Hybrid Digital Material Networked Learning: scruffy mongrel or sleek new breed? Practices and implications for blending physical and digital resources for learning in higher education

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Executive summary

The 'Hybrid Digital Material Networked Learning' project or 'The Mongrel Project' aimed to explore learning experiences involving networked physical and digital resources. Examples of these 'hybrid' resources include the PIRATE project, which allows groups of students to use a powerful telescope through a computer network, and the SenseBoard, which consists of a microprocessor and sensors, used by students to collect and share data across a computer network. This report details the process by which we carried out a systematic review of the literature with the aim of determining the 'state of the art' of hybrids used in Science, Engineering and Technology (SET) learning. The report includes the main results of the search process and the themes emerging from an in-depth review of a subset of the papers located.

Conducting the systematic review entailed searching online databases of literature that covered Engineering, Science and Technology Education publications. Identifying suitable search terms was challenging as the field is under-researched and, as yet, there is not a defined or established vocabulary. We devised three sets of search terms, some generated from our own experience and some that were 'crowd-sourced' from STEM practitioners and researchers, which encompassed the material or physical object, the network and the learning components of the hybrid. The references generated by the combinations of search terms were imported into Mendeley reference management software for further analysis.

The next stage of the review entailed coding papers using metadata such as title, abstract and keywords. From the 808 papers identified as relevant to the project, we found that remote laboratories are the most common form of hybrid (83.9%), although there are examples of other technologies being used, such as robotics and augmented reality. Most of the literature found in our study was concerned with remote laboratories being used in Engineering, some 81.1% of papers, with relatively few reports on their use in Science, (5.4%). The majority of papers (55.8%) focussed on the technology of the hybrid and only 14.9% of papers focussed on pedagogy while a total of 87.45% were descriptive studies and 9.5% of papers were evaluative.

The coding process enabled us to identify a subset of papers that were focussed on pedagogical and organisational issues and were of a conceptual, evaluative or review type for further study. The pedagogical and organisational themes that appeared or emerged in the detailed review include: (a) the importance of the real world in learning; (b) lack of clarity of purpose in laboratory-based learning; (c) the importance of experiential learning in SET education; (d) diversity of views on effectiveness of remote labs in teaching and learning; (e) locus of control and responsiveness in using hybrids (f) varying rationales for utilisation of remote laboratories and (g) a range of approaches to the development of technologies in hybrids.

These new hybrid digital material pedagogies may provide a fresh lens with which to view more traditional material pedagogies, e.g. laboratory-based learning, and purely digital pedagogies, e.g. virtual laboratories. We conclude with some observations about the current state of research into hybrids in that papers dealing with pedagogies are relatively few. We suggest that our findings reflect the emerging nature of the field in that researchers have been primarily concerned with developing the technology and that the pedagogical issues have been less of a priority. However, as the technologies become more mature and more widely used in SET education, the research community must give more attention to the pedagogical issues.

Introduction

The 'Hybrid Digital Material Networked Learning' project or 'The Mongrel Project' aimed to explore learning experiences involving interconnected physical and digital resources. Examples of these 'hybrid' learning resources from the Open University include the PIRATE project used in Science modules and the SenseBoard used in a level 1 Computing and Information Technology module. The PIRATE project allows astronomy students working as a small group to access a powerful telescope in another country through a computer network, and the SenseBoard, which contains a microprocessor and sensors, is used to share data with other students across a computer network. Thus, both 'hybrids' involve resources that combine a physical, tangible presence connecting through computer networks with other digital, online resources to provide a 'real world' learning experience for distance learning students. These technologies are of particular relevance to Science, Engineering and Technology (SET) education.

We are using the term 'hybrid' in the sense of,

> Interplay between social interactions and sensor data, the blurring boundaries of the World Wide Web and tangible objects' (Knutsen et al, 2011, p199)

Therefore, we used the following 'working definition' of 'hybrid digital material networked learning' in conducting the project,

> The use of hybrids of tangible, physical objects and digital bits, connected to online services to create learning resources which connect to learners and learning communities.

Aims and scope of the project

The primary aim of our project was to carry out a 'state of the art' review to establish the key themes, opportunities and obstacles emerging from literature on hybrid digital material networked learning at this point in time. Through the project we hoped to address issues such as:

- the range and variety of 'hybrid' learning experiences and the learning contexts in which they are used;
- the stage of technological development and the skills and resources required both by educators and students, and
- the underlying theories of learning in the hybrid learning experiences.

Activities

A literature review is usually carried out to discover what is already known about the area and to identify the concepts and theories relevant to the area of study. In this situation, a lot is known about student learning in a laboratory setting and in fieldwork and there is a substantial body of literature about students learning online. However, little is known about what happens when we put these two things together as these 'hybrid' learning practices have not been extensively studied. Therefore, we decided to conduct a form of systematic review of the literature which, although it is normally employed in an established field with a precisely defined research question rather than in an emerging field, seemed an appropriate means of establishing the 'state of the art' of hybrids.

Systematic review of literature

In order to be as systematic as possible, a review should entail 'explicit and rigorous methods to identify, critically appraise and synthesise relevant studies' (Mulrow et al, 1997, p. 389). The systematic approach has its limitations, given the innovative concepts involved and the lack of an established terminology with which to describe hybrids. However, the project aimed to use rigorous and explicit methods in conducting the review to establish a solid foundation for future research. Therefore, we developed and used explicit protocols to be followed throughout the study and kept detailed records at each stage. Since the object of our research was likely to have different characteristics and it is an under-researched, developing field, it seemed likely that a mixed-method strategy would be the most successful choice for the review in that we could gain an idea of the 'scope' of this new field through quantitative means and then look in detail at a small number of examples through qualitative analysis.

