

Open Research Online

The Open University's repository of research publications and other research outputs

Examining hybrid digital/material resources in networked learning: a critical realist approach

Conference or Workshop Item

How to cite:

Walker, Steve and Davies, Sarah-Jane (2014). Examining hybrid digital/material resources in networked learning: a critical realist approach. In: Proceedings of the 9th International Conference on Networked Learning 2014, pp. 315–322.

For guidance on citations see [FAQs](#).

© 2014 The Authors

Version: Version of Record

Link(s) to article on publisher's website:

<http://www.networkedlearningconference.org.uk/index.html>

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data [policy](#) on reuse of materials please consult the policies page.

oro.open.ac.uk

Examining hybrid digital/material resources in networked learning: a critical realist approach

Steve Walker, Sarah Davies

Faculty of Mathematics, Computing & Technology; Faculty of Science; The Open University,
steve.walker@open.ac.uk, s.j.m.davies@open.ac.uk

Abstract

'Sociomateriality' refers to a range of perspectives on the problematic relationship between people and technology that has recently gained traction in the learning technology literature. Sociomaterialists typically draw on actor network or agential realist approaches to the understanding of technology. The ways these approaches understand the world, we argue, have limitations and we propose an alternative approach to conceptualising the complex relationship between people, artefacts and organisation drawing on critical realist perspectives on technology. This approach accepts that our understandings of a particular technology are mediated by our theories both of a technology's inherent material and nonmaterial properties and of its social situation. It also recognises that aspects of the natural world are autonomous from our understandings and that these are inherent in our technologies. We suggest a similar autonomy for the underlying mathematics which structure the possibilities of the digital world.

Hybrid artefacts are comprised both of a digital component, as is typical of networked learning technologies, but also important and distinctive physically material aspects. Many examples of the remote control of experimental devices can be found in the engineering and science education literatures where physical experimental devices incorporate digital control, sensor and other informational components in physical equipment such as telescopes or nuclear reactors. With the emergence of the 'internet of things' we expect to see increasing experimentation in the use of hybrid technologies in learning contexts.

The distinctive materiality of these hybrid devices offers an interesting context in which to develop a theory of the relationship between the social and the material in (learning) technology. We elaborate a framework for thinking about 'hybrid' digital/material artefacts in networked learning drawing on contributions from the critical realist literature and illustrate how this may be used through the example of a remote student experiment to measure biochemical oxygen demand, as part of a practical distance learning Level 2 environmental science module at the Open University. The experiment is a relatively simple example of a remote experiment, requiring students to observe digital pressure sensors on samples of water and wastewater as a measure of biological activity.

We conclude with a brief discussion of the strengths and weaknesses of our approach.

Keywords

Hybrid products; sociomaterialism; critical realism; networked learning;

Introduction

Sociomateriality has recently been gaining traction in the study of learning and education (e.g. Fenwick & Edwards, 2013) in general and learning technologies in particular (e.g. Johri, 2011). In this paper, we briefly discuss perspectives on sociomateriality and argue for an alternative conception of sociotechnical networks based on a critical realism (Lawson, 2008; Faulkner & Runde, 2013; Fleetwood, 2005; Walker & Creanor, 2012). We illustrate how this can give us a clearer grasp of the evolving materialities of learning. Our interest in hybrid digital/material (Knutsen et al, 2011) technologies with important physical, as well as digital, dimensions (see below) in part stems from their distinctive materiality in the context of networked learning. Our concern is to explore the potential of these hybrid technologies without sliding into either a generalised social constructivism or technological determinism. We are open to the possibility that in any particular instance the contribution of either the artefactual or the human to social change or social stability may be more pronounced.

The paper is structured as follows: firstly we give a very brief review and critique of sociomateriality conceived in actor network or agential realist terms; secondly we draw on work in a critical realist vein to elaborate a framework for thinking about the sociotechnical arrangements of networked learning technologies in general and hybrid digital/material learning artefacts in particular. We demonstrate this using the particular example of a remote laboratory biochemical oxygen demand experiment; this is an illustrative case study which outlines how we are approaching cases in a wider study. Finally we discuss some of the implications and limitations of such an approach.

