

Classroom e-Science: Exposing the Work to Make it Work

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ABSTRACT

Engaging students in science learning can be challenging, and incorporating new forms of technology into science has been shown to provide creative learning experiences. However most technology enhanced learning and e-Science experiences to date have been designed and run by researchers. There is significant challenge in moving these experiences into the hands of teachers to become an everyday part of learning. One step forward is to understand better the work involved in making these learning experiences work. We present a retrospective analysis of two educational e-Science research projects, each involving access to and analysis of scientific data from remote and handheld sensors; collaboration; and reviewing shared data using advanced software tools. We identify key categories of work from the effort, resources and issues entailed in setting-up and running these experiences. We propose these categories can be used: to help plan other technology enhanced learning experiences, to be further tested and evolved in future research, and as a basis for an overall experience framework to capture the process- and context-related aspects in which these tasks are embedded. Ultimately, the goal is to develop tools and resources that will support categories of significant work, enabling full classroom integration of e-Science learning experiences.

Keywords

Technology integration, Cooperative/ collaborative learning, Identifying categories of work, Learning communities, Framework

Introduction

Recent advances in wireless and mobile technologies have the potential to transform learning, both in and beyond, the classroom by engaging students in innovative exploratory learning activities (Luchini et al., 2002; Price et al., 2003; Sharples et al., 2002). Experiences have been created across a wide range of subject-areas using varying configurations of mobile devices, sensors, and wireless networks, and demonstrate the transformative potential of these technologies. Examples include: finding inspiration for creative writing (Halloran et al., 2006); collaborating remotely in canal explorations (Sharples et al., 2002); exploring local habitats with sensors, personal digital assistants (PDAs) and walkie-talkies e.g. Ambient Wood (Rogers et al., 2004); interacting with remote experts (Pea et al., 1997); and using mobile games and location-based role play e.g., to explore wild animal survival strategies in Savannah (Facer et al., 2004).

Scientific enquiry has been a particular focus for many of these mobile learning experiences, where science learning experiences comprise a wide variety of activities within a session; for example, personal research, group discussion and debate, small group experiment planning, exploratory data gathering, data review and reflection, and collaborative discussion. 'Educational e-Science' has been coined to more specifically denote "the use of ICT in education, to enable local and remote communication and collaboration on scientific topics and with scientific data" (Woodgate & Stanton Fraser, 2005). Such experiences make use of, or simulate use of, the same global e-Science infrastructures that 'real scientists' use for scientific data access, data visualisation and global scientific collaboration (De Roure & Goble, submitted; Gabrielli et al., 2006; Steed, 2004). Although currently no single application or platform provides the range of functionality implied for this science work, the availability and use of mobile technologies (e.g. sensors, mobile phones, PDAs) and web 2.0 technologies (e.g. for blogging, communication) in both learning and science research indicates a promising area for real-world, technology enhanced science learning. Educational e-Science is seen as having particular potential to engage young people with meaningful science in new ways and to support the development of new forms of scientific enquiry skills (Woodgate & Stanton Fraser, 2005). This is timely in the UK, as in many other countries, as there is increasing concern about the low uptake of science by students at higher levels, negative perceptions of typical scientists' work and working environments (Scherz & Oren, 2006) and the lack of current opportunities for 'creative science' within schools that inspire and challenge future scientists (Nesta, 2005).

However, while the potential for such innovative learning experiences is widely acknowledged (Heath et al., 2005; Kravcik et al., 2004; Roschelle, 2003; Sims Parr et al., 2002), moving these activities into the classroom on a large scale is a significant jump. Most projects to date have been researcher-led and run as pilot studies rather than being systemically embedded into teaching practices. Even where teachers have been closely involved, many of the studies, our own included, are largely owned, designed and run by the researchers, not by teachers and tend to be run as innovative one-off experiences, or over a limited number of sessions. They also tend to involve a team of researchers bringing different multi-disciplinary strengths, e.g., technology, pedagogy, interaction design. The fact that we as researchers need to spend some months planning and developing tools and setting up experiences points to the gap between what is potentially invaluable as a learning experience for children and what is practically deployable in repeatable, everyday ways. For example, McFarlane et al. (2007) have described the implementation of mobile learning projects as “logistically challenging”. Teachers work in highly time pressured environments and, in the main, do not have the time, skills or resources to experiment. They need to deliver learning experiences that integrate well both with the curriculum and the pragmatics of their busy daily school life and environments with limited access to time, resources and money.

The key question then is: how do we move from innovative researcher-led learning experiences to ‘everyday’ teacher-led learning experiences in the classroom? A first step in answering this question is to develop a systematic understanding of what is currently required to deliver these researcher-led innovative learning experiences. What is the work to make them work? If we can understand the effort required, along with the skills and resources that support this effort, we can start to think about how best to support the transition into the hands of the teachers and into everyday teaching practice.

To this end, we reflect on our experiences with two related environmental e-Science projects conducted with secondary school students over a nine month period. Our focus here is not on the learning related outcomes of those projects, which are available elsewhere (Smith et al., 2005; Smith et al., 2006; Stanton Fraser et al., 2005; Underwood et al., 2004) but rather on the work we needed to do to facilitate the setting up and running of educational technology enhanced experiences in authentic university and school contexts. From a retrospective analysis of project archives, including email communications and internal documents, combined with the participant-observer accounts of the researchers involved, we have identified a set of generic categories of ‘hidden work’.

The contribution from this work is twofold: the presentation of the categories themselves starts to articulate a vocabulary for anticipating as well as reporting on hidden work. Further, these categories, and the understandings and lessons learnt about the work entailed in them, have been used to develop an experience planning framework. We suggest this framework can be used in a variety of ways: to support and guide the planning and conduct of future technology enhanced learning projects; and to support the a priori collection of data about hidden work to further validate and evolve our categories. In revealing the variety of work required to make the sessions work we can also identify the support services that might be needed to enable regular delivery of similar learning experiences in real-world contexts. While these categories have been produced from a study of educational e-Science experiences, we suggest they will have more general applicability for the design of technology enhanced learning experiences.