Locating literature for the review

The first phase of the review involved identifying suitable databases to be searched and devising a pre-defined list of search terms to use in searching the databases. Material of interest included published material from journals and conferences and also 'grey' literature.

Search terms

Defining a list of search terms posed difficulties as the field is novel and emerging and, as far as the project group could ascertain, there was not an established terminology. Initially, we used our collective knowledge to generate a set of search terms and later used the opportunity of running a workshop at the 2nd eSTEeM conference in 2013 to 'crowd-source' search terms from the participants who were mainly practitioners and researchers in STEM education. By combining the 'crowd-sourced' terms with our own initial terms, we settled on three sets of search terms concerned with materiality, networks and learning which could be combined to identify papers relevant to the project. The list of search terms in each category is shown in Table 1.

Table 1 The three sets of search terms

Education	Materiality	Network
education or learning	remote lab*	Internet
distance education	internet of things	digital network
distance learning	manipulatives	ubiquitous computing
	tangible virtuality	
	robot*	
	home experiment	
	augmented reality	

Databases

Our selection of online databases covered Science Education, Engineering Education and Education, and had to be amenable to our search strategy which involved combining search terms `[term] AND [term] AND [term]` and entering them into the database's search engine. This meant that a small number of relevant databases were

excluded from the search because they were not amenable to the project's search strategy. The list of databases chosen for searching and the reasons for their inclusion or exclusion in the searches is shown in Appendix 1.

In keeping with the explicit protocols of the review, a purpose-designed project database was used to record details of the database being searched, the combination of search terms being used, along with the date on which the search was run (as databases get updated over time), the identity of the searcher and the number of papers returned by each search. As the database searches were carried out, the bibliographical records of the papers retrieved were exported into the Mendeley reference management tool. The protocol for searching databases, recording the results and exporting details of papers retrieved is shown in Appendix 2.

The coding process

Once the searches had been completed in that the data had reached saturation point (January 2014), the second phase commenced which involved coding the papers using the tagging facility in Mendeley. Firstly, a cleaning process was carried out to identify and remove separate listings of the same paper e.g. where the same paper might be listed in conference proceedings and also in a published collection of papers from the conference. Next, the coding process involved hand screening each paper's metadata, i.e. the title, abstract and any keywords supplied. The metadata for each paper was checked to determine whether it was 'in scope' i.e. that it included at least one of the search terms from each of the three search categories: Education, Materiality and Network. Whenever a paper returned in the searches was considered to be 'not in scope' the paper was tagged accordingly and excluded from further analysis. Figure 1 shows the tagging of papers in Mendeley.

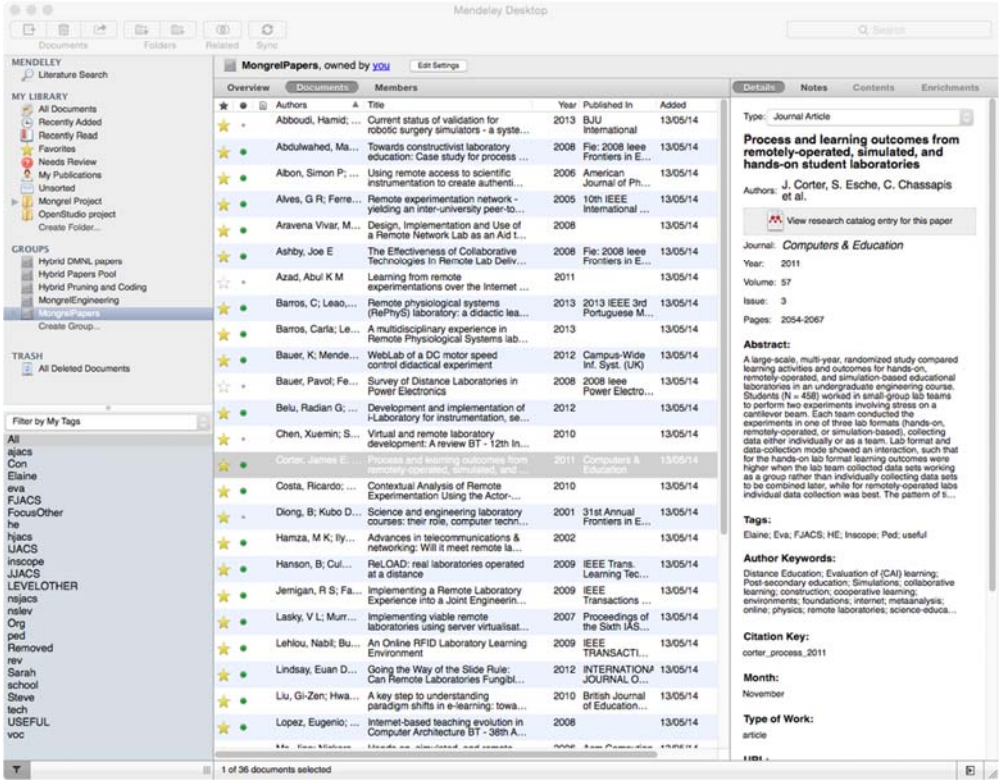

Figure 1 Tagged papers in Mendeley

The bibliographic details, along with the abstracts and keywords of papers that were deemed to be 'in scope', were then used to tag papers according to four categories of tag as shown in Table 2.