Background

Taking the material seriously - sociomateriality

Sociomateriality is a way of thinking about the problematic relationship between technology and people. Conventionally, the relationship has been broadly portrayed as a battle between, on the one hand, a technological determinism which conceives of technology as having more or less inevitable social consequences, and on the other hand a social constructivism which sees technologies as the more or less malleable products of human activity. There have been a number of attempts to overcome this binary divide. Recently the term ‘sociomateriality’ (Orlikowski & Scott, 2008) has been used to describe a collection of related attempts to supersede this division, typically drawing on actor network theory (ANT) (Latour, 2005) and after (Law and Hassard, 1999) and perhaps less commonly on the ‘practice lens’ (Orlikowski & Scott, 2008) and agential realism (Barad, 2003). It is often difficult to engage sociomaterialism as a coherent approach, something which some advocates at least rather celebrate (e.g. Law, 2009; Fenwick & Edwards, 2010). In general, though, sociomaterialist approaches are premised on the assertion that it is either impossible or fruitless, or both, to separate human agency from the material elements, including technologies, that are involved in activity. On this view, human activity is so deeply entwined with the material world that it is impossible to conceive of it without thinking of the material. In effect, there is no social, but only the sociomaterial. The entanglement is generally conceived of as networks of human and non-human actors (both referred to as actants in ANT terms).

Sociomaterialism and learning technology: some limitations

Reflecting the strong influence of ANT on much sociomaterial thinking, the relationship between people and technology is conceived of as having two related properties which, we contend, are problematic and which make the application of (ANT-based) sociomateriality difficult both in general and, as argued here, in the particular setting of learning technology. Firstly ANT supposes a flat ontology (Mutch, 2002). That is, it assumes that there is ‘only the network’ and that the research programme consists simply of ‘following the actants’ (Latour, 2005). Such an approach rejects both the ‘downward’ influence of social structure on individual behaviour and the ‘upward’ influence of particular properties of a network's constituent parts. ANT thus rules out a priori both the consideration of broader social structures (viewing power as merely another ‘network effect’) and any consideration of the specific properties of a particular network constituent (other than to open up the ‘black box’ to reveal it as another actor network).

Secondly, neither ANT nor agential realism, (Barad, 2003) distinguish analytically between the human and the non-human, arguing that they are mutually constitutive. ANT uses the term ‘actant’ to describe both human and non-human agents in a network and assumes a symmetry in the relationship between them. An insistence on symmetry among actants raises a rather obvious difficulty in the context of learning technology: the entire education enterprise aims to achieve cognitive, social or behavioural change in learners. Only some actants graduate; mobile phones don’t sit exams. A more realistic starting point would be to recognise the asymmetry in the relationship between the human and non-human. The co-constitution of the human and non-human is not symmetrical, that ‘persons and artefacts do not constitute each other *in the same way*’ (Suchman, 2007:269 emphasis in the original).

Further, since ANT is both descriptive and concerned only with relations at the level of the network (Law, 2009), a sociomateriality drawing on it helps little in understanding possible cause and effect or in the design of learning approaches or the technologies which support them. An ‘orthodox’ sociomaterial perspective, focussing exclusively at level of the network, leaves us with few places to go. We suggest that our critical realist informed sociotechnical network perspective, described below, offers us the opportunity to construct a framework taking

account of technology's social, ideal and material dimensions and can provide the basis of a more practical approach to researching and building learning technologies.

