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Technology enhanced learning in science: interactions, affordances and design based research

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Abstract: The role of an educational technologist is difficult to define. This paper reflects on the experience of working on a range of technology enhanced learning in science projects to review a number of working principles which have proved effective in the practice of educational technology. It discusses how these principles relate to the theories in use in educational technology. Three case studies are considered illustrating methods of participatory design, design based research and socio-cultural approaches. All the case studies are taken from the application of educational technology principles to the design of examples of science instruction. The paper offers an interpretation of the contemporary practice of educational technology

Keywords: Science learning, participatory design, design based research, affordances

Introduction

Over the past twenty five years as part of my work with the Computers and Learning research group (CALRG) at the Open University I have explored the ways in which technologies can be deployed to enhance the learning of science. The overall aim of such work is to improve the quality of student learning in science. In the course of this work I have used theories in use on learning science to develop a position on how to work as an educational technologist interested in the development of science learning. This position has been informed by the empirical research in which I have engaged and the range of methods I have developed to approach the challenging task of making sense of learning in complex contexts. The interactions between theories of learning and instruction, the roles of teachers and students in co-constructing instruction and the growing role for information and communication technologies in learning have presented a challenge for teachers and researchers. The complex settings to be studied have driven researchers to look for new ways of conceptualising learning settings. For example, a learner may be required to consult online reference sources, engage in collaborative work with others, face to face or via social media, produce an artifact such as a webpage, or respond to other media artifacts.

As an educational technologist, my work involves the design, implementation and evaluation of learning experiences. However, some aspects of the work of an educational technologist are technology driven: making use of what becomes practical or possible due to advances in contemporary technologies. This means that in addition to the complexity of learning situations to be studied, there is a need to develop appropriate methodologies to apply in situations where the goal is to produce meaningful findings, whether from the conduct of experiments, observations or design interventions whose result can be inspected.

Our approach: design based research

Issroff and Scanlon (2002) distinguish between two groups of theories in use in work with learning technologies. The first are related to '*principled decisions about the design of learning materials*' and the second are used to '*influence the way we frame our research on learning*'. They argue that both types of work are necessary to research learning in relation to technology. What we require as educational technologists are theories which provide a framework in which we can understand the complex interactions between learners, teachers and the resources they use. This framework can represent a world view or an orienting device for researchers (see e.g. the description by Mercer (1995) of the guided construction of knowledge.)

Working as an educational technologist there are many opportunities to design learning experiences. These designs can be based on theories and we can conduct evaluations to help us understand what range of factors can influence students in their learning.

> *Technology provides us with powerful tools to try out different designs, so that instead of theories of education, we may begin to develop a*

science of education.

But it cannot be an analytic science like physics or psychology; rather it must be a design science more like aeronautics or artificial intelligence. For example, in aeronautics the goal is to elucidate how different designs contribute to lift, drag manoeuvrability, etc. Similarly, a design science of education must determine how different designs of learning environments contribute to learning, cooperation, motivation, etc.

Collins (1993) (p. 24)

Design based research as a frame for educational technology research

Brown (1992) developed her approach to science learning by centering on tasks that have meaning and relevance to the students, and are the types of tasks that scientists are likely to do in real life. She has developed ideas of communities of thinking and learning which bring together active learning and collaborative approaches. She has described her approach as devising design experiments based on theoretical principles. Her goal in this activity was '*a theoretical model of learning and instruction rooted in a firm empirical base.*' In this work she has drawn on her background as a developmental psychologist.

More recently Collins et al. (2004) have written about the purpose of such design based research and developed guidelines for how it should be conducted. Collins et al (2004) " *Design experiments were developed as a way to carry out formative research to test and refine educational designs based on principles derived from prior research."* (p15)

Barab and Squire (2004) distinguish between formative evaluation and design based research in three ways. First, in contrast to evaluation design based research implies a constant impulse towards connecting design interventions with underlying theory. Second the possibility of generating new theories not just proving existing theory and finally the belief that the particular setting in which an intervention is tested provides a 'minimum ontology' (p5) in which the design can be investigated. That is that there is not a way in which the design intervention could return to the laboratory to further test the theoretical claims.