Table 2 Categories of tags used in coding

Category	
Subject area or discipline	Joint Academic Coding System (JACS) codes
Primary focus	Organisation, Pedagogy or Technology
Type of paper	Descriptive, Conceptual, Evaluative or Review
Level of education	schools, vocational, university, other, multiple, not-specified

Once a systematic process for coding/tagging the papers had been agreed and tested by the project group, a research assistant was employed to carry out the remainder of the work. A diagram illustrating the stages of the coding strategy is shown in Appendix 3.

In depth review of selected papers

The tagging process provided a means of identifying papers for inclusion in the quantitative analysis and also facilitated the selection of a subset of papers for the second phase which involved a detailed review. 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 adopted for the second phase of the systematic review. The interests of the project group lie in pedagogical and organisational aspects of SET learning and in conceptual, evaluative and review-based studies, rather than those that are merely descriptive, so the group used this subset for further analysis. 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. The full set of prompts used are shown in Appendix 6 and the final list of papers selected for detailed analysis is shown in Appendix 7.

Results

Quantitative analysis of papers located in the searches

Of the 2065 papers returned in the searches of databases, 38.8% were deemed to be out of scope and 22% had no abstracts which meant that they had to be discarded. This left a total of 808 papers (39.1%) to be included in the coding stage.

The majority of papers that we found related to the Engineering disciplines (81.1%) rather than Science (6.8%) and the majority of papers were technological in focus rather than organisational or pedagogical.

Table 3 Papers categorised by subject area, focus, study type and educational level

Category	**Percentage of 'in scope' papers (n=808)**		
Subject area	Science	Engineering & Technology	Unspecified

	6.8	81.1		12.6	
Primary focus of research study	Pedagogy	Technology	Organisation	Other	
	14.8	56.2	23.9	5.1	
Type of research study	Descriptive	Conceptual	Evaluative	Review	Other
	87.4	2.1	9.3	1.0	0.2

This information is shown in Table 3. Further details of the papers are shown in Tables 5-9 in Appendix 4.

A total of 39 papers were selected for a full-text review from these categories. At the review stage, a further seven papers were excluded because they were either false positives or were untraceable leaving 30 papers to be reviewed in depth (see Table 4 for codes).

Table 4 Numbers of Science, Engineering and Technology papers selected for in-depth review

Primary focus of research study	**Type of study**		
	Conceptual	Evaluative	Review
Organisation	2	4	
Pedagogy	2	15	3
Other			4

Results of the review of full papers

Types of hybrid

A brief description of the types of hybrids found in the review sample follows. The majority of the papers selected for detailed review based on our selection criteria concerned remote laboratories, but there were also papers on augmented reality and context aware systems.

Augmented reality

Yuen et al (2011) give an overview of applications where the real world is 'augmented' by digital content linked to specific places and/or activities. This is an emerging field that has applications in 'ubiquitous learning' in fields such as astronomy, geology and geography disciplines, medical training and architecture training.

A context aware system using RFID technologies

Liu and Hwang (2010) describe an instance of a context aware RFID system involving a butterfly garden for school age children with plants that are RFID tagged. As the children move around the garden they use handheld RFID readers which read their location from the tags and the system supports the children's learning by guiding them to particular areas and asking questions to assess their learning.

Tangible technologies

The ability to integrate digital technology into physical objects is called ‘tangible technologies’ or 'digital manipulatives' learning. Manches and O’Malley (2012)

summarise key debates about the representational advantages of using manipulatives with young children to teach number.

Remote laboratories

Communications technologies

The ReLI Project was developed for telecommunications experiments relating to computer networks, such as LANs, configuring routers, VoIP technologies and ATM technologies (Sicker et al, 2005).

A remote network laboratory is used for teaching on computer networks where students can interact remotely with commercial network devices, such as routers, switches and firewalls (Vivar & Magna, 2008).

Engineering

A remote version of a set of 'hands on' laboratory experiments on automatic control, e.g. calibration and hysteresis involving sensors and control valves, is used in conjunction with National Instruments LabView and a simulation (Abdulwahad & Nagy, 2008). The authors argue that the remote lab facilitates higher order learning and they propose a constructivist model of laboratory work using 'hands on', remote and virtual labs.

The iLab remote laboratory is being developed for instrumentation and measurement teaching, e.g. a vortex tube experiment where students collect temperature and pressure data for different flow conditions is described in Belu and Husanu (2012). Students control the experimental setup through a specially developed LabView interface.

The architecture of the ReLOAD system (Hanson et al, 2009) involves multiple experiments in mechanical engineering at multiple locations, all controlled by a central server. ReLOAD involves collaboration between the University of Lees (UK), the University of Columbia, Vancouver and the University of London (UK). Amongst other issues, the authors discuss accessibility issues, standardisation of teaching, the student's sense of immersion and ideas about 'presence'.

Jernigan et al (2009) report on an inexpensive remote laboratory for experiments on automatic control using readily available hardware and software. The remote laboratory consists of a physical experiment involving a beach ball and a dc blower; the control objective is to make the height of the aerodynamically levitated beach ball track a reference trajectory by manipulating the voltage to the blower. The experiment is controlled using MATLAB/Simulink coupled with xPC target, while distance learning students interact with the experiments via standard Internet video conferencing and Microsoft NetMeeting.

