DIGITAL, MATERIAL AND NETWORKED: SOME EMERGING THEMES FOR SET EDUCATION

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Abstract

Boundaries between the digital and material worlds are becoming blurred as the internet increasingly connects us to things as well as people and information. This is increasingly relevant to education as initiatives which significantly combine digital and material elements in networks are becoming a reality for Science, Engineering and Technology (SET) learning. Our paper reports on the initial findings of a project to carry out a 'state of the art' review of literature to establish the key themes, opportunities and obstacles that are emerging from the development and use of these 'hybrid' systems in learning. We wanted to explore the extent to which this new domain of study is being reported in the literature and to identify work representative of this area. Our aim was to investigate the depth of research in this area by going beyond the technologically descriptive to focus on pedagogical and organisational issues raised in the literature.

To identify the state of current research in the area we carried out a systematic search of databases of Science, Engineering and Technology education literature. We found 808 papers relating to the hybrid learning initiatives we are interested in, of which the majority, 81%, involved the Engineering and Technology disciplines while 6.8% related to Science. The vast majority of papers referred to remote laboratories and most of these were concerned with describing the technologies involved. In order to explore issues emerging from the research, we carried out an in-depth text review of a particular subset of the papers found that focussed on pedagogical issues. The three main themes that emerged were: the importance of real data and authenticity in learning; the importance of a sense of presence (e.g. telepresence, social presence and/or immersion) and the locus of control in, and responsiveness of, a hybrid system. We conclude that these new digital 'hybrid' pedagogies offer a lens with which to view both the more traditional material pedagogies, e.g. laboratory-based learning, and purely digital pedagogies, e.g. virtual labs. Finally, issues of authenticity, presence and control/responsiveness will be of increasing pedagogical importance to other 'hybrid' systems, such as those involving ubiquitous computing.

Introduction

In addition to connecting us to people and information, the internet also connects us to material objects, such as processors, sensors and RFID tags (as in ubiquitous computing). Initiatives which combine digital and material elements in networks are becoming increasingly relevant to education and are already a reality for Science, Engineering and Technology (SET) learning in, for example, remote laboratories. We have used the word 'hybrid' to refer to networked artefacts which significantly combine digital and material elements (Knutsen et al, 2011). By significant, we mean materiality which goes beyond providing different types of window on to the digital world, important though these differences may be. The project aims to carry out a 'state of the art' review to establish the key themes, opportunities and obstacles that are emerging from these 'hybrid' initiatives. This paper explains the context of the project in exploring the use of such technologies in distance learning. We briefly describe the systematic method we used to carry out the review of the literature and report some of the findings from the database searches. Finally, we discuss some of the themes we identified from the literature before presenting our initial conclusions.

Context

Accounts of learning technologies to support distance learning typically describe technologies that support discursive learning either through written text or, increasingly video and audio. Learning technologies are often seen as analogues of, for example, seminars, lectures or conferences. However, the boundaries between the digital and material worlds are becoming increasingly blurred as the internet increasingly connects us to things as well as other people. This may hold the potential to include mediated interaction with the material world in distance learning. We are particularly concerned with the opportunities this affords in science, technology and engineering[1] (SET) education, though of course there may be other opportunities in other disciplines. Broadly, SET subjects are primarily concerned either with understanding the material world (science) or with intervening in it to support human activity (engineering and technology), typically through experiments, observations, (physical) models and/or prototypes.

We are particularly concerned with the networked material and digital properties which distinguish hybrids from entirely digital artefacts such as online teaching texts, videos, wikis, blogs and so on. This use of the term ‘hybrid’ to describe the field is intentionally broad and in educational settings might include remote student access to specialised equipment or the students networking sensors local to them to share data as part of a collaborative project. An example of the kind of initiative that is beginning to emerge is The Open University Physics Department’s Pirate remote access astronomical telescope (Kolb et al, 2010). Astronomy undergraduates, predominantly based in the UK, work in small groups to control the telescope (in Mallorca, Spain) remotely across the internet to conduct observations as part of their assessed coursework. While the history of remotely controlled laboratory equipment might be traced back to the Argonne National Laboratory in 1954 (Ashby, 2008), contemporary computing and networking technologies may be making this it a viable mass approach in distributed and mass SET education. Our results below suggest that the most developed aspect of ubiquitous computing today, though, is in the development of remote access to laboratories, primarily in engineering (though this may also be a result of the greater standardisation of vocabulary among engineers, and a consequent over-representation in our search results).