Schoenfeld (1992) also cited in Barab and Squire addresses the issue of what is a sound methodology in social sciences research and isolates as prime requirements; trustworthiness, credibility, usefulness and the range of contexts to which the researcher believes findings extend. Barab and Squire are attracted by the criteria of usefulness and range of contexts to which the findings apply. This has implications for what they see as the goal of design based research which is to 'directly impact practice while extending theory' (p.6).

The theories with which we are concerned are those related to instructional design and learning science. In terms of instructional design, an influential reconceptualising of the instructional process and the role of technology was offered by Laurillard's conversational framework (2003). This framework contains some assumptions about the optimal learning process - that teachers and students need to talk to each other and exchange ideas, teachers set tasks for students, learners need opportunities to put ideas into practice, and learners need to reflect on what happens during their attempts to successfully complete tasks. These are the core elements of an instructional process involving teachers, students and technology. It has been applied to a number of examples in science education using information technology (see e.g. Scanlon et al., 2002). It is not however yet a model applicable to considering learning though experience or learning in informal settings.

What is special about working in science? A survey of trends and developments in theories of learning highlights how some key ideas in learning theory have developed and been interpreted in science education (see e.g. constructivism, Hodson, 1998, Millar, 1993, Millar et al, 2001). The early adoption of computer assisted learning in science, together with the rich mix of teaching approaches and contexts make science learning a particularly fruitful site for educational technology research. Computer supported collaborative learning research has been a particularly rich vein of instructional experiments, many of them in relation to the development of technology based tools for science education (see e.g. Hoadley, 2002).

Principles for the conduct of design experiments in science

In the course of my work with the CALRG I have developed the framework for an approach to this work which has the following components

- Multidisciplinary teams

A recent joint research council's programme on technology enhanced learning in its launch document (TLRP-TEL, 2006) described how technology enhanced learning (TEL) requires interdisciplinary collaboration across the disciplines of learning, cognition, information and communication technologies (ICT) and education, and broader social sciences. The design and evaluation of teaching material requires a multidisciplinary approach working as a team with a range of complimentary expertises. Recent work from this programme, (TLRP-TEL, 2009) talks about the challenges of interdisciplinary research particularly, in the effective communication of team members. For further discussion of interdisciplinary working in technology-enhanced learning see Conole et al. (2010) and Scanlon et al under review.

- Commitment to openness

With a commitment to the Four Opens (Open as to people places, methods and ideas) enshrined within our foundation as an Open University, Crowther (1969) signalled our intent of designing education for all. McAndrew (2010) has outlined how the connected world that we have now complicates the sets of resources which may be incorporated in to learning designs citing the more complicated blending of many different sources and tools. But openness in recent years has become an even more powerful principle for working and, as McAndrew points out, is to do with 'the ethos of the internet'. See also Conole, 2010 who reconceptualises openness in a modern context. She takes a particular position on the notion of "openness"; considering it from a broad perspective covering four major phases of the academic lifecycle: design, delivery, evaluation and research. As well as considering the potential of open educational resources the educational technologist needs to practice openness. For some educational technologists this means adopting open publishing, participation in social media forums and adopting open source tools.

- Authenticity

As Petraglia (1997) points out, authenticity is a quality which is often cited as evidence of good working practices in education. It carries with it notions of real and meaningful tasks, and settings and is often contrasted with the artificiality of toy tasks or artificial laboratory based contexts. This is a term which has been used to consider science learning. One interpretation of authenticity in that context is that tasks which are part of science activities need to be personally meaningful to the learner. Another is that they need to be the type of tasks or activities that scientists might undertake themselves, that is, they should be culturally authentic Petraglia also points out how difficult it is to pin down a clear definition or delineation of the term authentic. What it means for the practice of educational technology, I think, is an avoidance of artificial contexts.

- Affordances of technology

It seems sensible to consider the properties of technology as an important part of the educational technologist's area of expertise. However starting with the original definition of affordances by Gibson (1977), the current usage from Norman (1988) and commentary by Gaver (1991) there are continuing debates about the meaning of the term. Conole and Dyke (2004) helpfully emphasise the intended use of technology as an important part of their review of the potential of the technology. For Conole the term affordances are useful because it emphasizes both the co-evolution of users and tools and the contextual nature of tools in use. Conole and Dyke argue that it is in the interaction between the possible uses of technology and the unexpected uses that people make of the potential of technology in creative ways adapting them to their needs that more can be understood by educational technologists.