A critical realist response to sociomaterialism

Taking as given the observation that the practices of natural science work (in that, for example they explain phenomena in ways that can support other intentional practices that make up our world, such as building aeroplanes that fly), critical realism asks what the world must be like in order that such practices work (Bhaskar, 1998). It aims to reconcile the independent existence of a physical world 'out there' (is 'realist'), with the recognition that we can only know of it through our experiences, theories, ideas, practices and so on (hence 'critical', or at least not naïve realist). Our response develops earlier work (Walker & Creanor, 2012) and rests on the ontological building blocks of Fleetwood's (2005) 'ontology of the real', Faulkner & Runde's (2013) 'technological objects' and Lawson's (2008) relational conception of material artefacts.

Fleetwood's (2005) 'ontology of the real', proposed in the context of organisational studies, can help to clarify some of the elements of the relationships between the technological object and the human. For a critical realist, something is real if it has an effect in the world. In this sense, ideas, social relations and physical objects are all real though the nature of that reality differs; for example while an idea cannot exist without a (human) mind, a rock can and does. Fleetwood identifies four ways in which things can be real; ideally materially, socially and artefactually, the last of which is a composite of the preceding three. The 'ideally real' refers to discursive entities such as language, beliefs or theories which are real in the sense that they influence human behaviour, since people behave as they do in part at least because of the way they understand the world. Importantly, our knowledge of the other modes of reality is always mediated by our 'ideally real' theories and understandings of them. In considering technological artefacts, the ideally real component corresponds largely with the idea of technological frames (Orlikowski & Gash, 1994). 'Material reality' refers to things that exist independently of what we might 'say, do or think'. However, in the context of studying digital objects, and particularly hybrid digital/material products, we need to be able to distinguish between their physically material aspects and their embodiment of 'nonmaterial' software objects (Faulkner & Runde, 2013) which include programs and the data on which they operate. That these two aspects of their reality are distinct can be inferred from the techniques we use to study them. Our knowledge of physically material properties (such as size, mass, magnetic or electrical properties) is (broadly) derived from the experimental practices of the natural sciences. Our knowledge of the general properties of software is derived from the rather different practices of mathematics (most famously in the work of Turing) and are independent of the particular material devices in which they 'reside'. Importantly for our purposes, both the material and the nonmaterial bring particular enablements and constraints. Fleetwood's use of the word 'material' does not allow us to distinguish hardware and software in the way that Faulkner & Runde's use of material/nonmaterial does, so for our purpose we will use the term 'autonomous' reality as an umbrella term for material and nonmaterial, since it refers to properties independent of human activity. The 'socially real' refers to human practices and our social structures. These are inherently social in that they depend on shared human activity and are real in that they exert influence in the world. Although these are dependent on human activity, they may exist whether or not we know about them. For example, the patterning of thinking and behaviour involved in the social structure of communities of practice existed before Lave and Wenger's use of the term (Lave & Wenger, 1991); in this sense they were discovered rather than invented.

Table 1: Framework Summary	
Social	Relational (use-time): the positioning of a technological artefact among relations between positioned practices and other artefacts
	Inscription (design/build time): independent properties of an artefact chosen and built in at design time
Ideal	Technological frames: different groups/individuals/positioned practices are likely to have differing frames.
Autonomous	Material: the physical components and properties of an artefact (including those inscribed at design-time)
	Nonmaterial: (digitally) encoded programs and data structures instantiated in a material artefact

Making a similar move to many sociomaterialists, we can think of this social reality in terms of sociotechnical networks in which the patterns of both social and technological relationships enable and constrain activity. We take as a starting point for thinking about these networks Bhaskar's (1998) relational view of social structure as networks of 'positioned practices' that we take up in various aspects of our lives and the role within them of