Educationally, the availability of such hybrid learning resources may present important opportunities. Well known theories such as Kolb’s Learning Cycle (1984) are founded on the idea that a ‘concrete experience’ is important for learning followed by ‘reflective observation’ which enables the student to form an ‘abstract conceptualisation’ of the experience which then forms the basis for ‘active experimentation’. The term ‘authentic learning’ is widely used to refer to educational practices that connect what students learn in an educational setting with the kind of issues and problems encountered in professional or other practice. This involves developing

[1] We have used the term SET, rather than the more widely used STEM (science, technology, engineering and mathematics). While mathematics is an important component of SET disciplines, mathematics itself is perhaps the least material of all disciplines in its concern with entirely abstract concepts.

critical thinking, formal observation techniques appropriate to the discipline and problem-solving skills; all of which engineers and scientists require in their professional lives (Lombardi, 2007). Outside educational settings, people learn from their mistakes and from having to solve problems, for example where equipment doesn't work or unexpected results are generated or results are obscured by 'noise' and confounding factors. Experiment work often entails dealing with such complexity and uncertainty.

Methods

We carried out a review to establish the state of current research in digital material networked learning and to report on themes emerging from the literature. As this domain of study ranges across many disciplines, to locate the existing literature we chose the following databases on the basis of their coverage of science, engineering and technology (SET) education: Academic Search Complete, Article First, Educational Research Abstracts, ERIC, IngentaConnect, Inspec, Library, Information Science and Technology Abstracts, Web of Knowledge, EI Compendex and Education Research Complete.

We used a list of search terms (for example, remote laboratories, internet and education) which were selected specifically to cover the three key aspects of the field, namely: digital/materiality, networks and learning. Overall, we found 2,065 papers. Eliminating papers that were out of scope (i.e. not related to digital material networked learning) and those without abstracts produced a field of 808 papers. By reviewing titles, abstracts and metadata, we then categorised papers by subject area, primary focus of the research study and type of research study. The results (see Table 1) show that the majority of studies reported are in engineering and technology subjects (81.1%). The fact that studies are primarily technology (56.2%) or organisation focussed (23.9%) and descriptive in nature (87.4%) indicates that current research is focussed on pragmatic issues and the field is still developing.

Many relevant papers may not have been picked up by this review process and therefore the papers found should be seen as representative of this research area, but not as definitive. Search terms involving 'remote laboratories' yielded a high number of results, whereas other technologies that did appear in the results, such as RFID and Internet of things were found much less frequently. It is not as yet clear whether the focus on remote labs is a result of the methodology used or whether it is a true reflection of their prevalence in the field.

Table 1. Papers categorised by subject area, focus, study type and educational level

<table>
<tr><th>Category</th><th colspan="5">Percentage of 'in scope' papers (n=808)</th></tr>
<tr><td rowspan="2">Subject area</td><td>Science</td><td colspan="2">Engineering and Technology</td><td colspan="2">Unspecified</td></tr>
<tr><td>6.8</td><td colspan="2">81.1</td><td colspan="2">12.6</td></tr>
<tr><td rowspan="2">Primary focus of research study</td><td>Pedagogy</td><td>Technology</td><td>Organisation</td><td colspan="2">Other</td></tr>
<tr><td>14.8</td><td>56.2</td><td>23.9</td><td colspan="2">5.1</td></tr>
<tr><td rowspan="2">Type of research</td><td>Descriptive</td><td>Conceptual</td><td>Evaluative</td><td>Review</td><td>Other</td></tr>
<tr><td>87.4</td><td>2.1</td><td>9.3</td><td>1.0</td><td>0.2</td></tr>
</table>

study					

As our interests are in pedagogical and organisational aspects of SET learning and in conceptual, evaluative and review-based studies, rather than those that are merely descriptive, we selected 34 articles for a full-text review from these categories (see Table 2).