The I-ATMUS RFID laboratory environment (Lehlou et al, 2009) consists of two layers: an online layer and a remote laboratory. The online layer consists of a knowledge base on RFID technologies and a website with instructional materials, a search engine, student forums and other web-based resources. The remote laboratory itself consists of (i) a remotely controlled camera to enable students to observe the experiments, (ii) a manual control unit that allows students to control a robotic system that moves the RFID tags along parallel tracks. There are also programmable modules.

Students measure and compare voltages at specific test points in a circuit board as a way of linking theory with practice (Morton & Uhomoibhi, 2011).

Engineering experiments, such as the one-degree-of-vibration experiment involving a mechanical vibrations setup actuated electro-magnetically is used to illustrate an

assessment model for testing the effectiveness of hands-on, remote and simulated laboratories (Nickerson et al, 2007).

NetLab involves a realistic and interactive graphical user interface (GUI) which allows students to input data into a wave form generator and an oscilloscope (Nedic &Machotka, 2007). The authors contend that the NetLab GUI along with a web camera that shows the outputs of equipment in the physical laboratory create a sense of 'telepresence' that enhances students' learning experiences.

Stefanovic (2013) describes two experiments implemented as remote laboratories: an inverted pendulum (developed in the C# environment) and another with coupled water tanks (developed in LabView). There is also a web camera. Both experiments were developed as simulations and the study compared students' experience of using both modes and found that students preferred remote laboratories over simulations and real-world laboratories over both.

Robotics and Programmable Logic Controllers (PLCs)

Ashby (2008) discusses the ABET (Accreditation Board for Engineering and Technology) draft standards for online laboratory sessions, the importance of collaboration between students and the value of a sense of presence the context of six experiments on robotics and PLCs. Students receive feedback via video cameras, audio systems and control panels.

Science

A Gas Chromatography-Mass Spectrometry (GCMS) machine is used remotely by lecturers to demonstrate the equipment while students work on real-time data from the GCMS system in an example of inter-university and cross-border cooperation between British Columbia University and Western Washington University (Albon et al, 2006).

Reviews of remote laboratories

Bauer et al (2008) conducted a survey of eighteen remote control labs used in electronics engineering. They discuss PEMCWebLab which contains a large set of remotely controlled experiments on Power Electronics which are distributed all over Europe.

Chen et al (2010) review the technologies emerging that may be used to develop virtual and remote laboratories including LabView and Matlab/Simulink. The Virtual and Remote Laboratory (Vela) includes a server that works as the web publisher, lab scheduler, and data and database manager. Workstations are used to set up experiments and control devices such as National Instruments ELVIS (Educational Laboratory Virtual Instrumentation Suite) to carry out experiments. A video camera allows students to observe the experiments in real time. Students use clients to carry out the experiments remotely.

Corter et al (2010) compared the process and learning outcomes of hands-on, simulated and remote laboratories for groups of students carrying out experiments involving a stress on a cantilever beam. They suggest that students are more motivated when they are working with the real world laboratory than when using a simulated laboratory, but learning through remote laboratories can be improved by careful design of group and individual activities.

Ma and Nickerson (2006) conducted a comparative review of hands-on, simulated and remote laboratories. They conclude that those who advocate 'hands-on' laboratories tend to emphasise the design skills learning involved while those in favour of remote laboratories do not evaluate the their technologies in respect to design skills. They suggest that a mix of the three different types of environment might be most effective.

Medical applications

A systematic review of 19 studies on the use of simulators in robotic surgery (Aboudi et al, 2012) found five different systems in use. The authors argue that simulations are helpful as complementary tools in training surgeons in robotic surgery, but they are unlikely to replace the real world experience.

RePhyS (Remote Physiological Systems) (Barros et al, 2013a; Barros et al, 2013b) is a remote laboratory with two main features. The first system uses sensors for measuring physiological signals such as in electrocardiograms (ECG), galvanic skin response (GSR) and strain gauge. There is a camera for remote observation. The second system will involve the development of a mechanical heart and lung machine to be used in student experiments.

Other studies

Alves et al (2005) discuss the benefits and challenges associated with peer-to-peer remote laboratories used in higher education in Europe and Latin America. The authors see peer-to-peer networks as a helpful means of gaining employability skills and social skills.

Azad (2011) discusses the designs of remote laboratories in relation to standardisation and modularity in design; the integration of the learning management system; training of maintenance technicians and the potential for industry application.

Lindsay and Wankat (2012 use the example of the slide rule being superseded by calculators and ask whether remote laboratories can replace the real world experience. Their study suggests that, although a small number learning outcomes are not inter-changeable and can only be achieved in real-world laboratories, many learning outcomes can be achieved more easily and more cheaply in the remote mode, and additional learning outcomes are also possible.

Organisational issues

Papers with an organisational focus were mainly concerned with infrastructure development for remote laboratories e.g. for large-scale laboratories and interoperability between systems. Large-scale remote laboratories require numerous servers to provide the remote control, monitoring and management of the various experiments. Laski and Murray (2007) propose using physical servers to run virtual machines using virtualisation software such as VMWare in a remote laboratory for PLC experiments. Ponta et al (2009) examine the architectures of three different service oriented remote laboratories and proposes offering remote experiments to users as distributed services via the web. This service will improve interoperability. Mossin et al (2007) propose a new architecture for remote experiments based on the FOUNDATION Fieldbus protocols (Fieldbus is an industrial network system for real-time distributed control that connects instruments in a manufacturing plant) using a simulated environment.