Related work

The notion of understanding ‘the work to make things work’ is not new (Bowers, 1994) but because it tends to represent the ‘boring’ work, e.g., around the staging of an experience or in support of the more visible work, it is often overlooked in discussions.

A number of different concepts have emerged that capture some sense of the ‘double level’ nature of action, the two levels mostly reflecting a sense of the *core work activity*, here the science learning experience, and the *work about the work*. One commonly used distinction is between *formal and informal* work activities (Perin, 1991; Rodden & Schmidt, 1994). The formal work activities concern the visible performance of the work. The informal activities are more to do with the conversations about the work, the casual ad hoc interactions and activities often rendered invisible in formal accounts of work (Star, 1991) the ‘invisible work’ (Star & Strauss, 1999) or ‘hidden work’ (Schwarz et al., 1999). *Articulation work* (Strauss, 1988) is a concept closely associated with this invisible ‘work about the work’, ensuring that individual activities help achieve some collective goal: “. . . individual yet interdependent activities must be coordinated, scheduled, aligned, meshed, integrated, etc. — in short: articulated.

That is, the orderly accomplishment of cooperative work requires what has been termed *articulation work*.” (Schmidt & Simone, 1996, p. 158).

This ‘hidden work’ is critically important for the practical achievement of experiences on the ground – it is the work to make them work. The failure to take into account ‘hidden work’ has resulted in the development of inadequate technologies (Halloran et al., 2002) that often do not match work processes and contexts, to the point where they are either not used or people have to engage in elaborate work-arounds to enable them to do their job (Bowers et al., 1995). In the world of teaching, where concerns about the time and effort required for lesson-preparation are high, ‘hidden work’ becomes all the more important to understand if we are to move the design and delivery of e-Science experiences into the hands of the teachers. Understanding the broader delivery context of this work is critical and has been identified as a factor in the success or failure of technology in education (e.g. Wood et al., 1999).

To date, the focus of reporting of exploratory learning experiences has largely been on the visible work, i.e., the interactions during the experience. This is understandable given the exploratory nature of these experiences where researchers are looking to make the case for how new technologies can enhance the learning experience and so focus on the learner interactions. It may also be the case that people are reticent to specify the actual human input that was required to make the experience a success (Facer et al., 2004; Rogers et al., 2004). Either way, there is little to be gleaned from reports on educational e-Science experiences in particular, and technology enhanced learning experiences in general, about exactly what is required to put them to work, e.g. in the more organisational areas of effort required such as identifying and bringing together suitable participants; identifying, acquiring, troubleshooting and testing equipment, etc. Where there are such accounts, they are often comparative accounts of moving technologies outdoors. Harris et al. (2004), for example, report on the issues they encountered when creating an exploratory learning experience in a woodland area using wireless technologies and compare this to running a similar experience indoors. Azuma (1999) similarly reports the technology challenges faced when moving an augmented reality system outdoors. To our knowledge there has been little focus on, nor systematic accounts of, the human effort and resources involved in new learning activities. There has been a more recent effort to understand the longitudinal effort of embedding new tangible technologies into the classroom where Parkes et al. (2008) have reported on the design and pedagogical issues in using their Topobo system in different classrooms, identifying support for educators, such as through examples, as a key factor.

Now that the case for the learning-outcome value of innovative technologies is being made, it seems timely to turn attention to the next level of exploration and to understand the effort involved in delivering this value from the perspective of the designers/educators. We go on here to re-visit two educational e-Science projects we have been involved in as researchers and attempt to provide a post-hoc account of the nature and amount of ‘hidden work’ involved in delivering these projects. Whilst not a focus on teacher effort per se, it will start to point to the types of work they will need to undertake to deliver creative science learning experiences for learners. In the following section we go on to introduce these projects and explain the methodology we used to derive the categories of ‘work to put e-Science to work’.

Methodology

Context of case study: two e-Science projects

The two projects that form the focus of this paper are called ‘SENSE’ and ‘Public Understanding for Environmental e-Science’. Over a nine-month period we ran a total of 21 e-Science learning sessions with 13-16 year old science students and their teachers. There were two different types of sessions:

- A series of one-off sessions for ‘Gifted and Talented’ (G&T) students who participated in a university setting around themes of Antarctic remote sensing and urban carbon monoxide (CO) monitoring (Public Understanding project);
- A series of inter-connected sessions across the complete scientific enquiry process around urban CO monitoring for GCSE (in the UK, GCSE is the General Certificate of Secondary Education undertaken by all 16 year old students) pupils in the school context (SENSE project).

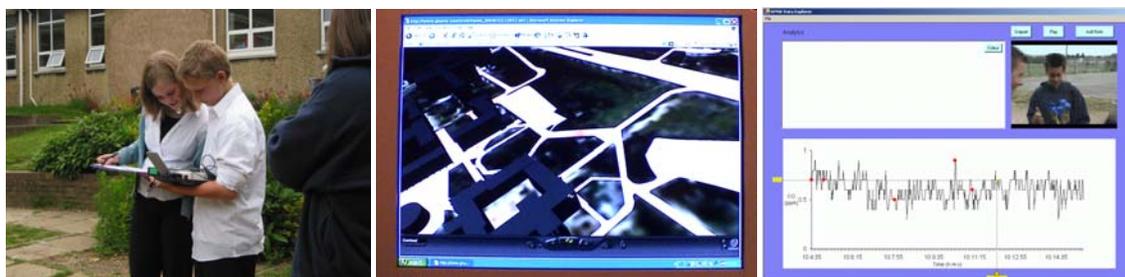


Figure 1 - Learners gather and analyse carbon monoxide data in their locality

The projects were largely researcher-led, however we engaged the teachers in the iterative design of the experiences as part of a user-centred approach. The teachers were also involved as observers, with one teacher additionally taking on a more direct role in the Public Understanding sessions. Both projects were designed to include e-Science related activities that challenged students to:

1. think about the work of real scientists in the domain of air pollution;
2. process and interpret data collected by others in remote locations;
3. engage in hands-on, practical data collection, processing, assimilation, and reflection to try out their own pollution hypotheses in their local environment;
4. communicate with real scientists in remote locations through known and readily available communication methods.