Table 2. Science, Engineering and Technology papers selected for in-depth review

Primary focus of research study	**Type of study**		
	Conceptual	Evaluative	Review
Organisation	2	5	
Pedagogy	2	16	4
Other			5

Because the exploratory nature of the project and the heterogeneity of the papers, a qualitative approach involving thematic analysis and synthesis (Thomas & Harden, 2008) was adapted for the second phase of the systematic review. Prompts used to guide the review included the reasons for setting up digital/material/networked learning, the specifics of the learning example, pedagogical aspects and theoretical perspectives. From the answers to these prompts, important and recurring themes were identified.

Discussion of themes

A number of important themes emerged from the in-depth analysis of the selected papers. The three major themes which we will highlight in this paper concern remote laboratories and include:

- the importance of real data and authenticity in learning
- the importance of a sense of presence, e.g. telepresence, social presence and/or immersion
- the locus of control in, and responsiveness of, the hybrid system

The importance of real data and authenticity in learning

The papers highlighted a number of issues in relation to the importance of the ‘real’ world in laboratory work. The objectives of laboratory work in SET disciplines were clarified only relatively recently by the US engineering body ABET (For further information see Feisal & Peterson; 2002; Feisal & Rosa 2005 cited in Ma & Nickerson, 2006; Lindsey & Wankat, 2012; Stefanovic, 2013 amongst others) Physical experiments are of particular value in that students learn how theoretical models of the world differ from the world itself, and link theory with practice (Hanson *et al*, 2009; Belu & Husanu, 2012).; Some of the papers in the study compared the learning experiences in ‘hands-on’, remote and virtual labs, assessing the strengths and weaknesses of each mode (e.g. Ma & Nickerson, 2006; Lindsey & Wankat, 2012) . In a remote laboratory where the student and the apparatus are physically separated and there is no tactile interaction with the equipment, there are limited opportunities to teach practical skills or craft (Hanson *et al*, 2009). Yet, many laboratory experiments are already mediated by computers (Nickerson, 2007; Corter *et al*, 2011) so conducting an experiment through a computer interface is part of the learning experience. Individual 'hands-on' experience of using the equipment to collect data is thought to enhance understanding and better recall but this is not always possible in a physical laboratory because of time and space constraints. However, individual interaction is easier to facilitate in remote and simulated laboratories (Ma & Nickerson, 2006). This opens the possibility of 'learning from failure' as remote and simulated experiments can be repeated (Stefanovic, 2013) which is particularly helpful for less-confident students who can explore and make mistakes privately and in their own time. Like a 'hands-on' lab, a remote lab can provide a 'real world' experience of dealing with uncertainty and 'noise' such as, vibration or friction or confounding factors in experiments. Furthermore, complex experiments where the outcomes are uncertain may be more motivating than ones where the outcomes are known (Nickerson, 2007), but these conditions of uncertainty and 'noise' factors are difficult to replicate in a virtual or simulated lab experiment (Hanson, et al, 2009). Thus the materiality of the remote laboratory, whether the experiment entails physically manipulating equipment from a distance or remotely gathering real data from physical equipment, offers significant advantages over the entirely digital virtual or simulated modality in terms of learning.

The importance of a sense of presence, e.g. telepresence, social presence and/or immersion

The importance of a student's sense of immediacy and control over remote laboratory equipment is implicit in many, if not all, of the papers we reviewed. Several of the papers (Abdulwahed & Nagy (2008); Ashby, 2008; Bauer et al (2008); Hanson et al (2009); Ma & Nickerson (2006); Nickerson et al, (2007)) use the terms 'presence' or 'telepresence' in considering students' sense of 'being there' in or with remote laboratories. Presence, though, is a rather slippery concept, as is reflected in the use of the term in our literature sample and this is compounded by differing use of terms. Abdulwahed & Nagy (2008) and Bauer et al (2008) use the terms 'virtual presence' and telepresence as a rather general term to describe a sense of involvement or realism by computer-mediated remote access to laboratory experiments. Ashby (2008) and Nickerson et al (2007), however, distinguish between a sense of 'being there' with the laboratory equipment (which they termed telepresence or physical presence respectively), and social presence as a sense of 'being there' with other people, typically other students in laboratory group work. This use of the term 'social presence' to refer to a sense of computer-mediated presence with other people has a long history in studies of computer-mediated communication since the 1970s (Short et al, 1976); it is of particular interest here because of the importance of team-working in laboratories as a desirable learning outcome.