The final three principles which will be developed in the case studies to follow are

- Socio-cultural approach to the study of learning
- Observation of interactions
- Participatory design

In what follows I illustrate how the last three of these principles have been developed in a number of CALRG projects: the socio-cultural approach as applied to the analysis of complex settings, the practical experimentation by access to remote learning (PEARL),

observation of interactions as applied to problem solving in mathematics and participatory design as applied to the Personal Inquiry (PI) project.

Case Study 1: the socio-cultural approach-the PEARL project

This example illustrates the benefit of taking a socio-cultural approach to consider technologically mediated practical work in science.

Socio-cultural views of learning have become prominent in recent years, emphasizing the importance of the individual and social nature of learning. Some have emphasized the importance of the priority given in this view to the ' *evolving bonds between the individual and others ... (which) makes salient the dialectic nature of the learning interaction*' (Sfard, p.6). Issroff and Scanlon (2002) have described how they have used Activity Theory as one of the key theories in use in this area. Activity Theory which builds on the work of Vygotsky (1978, 1986) facilitates the consideration of interaction in social contexts - a good starting point for studying contextually embedded practice. Kuutti (1996) describes the theory as *'a philosophical and cross-disciplinary framework for studying different forms of human practices as development processes, with both individual and social levels interlinked at the same time.'* (p. 25). Activity Theory is a way of considering learning using three key building blocks involving a subject (the learner), an object (the task or activity) and tool (mediating artifacts). The relationship between the subject and the object of an activity is mediated by a tool which can be either a material object or a tool for thinking. In this theory, the basic unit of analysis, the activity, involves human action but expanded in such a way as to include meaningful context. Engström (1987) further extended this and introduced the idea of Activity Systems to cope with the relations between an individual and his or her environment in an activity. The key premise is that human behaviour is situated within a social context which influences actions. The meanings of actions are mediated by the rules of their community and the division of labour within the community which influences the ways in which people behave. So, Activity Systems contain an additional main component - the community. This leads to a more complex web of interrelationships being considered including subject-community and community-object relationships. In this way, Activity Theory is extended to cope with the consideration of concepts such as context, situation and practice in relation to activities.

The particular example of technologically mediated practical work considered here to which this perspective has been applied is remotely accessible laboratory work in higher education in science. The rationale for including practical work in science instruction would seem to be beyond reproach (see e.g. Hodson, 1998). Although evidence of the impact of practical work on students' learning is at best mixed it retains a key place in defining the domain and as a means of learning about the tools and practices of science. Strong arguments are advanced for the importance of including practical work in science courses. However students are, by the nature of educational institutions and their goals, somewhat removed from 'real' laboratories and their purposes. There is a need to alter the contexts, tasks, resources and techniques for formal laboratory learning to enhance its relevance and meaning, to orientate students away from answers and towards problem-solving, and to better represent authentic cultural practices. What happens to the uneasy situation occupied by science educators when practical work is promoted as an 'authentic' representation of working as a scientist (although perhaps it is not) and practical work is promoted as a good way of learning difficult science concepts (although perhaps it isn't) on the introduction of possibilities for access to remote laboratory work? The impact of introducing technologically mediated practical work needs to be considered as well as the purposes which it serves. One important recent influence on these considerations is the need to extend the access to practical work of students who could not physically take part in conventional laboratory settings.

The situation in which practical work is understood to fill a particular role in the education of science students has currently been impacted by the changes in technology, and in its purpose. We will consider these by looking at certain aspects of an EU funded project Practical Experimentation through Accessible Remote Learning Project (see Scanlon et al., 2002), which involved Project partners from the Open University; University of Dundee; University of Porto; Trinity College, Dublin (TCD) and a commercial robotics company Zenon, Greece. The overall aims of the project were to develop a flexible system enabling students to conduct real experiments remotely over the Internet and to research the pedagogic impact of this approach by validating its developments in different educational contexts in Higher Education. The project delivered four working remote experiments in four specific contexts: in manufacturing engineering (TCD), in electronic engineering (Porto) in cell biology (Dundee) and in foundation level science (OU).