Both projects used environmental e-Science research supported by the Equator research group's e-Science theme ("Equator Research Group, e-Science Theme," 2008) to source devices, science experts and material for use in the sessions. Activities to contextualise the science domain included a webquest of challenges to create explanations for unfamiliar images relating to the air pollution topic. For the hands-on component (part 3 above) students worked in a group of four, accompanied by a facilitator, to capture data about their own outdoor environment (Figure 1). Each was given a role to play e.g., video recorder, CO and global positioning system (GPS) tracker, or route planner and note taker. In the process of collecting their data, they engaged in group decisions and accounts of their activities to reflect on readings on-the-fly. Once back in the classroom, we transferred their data from the handheld technology to a desk-top machine to combine and re-visualise the collected data sources and allow reflection on the experience as a whole. Additional activities included 'live' chats with a remote scientist (both projects) and collaboration with a remote classroom (SENSE only). For further detail see Smith et al. (2007).

Participants

Participants involved in each project were recruited on a voluntary basis from local schools in Brighton, UK. No participants were involved in both projects. A summary of their ages and session involvement is shown in Table 1.

Table 1 - Summary of participants and sessions

Session Type	Total Number of Learners	Number of Sessions and Duration	Age (yrs)	Participants per Session	Subject Matter
Public Understanding for Science [university campus]	43	5 sessions: Same 3 hour session repeated with different participants	14-16	8-14	Part 1 of session Antarctic remote sensing Part 2 of session urban CO monitoring
SENSE [school campus]	19	8 sessions: As series of 50 minute sessions involving same participants	13-14	8 and 11	Urban CO monitoring in school locality

Data Sources

In this paper we focus on questions around the production of innovative learning experiences. Here we systematically identify and analyse the ‘hidden work’ that went into these projects. As our initial project focus was on the learning sessions themselves and exploring the nature of children’s and teacher’s interaction with ‘novel’ technologies, we did not set up a priori data collection methods to capture the level and type of effort. However, a large amount of information relating to the activity surrounding our e-Science sessions was nonetheless captured. This data exists in the form of emails (of the order 520+); instant messaging (IM) logs (of the order 65+ messages); electronic and paper calendars, schedule documents, meeting notes, to-do lists (of the order 120+ documents); session videos (of the order 30 hours) and other paper and electronic documents collected over the 17 month period, in addition to our memories.

Data Analysis

Somewhat like archaeologists, we searched for, identified and interpreted relevant data in the archives of the two key researchers who were employed to work on the projects. We undertook a retrospective analysis of their project-related documents and communication trails, combined with reflective accounts of all the researchers involved in the process as participant observers.

Both of the researchers collated all available *documentation* relating to each of these projects. In the case of electronic documents, the search was greatly facilitated by recent innovations in desktop and email search applications (e.g. "Apple Spotlight," 2008; "Google Desktop Search," 2008). These applications helped recover documents containing keywords relating to these projects, created around the time periods these projects were happening and authored by parties involved. Having identified the relevant documentation we summarised the work they mentioned and any specific resources and skills referred to or implied. Often such documents prompted recall of related work that was not explicitly documented; if this related work was validated through discussion then we included this remembered work in our inventory. We excluded work that did not directly contribute to the delivery of the educational experiences, for example, the effort involved in supporting our own research goals e.g., the set-up and analysis of video and audio recordings for research purposes, discussions about methodology, etc.

This documentation was then collated as a single inventory of work across key researchers and the two projects. As a retrospective account, we do not claim it to be complete or comprehensive. We did not, for example, include the work of the project leaders as much of their involvement was around the shaping of the research itself rather than the delivery of the experience ‘on the ground’. Nor do we have access to data from others involved in the project beyond the time we spent with them, such as the teachers and ICT support officers at our schools, or the scientists, researchers and teachers at other sites that we used for remote collaboration sessions. As such, data that we present here, at least in the quantification of the work, should be read as indicative, and it could also be read as conservative.

The analytical approach then was similar to the methods of Grounded Theory (Glaser & Strauss, 1967) and using affinity diagramming techniques (Beyer & Holtzblatt, 1998) where we looked for emergent patterns in the data and created higher levels of categories to account for these patterns. As a first pass, we analysed all the items to identify key issues they indicated, for example, items that pointed to troubles getting the technologies to work. We also clustered and categorised related items in terms of achieving a specific e-Science session objective. For example, it became clear that one of the key objectives was getting an expert to participate remotely in a particular session and that various items of work were related to this e.g., making contact with that expert, sharing expectations about what would happen in the session, establishing availability, checking available technology for communication. We undertook a further level of category clustering and identified six major categories that worked across both projects. We stopped when these categories (elaborated in Table 3), appeared to be at a useful level of granularity and satisfactorily covered all the kinds of work performed in detail.

For each major category of work we will detail the main issues experienced and provide examples of the kind of work included, the participants, skills and other resources involved. In order to reveal the amount of collaboration required by some categories of work we also indicate the number of related communications (email, chat sessions, telephone conversations, etc.) as a summary table. Where individual communication items refer to several different kinds of work they are counted in all relevant categories. For example, an IM log that reports problems with a device

and arranges return of the device counts once in Equipment Management and once in Technology Testing, Breakdowns, Fixes. We also provide an estimate (indicated by +/-) for the amount of effort in person hours we believe we expended for each category and as suggested by the times of the documentation and our subsequent analysis of and reflection on them. Contributing to this, and to provide a realistic estimate of the work involved in an average communication such as an email or a phone conversation, we agreed an estimate time for each where length of time was not specified in the document (Table 2). This allowed us to develop a consistent assessment of the time requirement for the work involved in the two projects by totalling the communication, preparation and document work in each category, preserving the similarities and differences that occurred depending on the context of use (university or school); and the consequential level of control over ICT equipment. While inexact, these time estimations still provide a reasonable indicator of the relative amounts of effort expended in each category.