Finally, the only paper in our sample that attempted to use socio-technical theory (or any other theory about Technology and Society) uses actor-network theory (ANT) to explore remote experimentation as an actor-network (Costa et al, 2010). Four human actors were identified, students, teachers, developers and technicians. Non-human actors included access devices, networks, GUIs, infrastructure devices (e.g. devices for controlling and monitoring experiments), institutions e.g. faculties, the experiments, pedagogical materials and resources, and, finally, teamwork.

Major themes arising from the analysis

A series of major themes and issues arose from the studies in the papers reviewed. These are presented below with references to appropriate papers. Themes (a) to (d) are pedagogical in nature and (e)-(g) relate mainly to the organisation.

(a) The importance of the real world in learning

The relevance of real data and authenticity (including noise) in the learning experience (Corter et al, 2011).

Uncertainty and motivation: a student may be more motivated by a complex experiment where the outcomes are uncertain than one where the outcomes are known (Nickerson, 2007).

The value of learning from failure in experiments (Stefanovic, 2013).

(b) Lack of clarity of purpose in laboratory-based learning

Lack of agreement on what Science and Engineering labs are intending to teach (Corter et al, 2011).

Debates about whether the practical experience of setting up the equipment is part of the learning especially when the experience of the experiment may already mediated by a computer (Nickerson, 2007).

(c) The importance of experiential learning in SET education

(These are some of the examples of theories and models from the papers.)

remote laboratories provide opportunities for students to work collaboratively and also to practise skills individually (almost all papers).

The experiential learning model, e.g. Kolb's learning cycle is relevant as students learn better from interactive experience (Abdulwahad et al, 2008).

Importance of constructivist learning and practical experience (Abdulwahad et al 2008; Corter et al, 2011).

Students' preferred learning styles in disciplines such as engineering and the importance of 'active' learning through 'hands on' work rather than from purely digital resources such as VLEs (Ashby, 2008; Nickerson et al 2007; Morton & Uhomoibhi, 2011).

Using inquiry-based learning and discovery learning through RFID and mobile readers (Liu & Hwang, 2010).

Pedagogies are still developing (Liu & Hwang, 2010; Ma & Nickerson, 2006; Yuen et al, 2011).

Many authors suggest that using remote laboratories may promote higher levels of motivation, notably, Belu & Husanu, 2012; Barros et al, 2013; Corter et al, 2011).

(d) Diverse views on effectiveness of remote labs in teaching and learning

Remote laboratory work can be effective for learning higher order skills, but hands-on laboratory work is more effective (Abdulwahad & Nagy, 2008).

Hands-on labwork is better for group work but remote lab better for individual work e.g. data collection and analysis (Corter et al 2011; Vivar & Magna, 2008).

Improves confidence and knowledge (Lehlou et al, 2009).

(e) Locus of control and responsiveness in using hybrids

There are different means of using the remote laboratories, for example: the lecturer controls the remote lab in a lecture theatre setting, but students use real-time data from the system (Abdulwahad & Nagy, 2008). There are different types of student control for example, direct control or batch control (Belu & Husanu, 2012).

Students directly controlling equipment is important for a satisfactory learning experience (Barros et al, 2013a, 2013b; Corter et al, 2011). Immediate feedback is very important for the student in learning (Barros et al, 2013a). Remote responsiveness is comparable with direct control (Bauer & Mendes, 2012).

Some systems can deal with multiple users to mimic the real world laboratory experience (Nedic & Machotka, 2004). Others can only be used by single users or small groups e.g. a group of five (Mossin et al, 2007).

Queuing systems are an effective way of scheduling students' use of a remote laboratory (Bauer & Mendes (2012); Corter et al, 2011; Costa et al, 2010; Hanson et al, 2009; Lindsay & Wankat, 2012; Nickerson et al, 2007; Ponta et al, 2009; Sicker et al, 2005).

(f) Varying rationales for utilisation of remote laboratories

Sharing expensive resources between institutions and across national borders e.g. the Gas Chromatography and Mass Spectrometry (GCMS) lab time (Albon et al 2006; Alves, 2005; Vivar & Magna, 2008).

Using remote labs to teach large groups of students based in the institution and at a distance (Barros et al, 22013a, 2013b; Jernigan, 2009).

There may be limited access to equipment in real world labs because of space, time and cost associated with them (Corter et al, 2011; Ma & Nickerson, 2006; Nickerson, 2007).

Remote laboratory work means that theory and instruction need not be separated from the practical laboratory work whereas pressure on space in real world labs means that theory and instruction usually take place in lecture theatres (Vivar & Magna, 2008).

Where observation of real systems is needed remote labs can allow access over a 24-hour period and use in distance learning context (Ashby, 2008; Jernigan et al, 2009).

There is a need to learn particular technologies such as RFID where there are skills shortages (Lehlou et al, 2009).

In the United States there is a public requirement for innovation e.g. the ABET learning outcomes (mentioned in Lindsey & Wanket, 2012; Stefanovic, 2013).

(g) A range of approaches to the development of technologies in hybrids

There is the 'bricolage' approach of using materials readily available e.g. the beach ball blower (Jernigan et al, 2009) and open software (Jernigan, 2009; Sicker, 2005).

Many systems involved using proprietary software already designed e.g. iLab, LabView and Matlab/Simulink (Bauer & Mendes, 2012; Belu & Husanu, 2012; Chen et al, 2010; Nedic & Machotka, 2004; Nickerson et al, 2007; Stefanovic, 2013).

There is also bespoke development such as the construction of RePhys, a machine representing the human heart and lungs **(**Barros et al, 2013a, 2013b).