Nickerson *et al* (2007) suggest that both social and physical presence may be important in the design of remote laboratories. The importance of physical presence seems to be a general implicit assumption among the remote laboratory papers we reviewed, though not always articulated explicitly. We can, though, broadly distinguish the understanding of both categories of presence into understandings which relate it directly to the types or amount of physical sensorimotor opportunities to interact with equipment or people (e.g. Lindsey and Wankat (2012), Morton and Uhomoibhi's (2011)) on the available technologies. The more subjective understanding is evident in Ma & Nickerson's (2006) consideration of the difference between the relationship between laboratory work and the real world, and students' beliefs about that relationship. The relationship between the specifics of a technology and the sense of presence generated in a particular setting has been widely debated in social studies of computer mediated communication (e.g. Spears & Lea, 1992); that the relationship is not simple is perhaps suggested by student behaviour in trading of one form of presence (moving from video to audio interaction with peers in order to free up screen 'real estate' to make interaction with experimental equipment (Bauer & Mendes, 2012).

The locus of control in, and responsiveness of, the hybrid system

As previously discussed, active involvement is important in learning so, therefore, the locus of control in laboratory experiments needs consideration. In some contexts remote labs are used in lectures to demonstrate the real world experiment e.g. the TriLab system (Abdulwahad & Nagy, 2008) where a lecturer demonstrates a remote lab process control experiment as preparation for students. However, remote labs do permit students to run experiments as would be the norm in 'hands-on' labs but parameters need to be set up to allow the different types of control.

Responsiveness of the lab systems we examined varied according to the technologies involved and other technological limitations such as how many students can access the system at the same time and network bandwidth. Seeing the results of an experiment is important feedback to students and a means of reinforcing learning. The time interval between conducting a remote experiment and the student receiving the results will impact on the learning experience. In some systems, batch processing (Nickerson et al, 2007) is used so the students receive their result at a later stage once all experiments have been run. In other remote labs the graphical user interface (GUI) of a remote laboratory is designed to provide 'feedback' to the user in terms of directly controlling real instruments at a distance, an experience which can be supported by a live webcam feed showing the effects of the student's actions (Matochka and Nedic, 2006). In interactive experiments such as in the vortex tube system described by Belu and Hasanu (2012); the lab system is committed to a single user during the experiment This involves a scheduling or queuing system so that each user gets access which is similar ecperience to a 'hands-on' lab. However, student can then control the lab hardware, perform real measurements, sensor tests and calibrations, and remotely see temperature, pressure and flow variations in real time. In another example involving a queuing system, ReLOAD, (Hanson et al, 2009), students can choose parameters on some experiments and completed results are returned to the student's web page. The delay is a matter of seconds and is dependent on length of experiment and numbers of students attempting to operate the experiment. Internet bandwidth is an important consideration in controlling remote experiments and impacts on responsiveness. Some systems are rival in the sense that only one remote user can carry out the experiments at one time e.g. Bauer et al (2008) explain that, while many users can observe experiments in PEMCWebLab at a time, access may be slow and only one user at a time can actually control the experiments. Other set-ups allow multiple users at the same e.g. RePhys, the lab for biomedical and physiological systems studies under development (Barros et al, 2013a) in which many students will be able to access the equipment independently and run their own experiments.

Conclusions

This study explored 'hybrid' digital material networked learning as an emerging area of interest for SET education. Our review shows that the literature is biased towards technological and descriptive reports, with fewer pedagogical and evaluative studies. This implies that the field is still maturing, with practitioners currently focusing on practical matters required for implementation. Our observations indicate that the terminology is still developing and there is not a clearly defined, shared language in the field. One term that has gained currency, however, is ‘remote laboratory’, with such systems being particularly prevalent in engineering education. From an in-depth review of a subset of papers, selected for pedagogical and evaluative quality, we identified three themes – the importance of real data and authenticity in learning; the importance of a sense of presence and the importance of the locus of control in, and responsiveness of, the hybrid system. Although these observations have emerged primarily from the remote laboratory literature, they can be used to inform wider work in the field. These new digital ‘hybrid’ pedagogies allow us to view more traditional material pedagogies, e.g. lab-based learning, and purely digital pedagogies, e.g. virtual labs, through a new lens. Issues of authenticity, presence and control/responsiveness will also be of pedagogical importance to other ‘hybrid’ systems, such as those involving the ‘internet of things’ and ubiquitous computing. These issues are likely to be of growing importance.

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