Table 2 - Time estimate of communication method used across projects

Communication method	Time estimate
Email construction	10 minutes
Face-to-face meeting	45 minutes
Instant message chat	15 minutes
Phone conversation	10 minutes

During the analysis for each work category we also subdivided specific work items by temporal order, according to whether they occurred prior to, during or after the sessions. There is a clear logical distinction between preparatory work required before a session can happen e.g., plan session, obtain, charge and test equipment; work during sessions e.g., facilitate learning, fix technology breakdowns; and follow-on work required after some sessions e.g., process data, evaluate. For the SENSE project, work required after sessions is particularly relevant as each session followed on from the previous one and frequently made use of its outputs. It was consequently important to maintain cross-session continuity. A further reason for subdividing our description of work in each category by temporal occurrence related to the practicalities of carrying out such work; there are potentially very different pressures and resource contexts before, during and after sessions e.g., in the classroom, at home, in the staffroom. Non-teaching work required during a session is likely very much more costly for a teacher than pre or post-session work as, ideally, as much as possible of her effort during a session should be dedicated to facilitating learning. Prior to or after a session different resources are available and work done is under less pressure, not in view of learners and in many cases might be taken on by someone other than the teacher e.g., ICT support technicians. The temporal order of activities will also be represented in the tables for each of the categories we discuss below.

Results: Categories of Hidden Work

In the following discussions we will elaborate on the definition of each category and the sub-categories of work that these entailed together with a discussion of the issues that we identified in each. To contextualise this discussion, we first present a summary of the resources used in both projects (Figure 2), and a summary of the complete set of work categories across both projects (Table 3). Figure 2 shows the relationships between projects, people and resources, and whilst many resources were used by both projects, not *all* example resources within each category were used by both projects. For example, the SENSE project collaborated with one remote scientist and the G&T project collaborated with five.

Table 3 as a summary of the complete set of categories, shows the relevant distribution of effort across the categories and illustrates that locating and/or creating contextualising material and testing, breakdown and fixes together constitute 72% of the effort.

We now go on to discuss each category and sub-category in turn, drawing in reference to the people and resources as relevant.

Match Learning Requirements

'Match learning requirements' is concerned with ensuring that the design of the sessions was in line with the learning needs of the students and was supported by the teachers. There were three major sub-categories here: relationship

building and collaborating with teachers; establishing the main goals of the sessions; and planning and refining the activity sessions. Table 4 shows how the resource allocation differed over both projects, for example SENSE researchers visited an after-school club to trial activities. Post-session feedback was particularly important for the G&T sessions since they were refined and repeated over time. We describe the main issues arising from these aspects of the projects in the following section.

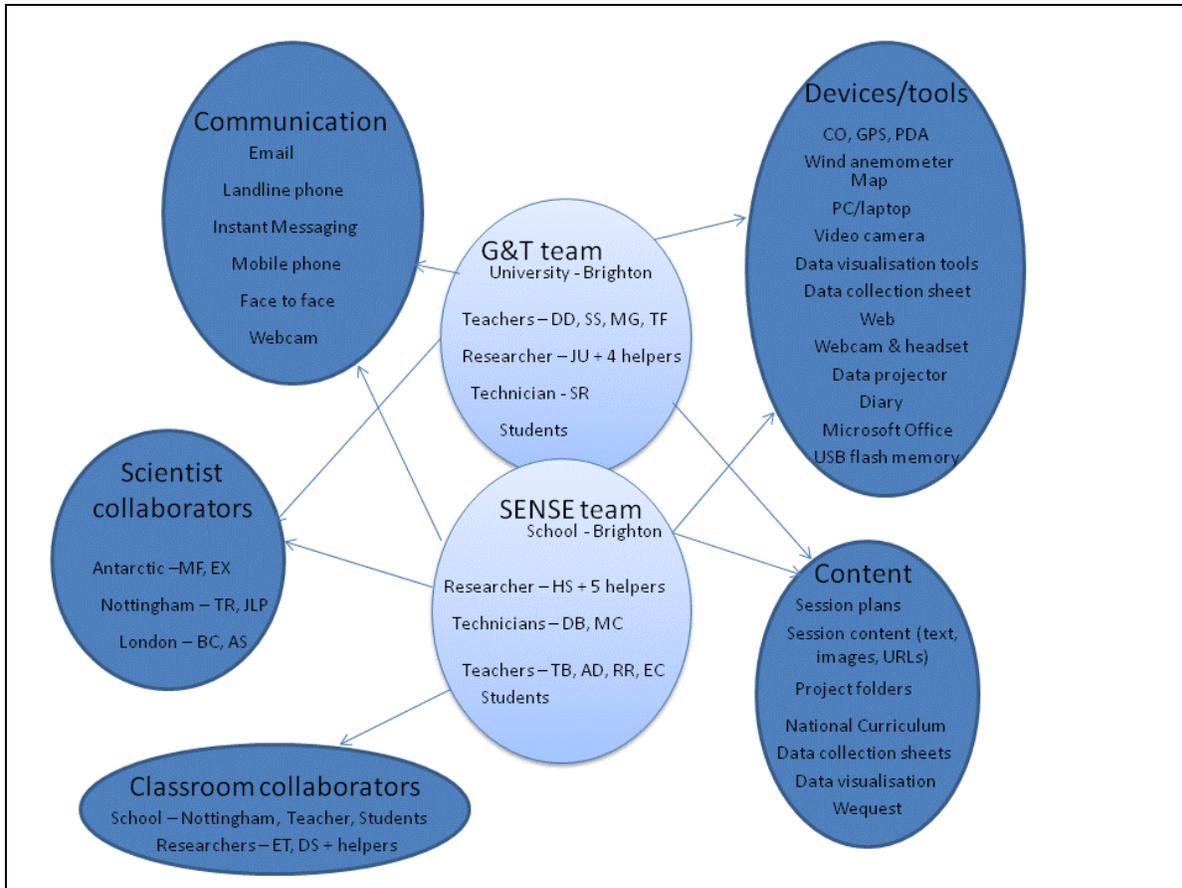


Figure 2 - Summary resource diagram showing people and resources used by each project