At TCD a post-graduate computer vision experiment was implemented to teach principles used in automated visual inspection in manufacturing engineering using a remote-controlled custom-made jig. At Porto, a digital electronics lab was implemented for a range of design and test tasks. At Dundee, the experiment involved the identification of proteins in biological samples using an electron microscope, an example of extending access to expensive equipment in the teaching lab. At the OU a series of linked experiments involving a spectrometer and simple wet chemistry introduced students to basic concepts in physics and chemistry. This was an example of motorisation of non-electronic equipment, and use of robot for manual tasks. These instantiations depended on remote controlled lab apparatus, collaborative tools and an accessible user interface sub-system. Certain aspects of the work are reported in Colwell et al. (2002), Scanlon et al. (2004) and Cooper (2007).

Mixed methods of data collection were used in this case study. Before the implementation of the system, interviews and focus groups involving experienced teachers in higher education uncovered the nature of the role that such systems might fill. Specific interviews with designers of the four experiments chosen for implementation, uncovered the original objectives of the experiments and tracked the changes to the objectives which resulted from the demands of remote implementation. The technological validation involved the collection of a variety of specific data such as the speed of response to the experimental instructions. The educational evaluation involved the detailed video recording of students in interactions with the system for later review, interviewing and collecting questionnaire data from the students and tutors involved. Finally focus groups were run with interested academics on the potential of the approach for future use. Data was collected from around 60 participants.

The PEARL approach was found to be technically successful (although there were variations from a unified approach in each case study), feasible for a variety of experiment types, valued by students and it also sparked interest in academics in a range of science subject areas. The results of our studies demonstrated that students undertook meaningful remote practical work which achieved the key objectives of the experiments.

The socio-cultural approach

The experimental work conducted in the OU involved the reimplementation of a spectroscopy experiment which had been included in the residential component of the introductory science course. An environmental monitoring scenario was used to situate the experimental activity. The activities were designed to provide experience in using experimental apparatus, making and recording observations, analysing and interpreting data and working collaboratively with other students. One activity involved examining the spectral wavelengths of different light sources and the analysis of those wavelengths. We were able to compare the reactions of students who had performed the activities at residential school and those who used our remote experiment system (see Scanlon et al., 2003 for more details on this). Students in both groups were asked about completing the tasks in the allocated time, working with another student. At the residential school students felt they had enough time to carry out the task whilst the students using the remote system felt they needed more time because they needed to communicate with their partner about what to do. In relation to time pressure students in the residential school group reported the strong motivational impact of working alongside other groups with the enthusiastic support of a tutor who supervised the lab group. A remote tutor was supplied in the other group. One student who had done the remote experiment expressed a particular preference for the more relaxed situation of working just with one other person

> *I think when there's a whole group of people doing the same thing you feel more pressurised to go at their speed and what have you. It's just you and the person you're working with here isn't it*

The tutor's role was valued by both groups. However, as one student remarked:

> *I suppose if he was here in the room with you it'd be easier to talk to him. But having said that he's not looking over your shoulder and you don't feel so conspicuous so that is an advantage.*

In terms of an Activity Theory analysis the results from the OU experiment can be described as a shift in the division of labour. One interesting feature in relation to the division of labour was the views of the role played by the tutor in the remotely implemented experiment. The communication tools between students and between students and tutor were an important part of the overall experience. Students worked remotely but needed to be able to plan their work as part of a team and discuss results with others and with their tutors. The tutor was found to play a key role in facilitating the experience but there were conflicting views about the impact of the tutor being at a distance. On the one hand, there was a perception that the impact on motivation of the students was lessened. On the other hand, there was a perceived benefit of anonymity.

Case Study 2: observation of interactions - problem solving in mathematics

This set of examples illustrates the importance of methods for tracking and observing interactions. Observational methods have been widely used in the analysis of human computer action (see e.g. Neal, 1989, for an argument on the benefits of using video data and Foster, 1996, for the difficulties inherent in trying to capture such data by using observational notes only).