technological artefacts (Lawson, 2008; Faulkner & Runde, 2013). Technological objects are irreducibly social in two senses (Lawson, 2008). Firstly, they are social at their point of use in that they 'slot into' the social relationships constituted by networks of positioned practices that make up the social (or now, sociotechnical) realm. As they become a part of relationships between positioned practices and they may or may not be part of processes of social transformation; that is an empirical question. However, the consequences of their introduction are conditioned both by the pre-existing social relations into which they fit and by their existence as material and nonmaterial objects. This relational view of sociotechnical networks is different from ANT-based sociomateriality in that it represents only one of many potential levels of analysis: social (or sociotechnical) structures may emerge from particular patterns of relations in ways that are not reducible to them, but which may constrain or enable certain actions at a lower level. The effect of these structures may be felt via the particular patterning of sociotechnical relations that precede any given social or sociotechnical actions, and which may have elements embedded in their material existence. Secondly, artefacts are social at the point of design or construction in that they are outcomes of social processes of design and carry the intentions and values of those involved in the design process embedded in their material and nonmaterial forms (similar to the 'inscription' of ANT). Table 1 summarises characteristics of the social, ideal and autonomous dimensions of this framework. We elaborate this approach below in exploring the issues and potential consequences of hybrid digital/material learning resources.

Hybrid learning resources and practices in networked learning

Networked learning has primarily been concerned with the role of informational learning resources in open and networked pedagogies. Initially this concern included analogue video and audio, though since the 1980s this interest has almost exclusively focussed on digital media and resources (McConnell et al., 2012). Since the 1990s there has been a burgeoning interest in learning networks constructed using web pages, online conferences, wikis and so on. The nonmaterial properties of these artefacts are generally taken as read: they are replicable at almost zero cost; they can be accessed from anywhere with an internet connection; they can be malleable and so on. The physical dimensions of their materiality had been of peripheral interest, at least until interest in the use of mobile devices emerged in the mid-2000s. Largely outside the mainstream of networked learning and learning technology literatures, there has also been a growing interest in what, following Knutsen et al (2011), we refer to as 'hybrid' products comprised of: "a hybrid of tangible atoms and digital bits" (Knutsen et al, 2011:196) and "products that are connected to online services, that are based around digital data (often from sensors) and that rely on digital networks to function. Central to a discussion of these hybrid products is the relationship between physical product, digital data, services and emerging technologies" (ibid). In the terminology we are using here, hybrid technologies have important material as well as nonmaterial dimensions. We focus here on an ontology of networked learning; this forms the basis of our ongoing work to understand the dynamics of hybrid learning technologies.

The spread of such hybrid artefacts, for example in growing interest in the 'internet of things' seems likely to create new arenas for networked learning (e.g. Thomas et al, 2012). There is, though, already a history of the use of hybrid objects in networked learning. While not figuring prominently in the networked learning literature, there is a substantial literature on 'remote laboratories' in the engineering education literature and to a lesser extent in the science education literature. Remote teaching laboratories, unlike virtual or simulated laboratories, allow students to access and sometimes control physical experimental equipment to carry out experiments. Students use hybrid material/nonmaterial products and measure results via some form of sensors. These remote laboratories may offer the opportunity for students to develop some of the practical skills and knowledge associated with the manipulation of material artefacts that have widely been thought necessary in the education of engineers and scientists. In the following, we develop the framework set out above to identify the issues we would expect to encounter in a study of hybrid learning technology in networked learning.

Socially relational aspects of hybrid learning technology

We can think of networked learning situations as sets of interlinked positioned practices, the most salient of which are probably between and among tutors, students and learning resources. These relations typically presuppose the existence of schools, colleges and universities and their associated policy and funding mechanisms as well as a wider web of other positioned practices including student support, administration, and technical support. These relationships are not static. Most obviously, we are in a period of massive change in the higher education sector driven by policy, economic and technological concerns. Nevertheless, distinctive elements of the relationships between educators and learners remain and rest on pedagogic practices (such as assessment, feedback, tutorials, laboratory experiments and so on). Technological artefacts such as email, VLEs,

word processed files, and so on 'slot into' these relationships and may influence them significantly, either reinforcing or challenging them, at times being part of establishing new relationships.