Relationship building and collaborating with teachers: Collaboration with science teachers at early stages was required to identify a fit with science curriculum topics, learning objectives and the learners’ needs and abilities. It was also required to build understanding and trust between researchers and the people responsible for the learners involved. The work here required knowledge of the e-Science research projects and an expertise in education. We relied heavily on our participants’ access to and familiarity with email and web browsing although in our experience teachers frequently have problems with school email, and messages are quite often reported as not having been received. We also had problems trying to schedule mutually suitable times to meet with the teachers because of timetable and school activity constraints.

*In Underwood et al. (2008) we combined scientist and classroom collaboration in the discussions under this category. Here we keep the detail of these different types of collaboration (remote scientist, remote classroom) as these have implications for how one might want to include them or trade-off relative effort in the design of a new experience. Presenting it in this way preserves the detail to enable more informed design decisions.

Establishing the main goals of the sessions: Substantial communication was required to establish a clear understanding of the teachers’ objectives for these sessions, and for the teachers’ an understanding of the e-Science research projects and the opportunities for learning these afforded. Our projects’ session goals were to match curriculum requirements for hands-on data gathering, data review and ability to re-visit and improve on data gathering (SENSE) and engaging and stretching able learners throughout the session and prompting them to reflect

on the nature of e-Science and new technologies in the service of science (G&T). The researchers were able to identify relevant areas of the science National Curriculum that would point to the necessary learning outcomes and skills, but it was the teachers who were able to advise on how to apply goals to the sessions we wanted to create.

Table 3 – Summary of hidden work categories

Work category	Sub-categories	Total time estimate
Match learning requirements	- Relationship building and collaborating with teachers - Establishing the main goals of the sessions - Planning and refining the activity sessions	+/- 16.5 person hours G&T +/- 20 person hours SENSE 8% of total
Locate and/or create contextualising materials	- Preparation of introductory materials - Sharing resources - Tracking session progress	+/- 105 person hours G&T +/- 96.5 person hours SENSE 47% of total
Co-ordinate collaboration and communication*	With science experts: - Initiating contact with relevant scientists - Scheduling sessions with a scientist - Managing and maintaining the scientist relationship With collaborating classroom: - Scheduling sessions with the remote classroom - Managing and maintaining the classroom relationship	+/- 13.5 person hours G&T +/- 9 person hours SENSE +/- 3 person hours SENSE only 6% of total
Data manipulation	- Transfer CO and GPS data - Process data to apply it to a visualisation tool - Make data available for others to view	+/- 4.5 person hours G&T +/- 36.5 person hours SENSE 9% of total
Equipment management	- Equipment sourcing and scheduling - Determining needs of the equipment - Ensuring good health of equipment	+/- 10 person hours G&T +/- 12 person hours SENSE both figures exclude travel 5% of total
Testing, breakdowns and fixes	- Installing and testing software on PCs and laptops to be used in sessions - Requesting support from school ICT technicians - Troubleshooting in-session and on-the-fly	+/- 33.5 person hours G&T +/- 72.5 person hours SENSE 25% of total
	Total time for G&T Total time for SENSE	+/- 183 person hours +/- 249.5 person hours

Table 4 - Resource summary for match learning requirements

Example types of work and when they occurred relative to the session	Participants involved	Resources involved	No. of communications	Total time estimate per project
Pre: Face-to-face meetings, email exchanges to identify learning requirements; curriculum goals. Design activities for low-technology devices and visualisation tools. Teacher time to provide feedback on plans. School planning and timetabling discussions.	7 teachers 5 researchers, two of whom were present at all sessions and two more provided behind the scenes support.	Email Planning documents Device plans National Curriculum information Device prototypes Research project information Prototype lesson materials	56 emails 13 face-to-face meetings 5 phone calls	+/- 16.5 person hours for G&T +/- 20 person hours for SENSE
In: “Teaching work” modifying session structure and pace to adjust to learner needs.	1 after-school science club			
Post: Face-to-face meetings and email for post session feedback, improvements.				

Planning and refining the activity sessions: Part of the work involved in creating a cohesive series of SENSE activities included trying out session formats with an informal after-school science club. Examples included using a windsock and ribbons to determine wind direction and derive where the CO monitor should be located to record CO readings. This was an iterative process involving presentation of the e-Science research and devices, conversation and reflection around evolving session plans and prototype materials. For both projects, session teachers were also particularly keen to include activities they felt would be motivating such as communicating with ‘real’ scientists, and hands-on use of advanced technology. The need to keep individual learners engaged and challenged throughout sessions meant that some work was done within sessions by adjusting plans, varying pace, or pushing faster working learners. Between sessions teachers and researchers reflected on what had worked and what had not worked and adjustments were made to materials and plans for future sessions.

Locate and/or Create Contextualising Materials

‘Locate and/or create contextualising materials’ is about the development of the core learning content of the science sessions. Creating these materials constituted by far the largest category of time (47%) and resources; it required the researchers’ time and skills to design and create the materials, and evaluative feedback from teachers and input from domain experts. The resource summary is given in Table 5 and shows the range of applications used to create resources, particularly for the interactive webquest. The repeat nature of the G&T sessions and the development series of the SENSE sessions both brought with them three main challenges as described in the following section.