San Diego et al. (2006 a and b) developed and used innovative methods of tracking interaction. The research problem they were trying to solve was that of approaching the analysis of problem solving using multiple mathematical representations. For the past forty years researchers have used the method of think aloud protocols where learners are asked to verbalise their thoughts (see e.g. Ericsson and Simon, 1984). Researchers have analysed utterances using video records of activity, drawing inference about intent, together with conducting a later analysis of paper-based worksheets. There are obvious methodological problems related to working out temporal order of problem solving from paper based records. San Diego et al. aimed to use eye-tracking, tablet PC screen capture, digital video cameras and the latest video analysis tools to help with these methodological problems. In one example of such studies, San Diego et al. (2006 a and b), used these methods to study the effect of varying representational instantiations (static, dynamic, and interactive) on 18 learners' problem-solving strategies. The methods allowed the considerations of gazes, utterances and actions.

Digital approaches to capturing, coordinating and analysing what the learners said, did, saw, and wrote were adopted. These digital records were time-stamped so that they could be viewed and analysed as a coordinated whole. The techniques take advantage of the latest analysis software that facilitates synchronisation and encoding of multiple video feeds, eye gazes, handwriting, and verbal transcripts (Figure 1). Utterances and action were captured, using a digital camcorder, as an indication of thought processes that might be occurring; real-time writing and sketching were captured with a tablet PC, to identify additional representations being used; and gazes were captured using an unobtrusive eye-tracking device, so as to identify objects of attention (see e.g. Hansen, 1991). The (data) analysis software showed 'saccades', traces of the paths that the eye took across the screen, and 'fixations', records of where the eyes lingered on a part of the screen. By superimposing saccades and fixations on the screen activity, the researcher can see shifts of learners' attention. When participants' speech, gestures and writing were integrated into the analysis, it was possible to identify a range of strategies for using multiple representations.

Results show a variation in frequencies of strategies that the participants of the study employed for using multiple representations. This indicated that instantiations of multiple> representations influence learners' strategies (see San Diego, 2008).

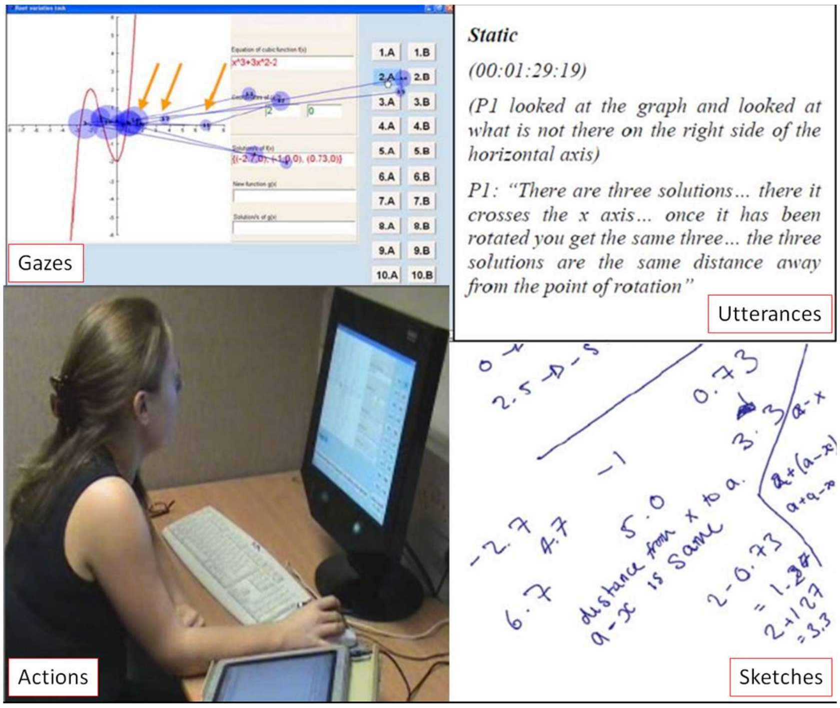

Figure 1 Examples of action, writing, screen and gaze

The video shown in the attached link illustrated the data collection and analysis strategy. http://www.youtube.com/watch?v=zVs_o8P8FDk

We can observe that capturing mouse screen and keyboard activity automatically is feasible. One drawback of capturing writing, utterances, actions, and gazes in such detail and volume, results in a huge amount of data. Many different programs are available to help with management and analysis of this data but there will still be methodological questions of the principles for selectivity. Cox (forthcoming) provides a discussion of the potential of technology enhanced research methods.