A second network of interlinked positioned practices comprise the context in which new technological artefacts are designed and built and which inscribe particular enablements and constraints. In the case of educational artefacts this network will often overlap with the networks of use as educators are typically involved in the design. In the case of hybrid technologies, small groups of academics and technicians seem to be prominent in the design of individual laboratory experiments. In some instances these networks need also to involve external suppliers. Technological artefacts are also likely to carry the inscriptions of the resource managers and, in the current climate, their requirements to reduce costs. It seems likely that the differing positioned practices in the sociotechnical networks of production will bring conflicting needs and interests to the process of design which will be reflected in the material artefact and in the arrangements to support it.

Ideally real aspects of hybrid networked learning technology

As noted above, the ideally real dimension of technology - people's perceptions of it - are essentially people's technological frames (Orlikowski & Gash, 1994). We might expect that different positioned practices will be associated with different perspectives on a technology, and with differing expectations; one aspect of the successful implementation of a technology will be the successful alignment of stakeholders' technological frames. Achieving such alignment may not be straightforward; we will often expect debate and contention among people occupying similar roles in relation to a technology and even more frequently between people occupying different roles. For example, when we look at the relationship between learning and material artefacts there are differences among science educators about the purpose and effectiveness of ('hands-on') lab work, and whether it primarily develops students' experimental design and understanding of uncertainty in measurement, and or more specific laboratory techniques and skills (Bruck et al, 2010). In the US, engineering educators have identified 13 learning outcomes from laboratory teaching that they consider important (Feisel & Rosa, 2005), including, for example, psychomotor skills. It is possible that differences in world views of scientists and engineers will lead to different perspectives on learning in general and the role of the physical in particular. Reviewing the literature on remote, hands-on and simulated laboratories in education, Ma & Nickerson (2006) concluded that hands-on lab advocates tended to emphasise design skills whilst remote lab advocates focussed on conceptual understanding. Their additional observation that there was often evangelism for one particular format without sufficient empirical evidence, supports the idea of unstated individual technological frames. Similarly, we expect that students' beliefs about the relationship between themselves and the remote laboratory equipment would also influence their preferences and performance (ibid). As the potential for using hybrid networked learning objects spreads, for example through the growing interest in the 'internet of things', we might also expect to see other sets of expectations and values become more prominent; for example the growing 'maker' culture which values 'informal, networked, peer led, and shared learning motivated by fun and self-fulfilment' (Sharples et al, 2013:34) would be likely to bring a rather different perspective to learning with hybrid resources compared with more traditional science and engineering educators.

Autonomous reality of hybrid networked learning technologies

Our interest in hybrid learning objects in part stems from their distinctive materiality in the context of networked learning. Unlike purely digital objects they cannot be replicated at close to zero cost; they cannot be moved very quickly, they are rival (that is, if one person or group is using an object another can't) and so on. This will immediately place constraints on the opportunities for hybrid networked learning that are different to those of the purely digital. In the natural sciences, the nature of the equipment that a researcher uses is closely tied to the kind of natural phenomena to be investigated, and this places certain physical constraints on what is achievable. For example, an astronomical telescope is large in order to maximise the amount of light it can capture to resolve images of distant, and very dim, celestial objects. Telescopes are also more effective when located away from light and atmospheric pollution. These aspects of materiality are intrinsic to the object's relationship with the natural world as part of the practice of science and in science education; networked infrastructures allow learners to have remote access to a single, complex and remote artefact. Other aspects of an object's materiality which might be expected to link to particular sociotechnical arrangements include the use of consumables (for example reagents in a remote chemistry experiment) or the need for environmental control (for example to maintain biological processes to be observed remotely).

An illustrative case study

To illustrate how this approach might structure and illuminate a specific case, we briefly examine the Biochemical Oxygen Demand (BOD) remote experiment which is run at the Open University (OU) as part of a

practical science module for distance learning students in the natural and environmental sciences. Our aim is to outline the key components of the case and suggest some of the key dynamics at play in sustaining this use of hybrid technology. This is a preliminary element of a current project, and we are not able to make strong empirical claims. Rather, we are using it to illustrate how our framework enables us to structure our study. This will, we hope, lead to reporting of empirically stronger field studies in the near future.