Table 5 - Resource summary for locate and/or create contextualising materials

Example types of work and when they occurred relative to the session	Participants involved	Resources involved	No. of communications	Total time estimate per project
<p>Pre: Searches and requests for images and information, and context materials from a scientific data collection project. Class lesson preparation Develop and test Webquest and paper-based materials. Website development to report class activity. Organising within school timetable.</p> <p>Post: Implementation of suggested changes.</p>	<p>4 teachers 8 researchers, 6 of whom provided occasional session or material support 5 scientists provided occasional expert advice 1 class group</p>	<p>Google Macromedia Flash Dreamweaver Webquest guidelines Email Telephone Face to face meetings MSN chat Word documents Lesson plans Trial plans Paper folders Powerpoint</p>	<p>130+ emails 6 IM chats 12 phone calls 3 face to face meetings</p>	<p>+/- 105 person hours for G&T +/- 96.5 person hours for SENSE</p>

Preparation of introductory materials: As an example, an interactive ‘webquest’ (see <http://webquest.sdsu.edu/designsteps/index.html>) was developed to challenge students and structure their research during the one-off sessions. Resource production required specific expertise e.g., HTML, Flash and web publishing, online resource search skills and learning how to structure webquests. Production of these resources was iterative, they were evaluated by teachers and adjusted in line with the feedback received.

Sharing resources: Development of a CO familiarisation activity required search for and identification of suitable information websites as well as preparation of the students’ worksheets themselves. However, the outcomes of some of this work e.g., good CO information websites, were shared and reused across the SENSE and G&T sessions saving some effort in later phases.

Tracking session progress: Considerable effort was placed in ensuring the two collaborating classrooms conducted similar projects, at similar times, using related equipment to facilitate understanding by each group of the other group’s data, environmental context and equipment. To help maintain a coherent session structure across the series of SENSE sessions, a project-based website tracked progress through the 8 sessions. This helped the researchers in the collaborating classrooms maintain contact with progress and for students to review their activities. Continuity

also had to be maintained to match correct data to the groups who had collected it, aided by the use of consistent groups and of physical project folders in which the groups kept their work.

Co-ordinate Collaboration and Communication

‘Coordinate collaboration and communication’ was the work required to manage the relationships with the external collaborators, a core theme for e-Science methods. Here we have dealt with two similar but distinct areas of work to indicate how the required time and skills varied depending on whom these collaborators were: science experts or classroom collaborators. Two categories they both shared were initiating contact with relevant parties and maintaining the relationships.

Co-ordinating with Science Experts

Collaborating with real scientists working on similar projects to those that the students themselves were working on – here Antarctic and pollution scientists – was a potentially highly-engaging aspect of the e-Science sessions. As such, we placed a high level of importance on arranging, managing and keeping the contact between the students and remote scientists. The effort here related to scheduling time, relationship building and expectation setting with the scientists. The summary in Table 6 highlights the higher number of scientists participating in the G&T sessions (5) compared to 1 for the SENSE groups.

Table 6 - Resource summary for co-ordinating with science experts

Example types of work and when they occurred relative to the session	Participants involved	Resources involved	No. of communications	Total time estimate per project
<p>Pre: Introductions and requests for collaboration. Scheduling collaboration opportunities. Requesting and providing information. Asking difficult questions raised.</p> <p>Post: Thanking and providing feedback on participation. Resolving issues. Re-scheduling sessions.</p>	2 researchers 6 scientists: from Antarctic - 1 environmental scientist, 1 engineer; from UK - 2 environmental scientists, 1 computer scientist, 1 pollution scientist	Email MSN messenger Telephone Diary Planning spreadsheet Data photos Scientist’s slide-show Scientist’s website	70 emails, more than 30 chat sessions, 7 phone calls	+/- 13.5 person hours for G&T +/- 9 person hours for SENSE

Initiating contact with relevant scientists: We were able to identify and contact suitable science experts to engage in the sessions through our close involvement in the Equator e-Science research projects. From colleagues’ recommendations, scientists were approached for their interest in our projects. Part of this work involved informally establishing that each of the scientists were known to other researchers that we knew, and checking they were sufficiently reputable to be involved in direct communication with young students.

We ascertained with each scientist what their session involvement would be beforehand to manage their expectations and prepare them for any foreseeable problems, e.g. technology breakdown. Contingency plans were mentioned at this stage, and in some cases we ‘rehearsed’ a simulated learner chat with our scientists in the chat environment to prepare for the kinds of questions we expected the students might ask. We needed to ‘present’ our science experts to learners and teachers, and some work and communication was required to obtain photos and short texts describing who the experts were, where they were located and what they did.

Scheduling sessions with a scientist: School timetables were our main time constraint on both projects since the students were only available at specific times. In contrast, our scientists had varying degrees of flexibility in their schedule and it was important that we had a variety of scientists to choose from, should one not be available. Establishing time slots for live chat between scientists and children required several emails; sometimes working across time zones. Antarctic times were particularly challenging and on one occasion failing to take into account a move to Summer Time in one zone but not the other resulted in a missed chat session. It was rare to have a back-up

scientist in-case the first was not available, but on this occasion we worked more ‘chat’ between expectant students and another remote scientist who was scheduled in.

Managing and maintaining the scientist relationship: In addition to the setting-up of scientist contact prior to live chat sessions between experts and learners, we needed to communicate to experts whether they were in a ‘private’ chat visible only to the researchers and teachers or whether the chat was currently displayed (via a data projector) and visible to all learners. This ensured comments not intended for learners or inappropriate language was not publicly visible.

Post-session, we thanked the scientists, and explained any technology failures or disruptions that would not have been detectable through the communication channel. At one school we eventually resorted to a one-to-one telephone instead of the IM software we had previously successfully used at our university, because such software was blocked on the school network and the conference phone we brought into school was incompatible with the school phone system. Such ICT problems are frustrating and waste time both at the school and the remote scientist’s end with apologies and updates on changes to the schedule and technology. On the missed slot due to Summer Time changes, additional communication was required post-session to resolve why the slot had been missed and to ‘patch up’ relations.