Discussion of findings

The lack of an established vocabulary to describe the phenomenon posed challenges in conducting the review. At the search stage, using combinations of search terms resulted in a large number of false positive returns. Therefore, identifying a suitable set of papers for further analysis and review entailed a lengthy and labour-intensive process of hand checking the meta-data of individual papers. The number of false positive returns is also largely due to the field being relatively new without an established vocabulary. We did not find any common vocabulary in use apart from 'remote laboratory' which we had already identified.

The majority of papers identified were studies of single cases. Many studies concerned with evaluating the effectiveness of hybrid cases used pre-test/test procedures along with self-evaluation questionnaire completed by the students, and some studies compared results with cohorts from previous years. The student participants tended to be of a similar age and level of educational attainment and are usually living on campus which means that they are different from the mature students studying at a distance with the Open University. On the other hand, some remote laboratories are being used effectively across national boundaries.

We can tentatively categorise hybrid instances according to location of material aspect in relation to the student and the learning organisation:

1. Centralised physical resource accessed over the internet by distributed students e.g. remote labs accessed over the internet.
2. Physical resources distributed in a particular location which students access by wireless technologies using handheld devices e.g. the RFID garden, ubiquitous computing.
3. Physical resource is co-located with distributed students who share data through the internet e.g. SenseBoard, the internet of things.

Our study of this field (as represented by the papers located during the project) suggests that there is a relative lack of papers on pedagogies associated with the hybrids in SET learning. This paucity of research on the pedagogies of hybrids, coupled with the finding of only one paper written from a socio-technical perspective, suggest that further research ought to be carried out to provide firmer theoretical foundations for learning involving hybrid networks of physical and digital resources.

Impact

We were able to identify and abstract a set of papers concerned with the pedagogy of Electronics Engineering remote laboratories which could give to faculty colleagues applying for funding for the STEM remote laboratory. The findings from this study is

likely to have further impact as the new laboratory is implemented and used in Open university teaching.

Conclusions

The Mongrel Project explored 'hybrid' digital material networked learning as an emerging area of interest for SET education. Our 'state of the art' review of hybrid digital material networked learning suggests that the literature mainly consists of technological and descriptive reports, with relatively few conceptual, pedagogical and evaluative studies. This implies that the field is still maturing, with researchers mainly focusing on practical matters required for implementing the hybrid. 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 organisational and pedagogical reasons and their conceptual, evaluative or review qualities, we identified a number of key themes – the importance of the real world in learning; the lack of clarity of purpose in laboratory-based learning; the importance of experiential learning in SET education; diversity of views on effectiveness of remote labs in teaching and learning; locus of control and responsiveness in using hybrids; varying rationales for utilisation of remote laboratories and, finally, the range of approaches to development of technologies in hybrids.

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. laboratory-based learning, and purely digital pedagogies, e.g. virtual laboratories, through a new lens. Issues of authenticity, experiential learning, 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 in the near future as the technologies mature and they become more widely used in SET education, so it is vital that further research is carried out on the pedagogical and organisational issues relating to the use of hybrids in SET learning.

Deliverables

Conference paper

Davies, Sarah-Jane; Thomas, Elaine and Walker, Steve (2015). Digital, material and networked: some emerging themes for SET education. In: *EDEN 2015 Annual Conference Expanding Learning Scenarios: Opening Out the Educational Landscape* (Teixeira, António Moreira; Szűcs, András and Mázár, Ildikó eds.), 9-12 June 2015, Barcelona, Spain, European Distance and E-Learning Network, pp. 91–99.

Conference presentations

Thomas, Elaine; Walker, Steve and Davies, Sarah (2013) Hybrid digital/material/networked learning: scruffy mongrel or sleek new breed. Structured discussion at 2nd eSTEeM Annual Conference *STEM Futures: Innovations and impact* 26th March 2013.

Thomas, Elaine; Walker, Steve and Davies, Sarah (2014) Hybrid/Digital Networked Learning scruffy mongrel or sleek new breed? Practices and implications of blending physical and digital resources for learning in HE – progress to date. Presentation at 3rd eSTEeM Annual Conference *STEM Futures – Reflecting on Teaching and Learning* 6th May 2014.

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Appendix 1 Databases identified for searching

Database	Reason for searching/not searching
Academic Search Complete	Large database
Article First	Large database
Educational Research Abstracts	Large database on research in Education
ERIC	Searched
HighWire library	Not amenable to searching
ICR Virtual Library	Civil Engineering – not worth searching
IEEE Xplore	Included in Inspec eiCompendex
IngentaConnect	Searched
Inspec	Searched
Library, information science and tech abstracts	Searched
Science Citation Index	included in Web of knowledge
Science Direct	Not amenable to searching*
Social Science Citation Index	included in Web of knowledge
Web of Knowledge	Searched
Web of Science	included in Web of knowledge
EI Compendex	Searched
Education Research Complete	Searched
Educause	Not amenable to searching

Appendix 2 The search protocol

Using the Mongrel database:

1. Enter the date of the search.
2. Select your Searcher name from drop-down list.
3. Select the name of database to be searched from drop-down list.
4. Select the Education term from the drop-down list.
5. Select the Network term from the drop-down list.
6. Select the Materiality term from the drop-down list.
7. Carry out the search of the selected database using the combination of search terms as you have recorded e.g. (education or learning) AND remote lab* AND Internet.
8. Record the number of hits in the 'No Hits' field of the Mongrel database.
9. Export the citations resulting from your search as a .bib or .ris file and then import them to Mendeley Desktop.
10. In Mendeley, use the 'Check for duplicates' facility in the Tools menu to identify and merge duplicates. Record the number of duplicates in the 'No duplicates' field of the Mongrel database.