For brevity, we emphasise those elements of the case that relate distinctively to the particular materiality of the BOD experiment rather than give an exhaustive description of its location in the OU's wider approach to science education. We have chosen the BOD remote experiment because it represents perhaps the simplest case of using a hybrid digital/material technology; a digital pressure sensor observed via a video camera. In this example students exercised no control over the experiment itself. The experiment involves a remote laboratory set up for real-time BOD experiments on water samples using pressure-measuring devices with electronic read-outs. BOD, a measure of the degree of organic pollution in water, is determined by the oxygen taken up by aerobic bacteria as they decompose the organic matter in the water samples. The BOD test is carried out by incubating a sample in a sealed bottle for 5 days at 20 °C, using the fact that reduction in the oxygen level results in a reduction of the headspace air pressure in the bottle.

Our preliminary identification of relevant positioned practices relies on an understanding of the structure of higher education in general, and the Open University's particular approach within that. Hence, we can identify students, associate lecturers (tutors), laboratory technicians and the module team (comprising academics and related staff)¹. Students record real-time data over a week, using a webcam to observe the experiment remotely. Background information and instructions were provided on a module website and students were supported by academic topic specialists through a dedicated online forum. Students decide when to observe the experiment, record values, plot data and calculate the BOD rate constant and ultimate oxygen demand of the samples, thereby determining levels of organic pollution in the water samples. The BOD remote experiment has been run successfully with multiple groups of students over two presentations of the module.

The values and beliefs of the science educators, as expressed in the design of the learning technology and the learning experience, included providing practical science experience to distance learning students, a focus on real data (as opposed to modelled or simulated experiments) and the development of skills in observation, decision-making, analysis and interpretation.

Operating this experiment with learners led to some interesting observations of evolving practices and learning. Students' close observation of the remote experiment allowed them to note fluctuations in temperature and pressure over periods ranging from minutes to days, leading to discussions over sources of error, uncertainty in measurement and experimental design. The pressure measuring devices produced 6 digital read-outs every 30 seconds; some students had difficulty reading these, and strategies were evolved by students and educators to solve this problem by recording read-outs in batches, pausing the live video feed or using Print Screen to save the student's own computer screen view of the read-outs. As students were allowed to observe the experiment at times convenient to themselves, the laboratory lights needed to be on at night. This was not a usual lab practice and there was an instance of the lab technician turning off the lights, a situation quickly remedied after the students raised the issue on the forum. In Table 2 we place the BOD remote experiment within our framework, allowing us to consider the dimensions of reality and surface the properties and structures involved, be they designed, implicit or emergent.

So, what are the consequences of the particular materiality of the BOD experiment? Firstly, multiple students can access the physical experiment simultaneously. The (nonmaterial) video stream that students see is nonrival - that one student is viewing it does not prevent another from doing so. This may be a feature of all remote experiments which do not grant the student control over the equipment involved; the information generated by the experiment is carried to users as a nonmaterial bitstream. An alternative approach might allow students remotely to control variables such as temperature or light and measure their effect on biochemical oxygen

¹ At this stage, we do not claim that this is definitive for two reasons. Firstly, more detailed empirical work may identify additional relevant groups of actors. Secondly, we contend that by focussing on the positioned practices and their relationships through which social structures are reproduced, our approach offers an opportunity to overcome some of the limitations of 'relevant social groups' as conceived in the SCOT literature through a consideration of social structure as proposed by Klein and Kleinman (2002), though space precludes further exploration of this here.

demand. This would necessarily, though, introduce 'rivalry' into the experiment in the sense that different students could not control the experiment simultaneously and other mechanisms would need to be used to allow access (e.g. running multiple instances of the experiment; creating booking schedules for students to access at different times). Secondly, the experimental design carries the inscription of an understanding of how students learn science, and the value of 'real' data. Students are able to see the messiness involved in data collection 'for real'. While it would be straightforward to build a purely digital emulator of this experiment, with all of the advantages that would bring, the designers clearly believe there is a value in students' experiencing data collection with all of the real-world vagaries that involves. Thirdly, it allows us to consider the implications for the networks of positioned practices involved in running the experiment; compared with traditional networked learning resources we have immediately introduced the additional practice of the biology lab technician responsible for setting up and maintaining the experiment.