Co-ordinating with Collaborating Classroom

In the SENSE project, collaboration also involved a remote classroom and was set-up to provide two classes of students, unknown to each other in advance, an opportunity to communicate about the science project they had both been conducting. The major work areas are summarised in Table 7 and described below. Technology co-ordination was required for data file sharing to ensure researchers at both locations could download each other’s data prior to the live chat, and this is detailed in the ‘Data manipulation’ section.

Table 7 - Resource summary for co-ordination and collaboration with collaborating classroom

Example types of work and when they occurred relative to the session	Participants involved	Resources involved	No. of communications	Total time estimate per project
Pre: Discussing scheduling. Planning in-class phone chat.	3 researchers	Email Telephone	3 emails 1 phone call	+/- 3 person hours for SENSE
Post: Thanking remote classroom. Providing feedback.	2 school classrooms	Diary schedule		

Scheduling sessions with the remote classroom: Scheduling and planning around school timetables with the classroom teachers was performed via the researchers, who were already communicating regularly. The scheduling of the live communication session was eased by a more flexible time-table in one (primary) school to allow this session to work. Had this not been the case a more complicated planning stage would have been necessary time-table changes needed to co-ordinate the session.

Managing and maintaining the classroom relationship: In contrast to setting a collaboration session up from the beginning, there was less need here to establish detailed expectations to the same degree as had been required for the scientists’ contact. We were able to capitalise on the researchers being in contact and previously agreeing on project requirements and timescales during the school-term as part of the research activity. However, the pitch of the session did need to be managed since our classrooms were not the same age group: one was a top-primary group (10-11 years), the other being a GCSE group (14-15 years).

Data Manipulation

A main focus of e-Science methods is the ability to share, visualise and reflect on data rapidly. ‘Data manipulation’ includes the work required to integrate, collate and visualise the information gathered by the students on their different devices. In our exploratory sessions, there were no simple ways to join-up the technologies so that each piece of hardware could automatically transfer data to a central hub or data store and be immediately available to our

collaborators. We therefore had to manually transfer and edit the data to allow, for example, visualisation of a remote data set (Antarctic lake ice depth data), analysis of the CO data against initial expectations, and sharing the data with others. The large difference in this work between the projects is summarised in Table 8 and reflects the work involved in maintaining continuity for each small group to access their data in subsequent SENSE sessions.

Table 8 - Resource summary for data manipulation

Example types of work and when they occurred relative to the session	Participants involved	Resources involved	No. of communications	Total time estimate per project
<p>Pre: Learn how to transfer data from sensor device, and into visualisation tools Connectivity with class and scientist</p> <p>In: Transfer data: from mobile sensor to PC, upload to web visualisation services. Download data from Antarctic device web data service, import into Excel.</p> <p>Post: Prepare data for collaborator sharing</p>	4 researchers Students involved in sessions.	Excel Web-based service interfaces Data transfer software Laptops Web site for private data sharing Emails, IM chats	56 emails 10 instant message chats	+/- 4.5 person hours for G&T +/- 36.5 person hours for SENSE

Transfer CO and GPS data: Data transfer between the mobile data-storage device and the PCs used back in the science lab was necessary for the visualisation activities to occur. Prior to the sessions we needed to learn how to navigate the PDAs with PCs, how and where the sensor data files were stored and how to transfer them to the PCs in the absence of a network.

Process data to apply it to visualisation tool: For our one-off sessions, once provided with their data on their own PC, the learners were able to upload data for processing and visualisation via a web-service and load and graph it with no need for non-teaching work by teacher or researchers. The data processing for the SENSE project needed to occur between sessions e.g. transfer of the collected data from PDAs to project laptops, the video recordings from tape to hard-disk, time-synchronise the video with collected data, and transfer to laptops for children to review in the data-analysis sessions. Students' data annotations were checked before being shared with the remote class students to ensure appropriate for viewing by other children.

Make data available for others to view: Sharing data happened within class groups for both projects, and across school classes on the SENSE project. Within class, the sharing of data via a USB memory drive was time consuming but meant we were easily able to provide every group with other groups' data should they have the opportunity to compare data. Across schools, a sample of data was made available on a private website (meaning the data's use could be protected) for download by the collaborating class prior to the live phone conference.

Table 9 - Resource summary for equipment management

Example types of work and when they occurred relative to the session	Participants involved	Resources involved	No. of communications	Total time estimate per project
<p>Pre: Schedule loan and collection of devices from 'owners' Order video tapes</p> <p>Post: Return to 'owners' Explain issues: broken sockets, problems, questions.</p>	4 teachers, 7 researchers, 2 device 'owners'	Mobile sensors (PDA + GPS + CO Sensor) Anemometers Low tech sensors	57 emails 6 chat sessions 8 phone calls	Excluding travel time: +/- 10 person hours for G&T +/- 12 person hours for SENSE

Equipment Management

'Equipment management' is concerned with the sourcing and loan of the equipment from research scientists. The technologies were fundamental to the success of our e-Science sessions since without them we would have struggled

to provide such an engaging hands-on e-Science experience. This work required no special skills but did require substantial communication, negotiation and organisation effort and relied heavily on our relationship with the equipment providers. The work involved here, summarised in Table 9, was fairly even across both projects.

Equipment sourcing and scheduling: We had relatively good access to the devices used in these sessions as a result of our research relationship with the device owners. We needed to communicate extensively to establish when they could be used, negotiate for pick-up and return dates, and how they would be transported between sites.

Determining needs of the equipment: The equipment was not accompanied by a ‘How to use’ handbook, and thus we became familiar with the equipment through establishing the requirements for the loaned devices, chargers, cables for data transfer, etc. and ensuring we had adequate access to all of these, in particular sufficient chargers.

Ensuring ‘good health’ of the equipment: Since we were very dependent on the equipment providers for continuing the projects it was imperative that the equipment was treated with respect and any problems reported when known - both by the researchers and equipment owners. This honesty was appreciated by both parties and kept the equipment at maximum productivity.