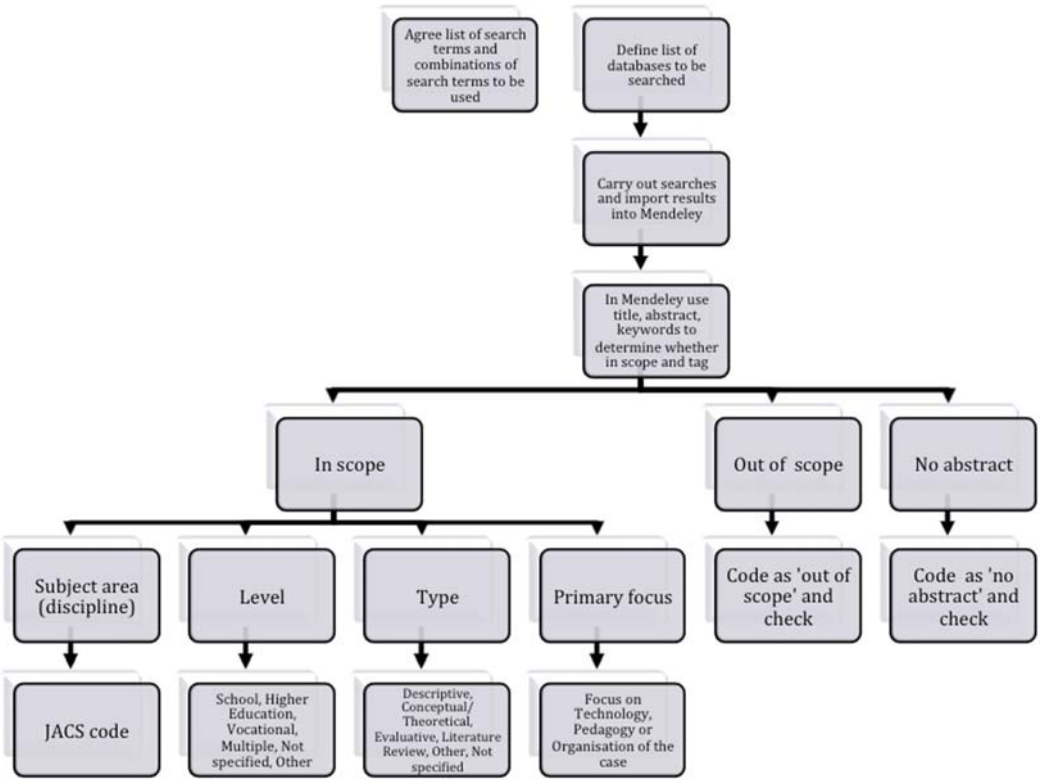
For the next set of search terms repeat Step 1 as detailed above changing to the next Education term but keeping the same Network term and the same Materiality term e.g. ''distance education' AND remote lab* AND Internet. Then repeat Step 2 to Step 5.

Once all the Education terms in the list have been used up, repeat the procedure from Step 1 to Step 5 using each search term in the Materiality term list. Table 1 at the end of this document shows how the search terms have been combined in a previous search.

Note

The search facility may differ from one database to another, so sometimes you may need to use inverted commas around search terms of more than one word e.g. 'internet of things' works without the inverted commas in some databases but not in others.

Appendix 3 Stages in the tagging process



Appendix 4 Tables of the results from coding

Table 5 Proportions of papers according to usability

	Raw data	% of total
In scope	808	39.1
Out of scope	802	38.8
No Abstract	455	22.0
Total	2065	100.0

Table 6 Papers coded according to level

Level	Raw data	% of total
LevelOther	9	1.1
Higher Education	365	45.2
School	19	2.4
Level unclear (NSLev)	391	48.4
Multiple (Mul)	20	2.5
Vocational	3	0.4
Total	807	99.9

Table 7 Numbers of papers according to discipline (JACS) code

Level	Raw data	% of total
Medicine and Dentistry AJACS	7	0.9
Allied to Medicine BJACS	2	0.2
Biological Sciences CJACS	6	0.7
Veterinary Sciences DJACS	3	0.4
Physical Sciences FJACS	37	4.6
Engineering HJACS	614	76.0
Computer Sciences IJACS	34	4.2
Technologies JJACS	3	0.4
Ubiquitous computing UBJACS	4	0.5
Not specified NSJACS	102	12.6
TOTAL	**812**	**100.5**