Table 2. Biochemical Oxygen Demand remote experiment		
Social	Relational	Networks of educators, distance learners with connections mediated by online forums, online learning texts and experimental equipment to sustain standard BOD test conditions Focal network supported by wider network of administrators, laboratory technicians, computer help desk.
	Inscription	Intentions and values of educators: use of real data, real-time student participation, practical experience for distance learners;
Ideal	Technological frames	Distance learners - organising own time to observe the experiment and take readings and discuss with peers and educators Educators - student appreciation of experimental design and uncertainty in measurement, development of student skills in observation, decision-making, recording, analysis and interpretation
Autonomous	Material	Thermostatically controlled laboratory (20 °C), laboratory lighting, BOD dark glass bottles, stirrers and stirring unit, water samples and controls, soda lime to absorb carbon dioxide, seeding microorganisms, pressure-measuring devices with electronic read-outs, web cam, student computer
	Nonmaterial	Software is largely standard, e.g. video streaming; conversion of physical pressure readings in to digital read out

Discussion and conclusion

Thinking of networked hybrid learning technologies using a critical realist framework as in the BOD case above achieves, we argue, two things. Firstly it prevents us from thinking in simple technology impact terms and forces us to think about what might have been inscribed into a particular artefact while simultaneously allowing us to think about the enablements and constraints inherent in the autonomous reality of the experiment. Secondly, unlike ANT, it allows us to think *a priori* about the implications of particular (non)materialities and their potential consequences for the design of learning interventions; we can start to build theories of hybrid networked learning and how particular arrangements will, in certain contexts, tend to lead to particular outcomes. Such a theory would, according to the ontology presented here, need to explain relationships between particular understandings and practices of science, engineering and technology as well as their associated pedagogies; the relationships to particular technologies and the material world; and how we might approach bringing their autonomous realities in to the social practices in education. These are empirical questions, and our answers will always be mediated by the theories we use and hence open to correction and refutation. This will, though, be the next phase of our research into hybrid learning technologies in networked learning contexts.

Acknowledgements: The authors would like to acknowledge the help and advice of colleagues on the 'Practical Science' module team, whose work on the Biochemical Oxygen Demand remote experiment is described here: Nick Braithwaite, Maria Velasco and Eleanor Crabb.

References

Barad, K. (2003). Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter. *Signs: Journal of Women in Culture and Society*, 28(3), pp.801–831.