Sometimes educational technologists retreat from the mass of data that technology allows them to collect. There are certainly issues if data is collected simply because it is possible to do so. However in cases such as that described above the development of key technologies to capture data made possible an analysis of the impact of learning design on learner's problem solving capabilities.

Case study 3: participatory design - the Personal Inquiry project

This example illustrated the benefit of taking a participatory approach to design. In the Personal Inquiry (PI) project (http://www.pi-project.ac.uk/), we are designing technology enhanced instruction to help school students learn the skills of evidence-based inquiry, on topic themes of personal relevance in settings ranging from formal to informal. Students are supported to understand the inquiry learning process by being guided through a process of posing inquiry questions, gathering and assessing evidence and conducting experiments. We are developing a personal inquiry toolkit incorporating an innovative 'scripted personal inquiry learning' approach. This consists of a software application, called nQuire (available at http://www.nquire.org.uk together with the associated hardware support for conducting the inquiry which supports students in defining, organising and carrying out their inquiry, and resources their decision making and progression through the inquiry.

We are applying design based research methods to the design and development of our interventions and we have taken a socio-cultural approach to the analysis of our case studies. The design and evaluation of technology-based interventions in learning, requires the involvement of all stakeholders (pupils, teachers, technology designers). This is often referred to as a participatory design approach (see e.g. Namioka and Schuler, 1993). However, it is sometimes difficult to pin down exactly what this means in practice, while accepting the overall premise that users need to be actively engaged in the design process for using technology in learning to ensure that it meets their needs. The particular context has a bearing on the way in which participatory design is approached. So participatory design is not a homogenous approach but needs to be applied differently according to the context. In the personal inquiry project we needed to ensure that there is ongoing engagement by all stakeholders in the design and implementation of the interventions and that the impact of the interventions inform future developments engaging stakeholders further in reflection about the interventions. Our development process involved eight trials where we developed an instantiation of the toolkit in a particular school setting, ran the trial and used the findings to develop the toolkit for the next setting. The steps we followed included running workshops, focus groups and individual meetings with stakeholders to develop the design which was then incorporated into the trial, and organizing a set of stakeholder interviews or focus groups to reflect on the strength and weaknesses exposed. (Other approaches to participatory design are to be seen in e.g. the future technology workshops (Vavoula and Sharples, 2007)).

During the project we conducted trials with more than 400 students in two schools. Inquiries have been conducted on healthy eating, urban heat islands (twice), microclimates, the link between exercise and heart rate, food packaging, and the influence of noise pollution on bird feeding. The Figure below shows a screendump from the instantiation of nQuire (the Sustainability Investigator) used in an after school club setting called the Sustainability Squad. This club was organised by geography teachers for 30 children of ages from 12-15 years and focused on the sustainability of the food production cycle. The activities were chosen to link with the curriculum focus in the school. It ran for one hour a week. The activities planned for the club were developed in a series of participatory design meetings involving the researchers and the three organizing teachers. Students worked in small groups and selected a food product to investigate, researching the sustainability of the food in the club and at home. They designed inquiries into the packaging and storage of food, which then were carried out at home. Figure 2 shows the data collected as part of an inquiry about bananas. The students were advised on the feasibility of their planned inquiries and the measures they might take and equipment they might consider using. So the participatory design in this case was quite fluid. Activities and the software design to support it needed to be developed during the club in line with the direction taken by the young people's choices of what and how to investigate.