Table 8 Types of hybrid identified in the data set

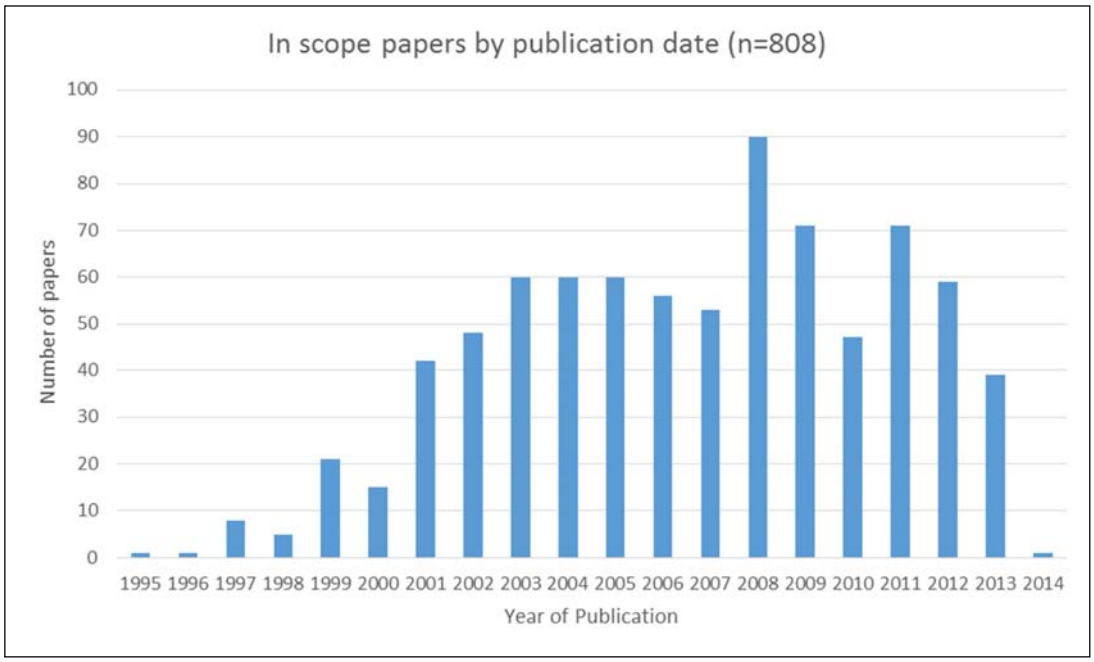
Search term	Number of papers	Materiality term as %
Remote laboratory	678	83.9
Internet of things	7	0.9
Augmented reality	15	1.9
Manipulative	2	0.2
Ubiquitous computing	11	1.4
Robot	147	18.2
Home experiment	1	0.1
Tangible virtuality	3	0.4
Total	864	106.9

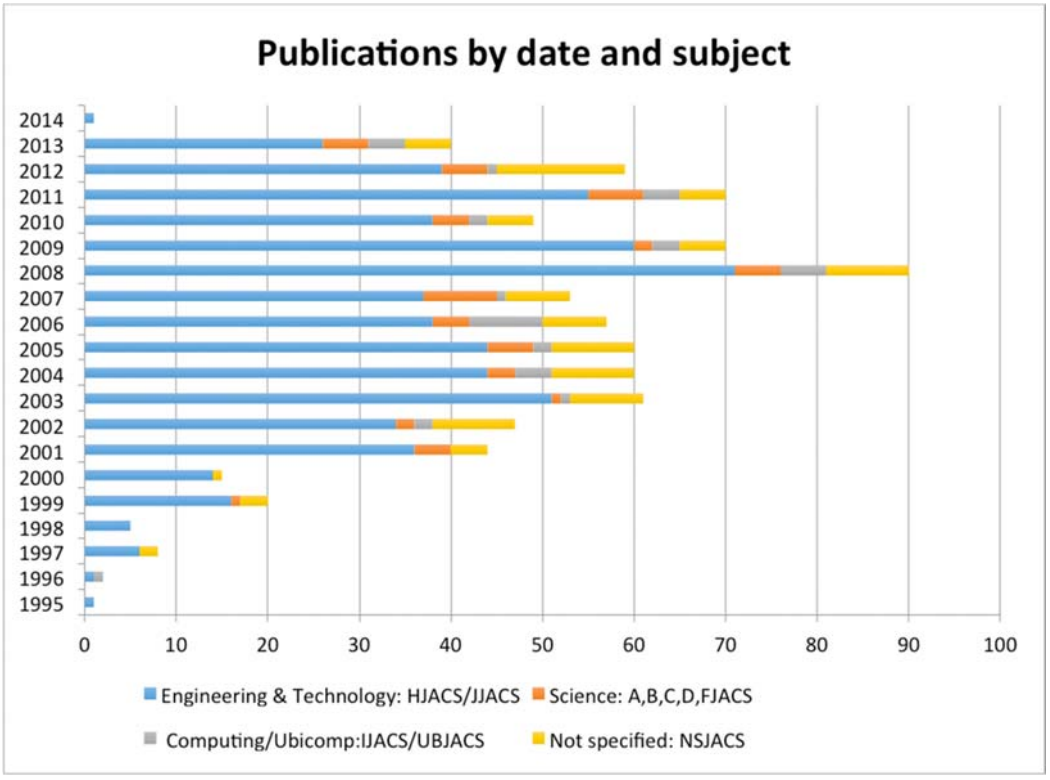
(Some papers include more than one materiality)

Table 9 Types of papers in the data set

Type of paper	Number of papers	% of all papers for each type
Conceptual	16	2.0
Descriptive	702	87.3
Evaluative	76	9.5
Review	8	1.0
Type not specified	1	0.1
Type other	1	0.1
Total	804	100

Appendix 5 Charts showing spread of publications by date and subject





Appendix 6 List of prompts for review of selected papers

Prompt

1. Why set up hybrid physical/digital/networked learning?
2. The hybrid learning example
    a. The artefact (e.g. what's where)
    b. Dramatis personae
    c. Learning arrangements (pedagogical arrangements)
3. Pedagogical/research issues (from the literature review)
4. What comes out of it?
5. Meta – what is the quality of the study?

Appendix 7 List of papers selected for detailed review

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