- Bhaskar, R. (1998). *The Possibility of Naturalism: A Philosophical Critique of the Contemporary Human Sciences*. London: Routledge
- Bhaskar, R. (2008) *A Realist Theory of Science* (3rd ed), Verso: London
- Bruck, L.B., Towns, Marcy and Bretz, Stacey Lowery. (2010). Faculty Perspectives of Undergraduate Chemistry Laboratory: Goals and Obstacles to Success. *Journal of Chemical Education*, 87(12), pp.1416–1424.
- Faulkner, P. and Runde, J. (2013) Technological Objects, Social Positions, and the Transformational Model of Social Activity. *MIS Quarterly*, 37(3), pp.803–818.
- Feisel, L., D. and Rosa, A.J. (2005). The Role of the Laboratory in Undergraduate Engineering Education. *Journal of Engineering Education*, 94(1), pp.121–130.
- Fenwick, T. and Edwards, R. (2010). *Actor-Network Theory in Education*. Abingdon, UK: Routledge.
- Fleetwood, S. (2005). Ontology in Organization and Management Studies: A Critical Realist Perspective. *Organization*, 12(2), pp.197–222.
- Johri, A. (2011). The socio-materiality of learning practices and implications for the field of learning technology. *Research in Learning Technology*, 19(3), pp.207–217.
- Klein, H.K. and Kleinman, D.L. (2002). The Social Construction of Technology: Structural Considerations. *Science, Technology & Human Values*, 27(1), pp.28–52.
- Knutsen, J., Martinussen, E., Arnall, T. & Morrison, A. (2011) Investigating an ‘Internet of Hybrid Products’: Assembling Products, Interactions, Services, and Networks through Design. *Computers and Composition*, 28(3) 195–204
- Latour, B. (2005). *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford: Oxford University Press
- Lave, J. and Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.
- Law, J. and Hassard, J. *Actor Network Theory and after*. Oxford: Blackwell Publishers.
- Law, J. (2009). Actor Network Theory and Material Semiotics. In Turner B.S. (Ed) *The New Blackwell Companion to Social Theory*. Oxford: Blackwell Publishing, pp. 141–158.
- Lawson, C. (2008). An Ontology of Technology: Artefacts, Relations and Functions. *Techné: Research in Philosophy and Technology*, 12(1). [online]. Available from: <http://scholar.lib.vt.edu/ejournals/SPT/v12n1/lawson.html>.
- Ma, J. and Nickerson, J.V. (2006). Hands-on, simulated, and remote laboratories. *ACM Computing Surveys*, 38(3), p.1-23.
- Malkawi, S. and Al-Araidah, O. (2013). Students’ assessment of interactive distance experimentation in nuclear reactor physics laboratory education. *European Journal of Engineering Education*, pp.1–7.
- McConnell, D., Hodgson, V. and Dirckinck-Holmfeld, L. (2012). Networked Learning: A Brief History and New Trends in Dirckinck-Holmfeld, L., Hodgson, V. & McConnell, D. (Eds) *Exploring the Theory, Pedagogy and Practice of Networked Learning*. London: Springer, pp. 3–24
- Mutch, A. (2002) Actors and Networks or Agents and Structures: Towards a Realist View of Information Systems. *Organization*, 9, 477-496.
- Orlikowski, W. and Gash, D. (1994). Technological Frames: Making Sense of Information Technology in Organizations’. *ACM Transactions on Information Systems*, 12(2), pp.174–207.
- Orlikowski, W.J. and Scott, S.V. (2008). 10 Sociomateriality: Challenging the Separation of Technology, Work and Organization. *The Academy of Management Annals*, 2(1), pp.433–474.
- Sharples, M., McAndrew, P., Weller, M., Ferguson, R., FitzGerald, E., Hirst, T. & Gaved, M. (2013) *Innovating Pedagogy 2013: Open University Innovation Report 2*, The Open University, Milton Keynes
- Suchman, L. (2007) *Human-Machine Reconfigurations: Plans and Situated Actions*, Cambridge University Press, Cambridge
- Thomas, E., Walker, S. and Richardson, P. (2012). What did the Romans ever do for us? ‘Next generation’ networks and hybrid learning resources in Hodgson, V., Jones, C., de Laat, M., McConnell, D., Ryberg T. & Sloep, P. (Eds) *Proceedings of the Eighth International Conference on Networked Learning 2012*, Maastricht School of Management, Maastricht, The Netherlands/Maastricht: University of Lancaster 337–344
- Walker, S. and Creanor, L. (2012). Towards an ontology of networked learning resources in Hodgson, V., Jones, C., de Laat, M., McConnell, D., Ryberg T. & Sloep, P. (Eds) *Proceedings of the Eighth International Conference on Networked Learning 2012*, Maastricht School of Management, Maastricht, The Netherlands/Maastricht: University of Lancaster 448–455