable methods of attack for the solution of new problems*”.

Interestingly, given the above comments on the physical model of a laboratory experience, Knox went on to say:

> “*[T]he term "laboratory method" will be employed in the popular sense, meaning a procedure wherein the pupils perform experiments individually or in groups*”

For the next 80-odd years there is little additional insight in the literature with regard to the purpose of experimental learning. There is much research into various experimental approaches and aspects such as student reactions to experimental methods, and evolving accreditation processes continued to refer to the need for laboratories (see, for example, the early Grinter report (Grinter 1955) and the much later ABET criteria (Accreditation Board for Engineering and Technology Inc 1999)). This work generally didn’t however flow through into considering the core purpose of the laboratory experimentation, or the intended learning outcomes of these activities.

This finally began to change at the beginning of the 21st Century. Work that emerged out of a 2002 ABET Colloquy on laboratory education resulted in the articulation of a taxonomy of thirteen learning objectives (Feisel & Rosa 2005) that might be relevant to laboratory activities. Whilst this taxonomy has subsequently been used in comparing different laboratory designs (see, for example, (Corter et al. 2011; Lindsay and Good 2005)) there has been little consideration more generally of its role in specific educational design of laboratory activities. Where such work has occurred, the focus has generally been on specific characteristics rather than broader design approaches. For example Terkowsky and Heartel (2014) explored the types of objectives and activities that might be suited to developing creativity.

An analysis of the ABET taxonomy highlights a useful (though not unexpected) pattern: almost all of the objectives are deeply grounded in a connection with a real-world physical reality. Consider, for example (Feisel & Rosa 2005):

> "Objective 1: … to make measurements of physical quantities."
>
> "Objective 2: … predictors of real-world behaviours … describes a physical event …".
>
> "Objective 6: … due to faulty equipment …"
>
> "Objective 7: … real-world problem solving …"
>
> "Objective 13: … human senses … real-world problems …".

The exceptions to this explicit connection to a physical reality are objectives 10 (communication), 11 (teamwork) and 12 (ethics). In this case there is potentially an implication that real-world environments might provide a useful context within which these objectives might be productively explored.

Given these observations, we can posit that the core underlying purpose of experimental learning is to engage students in understanding the nature of physical phenomena through engagement with (and often manipulation of) those phenomena, and particularly to understand the relationship between those physical phenomena and the conceptual models that we use to describe the phenomena.

Within this context the significance of using laboratory-based experimental equipment comes from their role as a proxy for a broader reality in which the phenomena might normally be experienced (Machet et al. 2012). Students use experimental apparatus to recreate simplified versions of naturally occurring phenomena (which may be physical, chemical or biological) in order to grasp the underlying principles and achieve learning objectives.

Recognising, however, that the core purpose of experimental learning is about engagement with physical phenomena and that the laboratory setting is simply one vehicle for achieving that engagement should allow us to then consider alternative ways in which experimental learning can be achieved, and to hence move beyond an assumption that experimental learning is synonymous with laboratory-based activities.

3 ILLUSTRATIVE EXAMPLES OF ALTERNATIVE EXPERIMENTAL LEARNING

We can illustrate a more inclusive (and diverse) view of experimental learning by considering several illustrative examples that go beyond controlled laboratory-based activities.

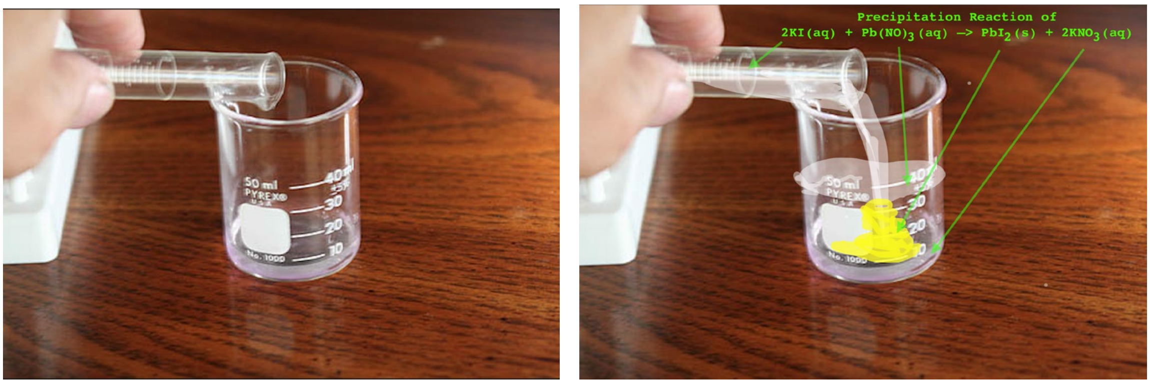
In this scenario, whilst elements of the experiment are virtual, the tight coupling between the “real” aspects and augmented aspects anchors the experience in the real-world and provides the student with the experience of manipulating reality whilst allowing a much richer set of experiences than might otherwise be the case.

Experimentation outside the lab: Figure 3 illustrates a hybrid experimental setup using augmented reality (discussed in more detail in (Lowe & Liu 2017)). In this scenario the real physical aspects of the experimentation that are readily accessible to students outside of a normal laboratory environment are supplemented by virtual versions of those elements which might normally not be available (due to reasons such as cost or safety). In some respects this has parallels with the concept of kitchen science (Jones 2011) but expanded to allow a much richer collection of experimentation than might otherwise be the case.

Experimentation embedded in the wild: The increasing available of cheap powerful and easy to use IoT devices provides the potential for directly monitoring real-world phenomena, rather than relying on the controlled environment of the laboratory. Consider, for example, a scenario where a student places wireless Bluetooth strain gauges onto a footbridge and then collects data from the sensors as they walk across the footbridge.

In this scenario the students are using the real-world as their laboratory and everyday activities as the phenomena being monitored.

Experimentation from citizen science. Citizen science, or alternatively crowd-sourced science, involves scientific research conducted (to varying extents) by the general public. Often this will result in large data sets which – apart from their broader use in



(a) (b)

Fig. 3. A student conducts a hybrid precipitation experiment, where physical equipment is overlaid with virtual materials. (a) without Augmented Reality; (b) with the augmented reality overlay (from (Lowe & Liu 2017))

supporting the original research objectives - could then be mined as part of exploring the phenomena under consideration.

For example, consider a student wishing to explore fluid flow who is able to access a subset of a large meteorology database to extract a small set of data relevant to localised air pressure differences and associated wind vectors. In this scenario they are obviously not manipulated the "real-world" but rather they are selecting a subset from the data that lets them explore relevant variations in the desired phenomena.

4 CONCLUSIONS

Whilst laboratory experimentation has long been seen as a crucial element of applied science and engineering programs, there has been only limited consideration given to the underlying purpose of these student experiences and how they address intended learning outcomes. The result has been a lack of creativity in designing alternative experiences – particularly those that enabled by emerging technologies, particularly those related to networking and augmented and virtual reality.

In this paper we have argued for a deeper consideration of the nature of experimental learning and provided some illustrative examples that begin to move us beyond the conventional (but typically unquestioned) model of manipulation of standardised equipment in a laboratory classroom.

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