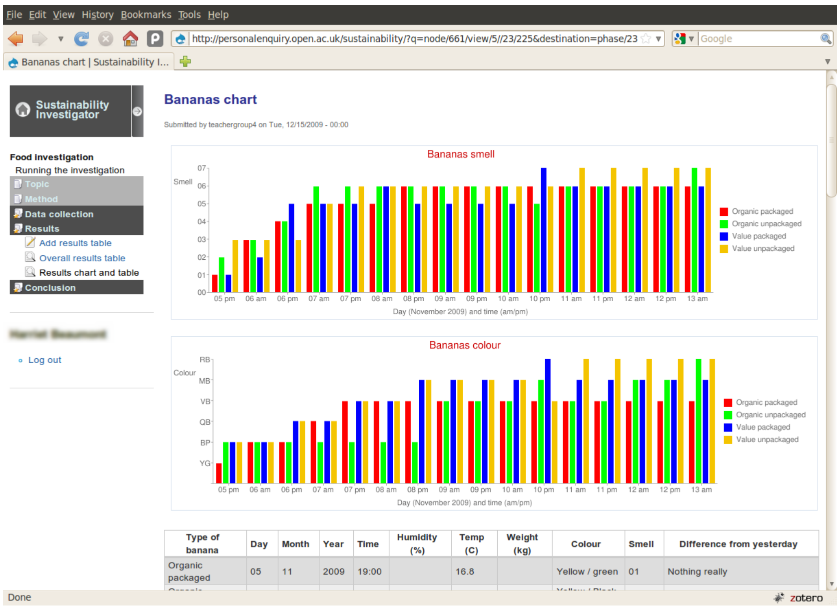

Figure 2: Data colected during an inquiry

Here is a link to a video on the PI project (also available via http://www.tlrp.org/tel)
http://www.youtube.com/watch?v=S62Fx14gRdw

Review

In terms of the contribution of educational technology to theory a number of commentators have reflected on the role of theory in educational technology. For example, Wilson (1997) has a helpful interpretation of how the development of authentic technologies requires collaboration by practitioners, technologists, scientists, craftspeople, and artists.

Reeves (2000) discusses the current requirement for educational research to be relevant and for requirements for research findings to be generalisable and usable. From this he constructs a set of requirements for socially responsible educational technology research.

Reiser (2001) has reflected on the history of instructional design and technology and echoes some previous work by Clark which attributed the relative lack of success to impoverished pedagogical models. Hokansen et al. (2008) reflect on the limited models of instructional design that have been adopted by instructional designers.

What is suggested in this paper is that the educational technologist needs to develop a set of principled working practices. The purpose of these accounts is to stimulate researchers and teachers to take on the roles of educational technologists in a principled manner and so develop working practices that contribute to a design science for education.

Conclusions

Working on a range of projects on the technology enhanced learning of science as an educational technologist has presented me with a number of opportunities to consider what works best. Conole et al. (2008) describes the key problem with developing the use of technologies in education as the gap between potential and actual practice. Educational technologists are best placed to work on this gap and hence the importance of developing and using new approaches to design and evaluation as a means of bridging this gap.

Above I have argued that educational technology is a design science and illustrated the way that such approaches can lead to improvements in learning designs. There is a danger however that however useful focussing on specific improvements to the design or manner in which a particular technology is deployed may be only part of the appropriate set of behaviours required of an educational technologist.

Hoadley (2002) points out that:

> *open-endedness proves to be an advantage in educational technology research because it means our designs are well suited to the types of open-ended questions our research addresses, such as, "How can we best use technology to support reasoning in thermodynamics?" (as compared to, "Are computers better than field trips?")*
>
> (p.1)

One surprising aspect of the practice of educational technology is the extent to which such work may be part of the development of theory. Although theoretical contributions have been part of the discourse of educational technology research for the past thirty years particularly those related to instructional design and the learning of science, the socio-cultural turn in educational theories has led to an understanding of the importance of studying complex educational settings involving technology. For some educators, theories provide a framework in which they can understand the complex interactions between learners, teachers and the resources they use, a world view or an orienting device, see e.g. Mercer (1995).

Contemporary theories of learning are offering a way in which socio-cultural understandings about the nature of learning can be examined for their impact on evaluation and the design of learning settings.

The three case studies in this paper offer three illustrations of key aspects of the useful tools developed as part of an educational technologist's toolkit.

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