Testing, Breakdowns and Fixes

‘Testing, breakdowns and fixes’ is closely related to equipment maintenance and repair as well as more general infrastructure issues. This category of work required as much pre-session preparation as necessary to install and run software required for all parts of the sessions, and is summarised in Table 10. The higher workload for SENSE indicates differences between running sessions in a university lab and a school lab, with different access to IT resources and permissions to run software as detailed below.

Table 10 - Resource summary for testing, breakdowns and fixes

Example types of work and when they occurred relative to the session	Participants involved	Resources involved	No. of communications	Total time estimate per project
<p>Pre: Charge, test sensor and recording equipment. Refer to owner to resolve problems. School IT department liaison. Load and test communications software</p>	3 technicians - 2 in school, 4 researchers, 2 computer scientists (developers of borrowed equipment), 1 school Head of IT	Mobile sensors, PCs, Laptops, Software, Telephone, Mobile phone, Email, Skype, Netmeeting, Conference phone	150 emails 13 IM chats 13 phone calls	+/- 33.5 person hours for G&T +/- 72.5 person hours for SENSE
<p>In: Troubleshoot breakdowns.</p>			5 in-school trials with school IT support	
<p>Post: Record any issues with borrowed equipment for reporting to owner.</p>				

The two projects varied in their locations: G&T sessions were held on a university campus where researchers had more control and more on-site pre-session time to organise equipment; the SENSE sessions were school classroom based with university laptops interfacing to the web via the school network. This strategic move to use the university laptops in school provided an increased confidence that the equipment would be available, resulting in substantial preparation and post-session time-savings and ensuring that most of the software would work with minimal room access pre-session. The main factors in this category of work were therefore installing and testing software, requesting support from ICT technicians and troubleshooting on-the-fly.

Installing and testing software on PCs and laptops: Across both projects much of the effort was spent testing and installing software on the PCs available for use in the sessions. Some activities could be performed in advance e.g. check web resource locator addresses and 3D data visualisation plug-ins are installed and up-to-date; add software to facilitate transfer of data and for live collaboration links; test applications in-situ e.g. connection for collaboration sessions on school network.

The kinds of issues that arose in this preparation work included the need to find a free Virtual Reality Modeling Language (VRML) plug-in that would work with the low specification PCs available for use in sessions, and testing IM software on the school network. Our in-school IM trials were unsuccessful and led on to a backup plan of using a phone, and it was here that we discovered a trade-off between familiar equipment and compatibility of software with the school network under pre-session set-up time pressures. Added complications included the variety of computer platforms in use, scientists preferring a more familiar application and variation in access and networking infrastructures at schools and universities.

Requesting support from school ICT technicians: Surprisingly, co-ordinating and testing the phone equipment in the school science lab needed expertise from the school’s phone technician. For example, an unconnected phone socket was temporarily ‘opened’ for the school collaboration session and tested with the remote school in advance of the session. Our testing used mobile phones to communicate between researchers and revealed further issues about which school could call the other, depending on the institution’s phone line permission policy for making local and national calls. We found a conference phone used at the university was incompatible with the school’s phone system, an unexpected complication from a tried-and-tested technology.

Troubleshooting in-session and on the fly: We experienced a large number of in-session technology breakdowns. For example, during some sessions a video and audio conference was attempted, but despite successes in earlier tests the sound failed at one end. We attempted to ‘fix’ the connection before resorting to text chat accompanied by live video. We also needed to prepare, and in the event had to use, back-up technology in the cases where planned technology failed e.g., the telephone call to a scientist, which in turn required the experts’ phone number and a working phone line in the classroom. We invested time resolving trivial breakdowns with the unfamiliar sensor equipment, e.g., how to turn the PDA sound up, how to ‘wake’ the screen up, and the need to wait for GPS satellite pickup during bad weather.

Summary

In this section we presented a discussion of the analysis of categories of work, and effort and resources required to undertake that work. The chart below (Figure 3) gives a visual indication of the proportion of time spent on the hidden work categories across both projects.

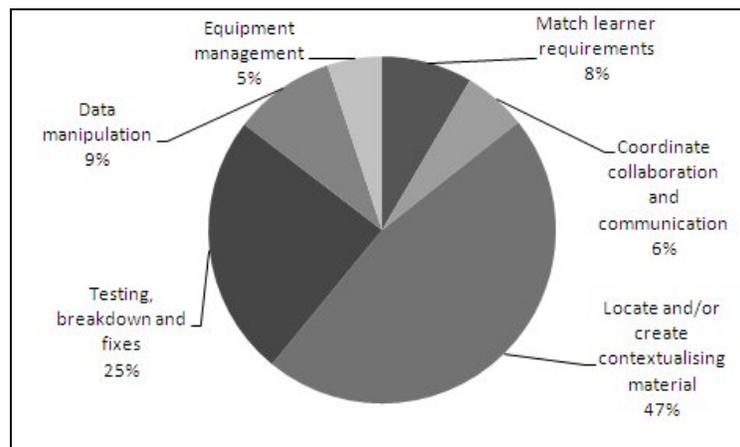


Figure 3 - Distribution of work across all categories

Discussion

Alsop and Thompset (2007) suggest that educational researchers must track and quantify the additional resources available in research contexts as they move from demonstrating effectiveness for learning to efficacy and efficiency in real contexts and furthermore they suggest that this is a necessary demonstration if educational practitioners are to be expected to adopt innovative practice from research. In this paper we identified the hidden work required to deliver novel technology enhanced learning experiences and suggest that through analysis of this work we can move

towards delivery of similar experiences in real world educational contexts. Analysis of our own experiences in running e-Science experiences in semi-realistic contexts indicates they involved a significant amount of 'hidden work': conservatively, we have estimated 183 person hours to re-run the same session 5 times (G&T) and 249 person hours to run a series of 8 sessions (SENSE). This order of effort is beyond what is usually practical within teachers' limited lesson planning time.

Further our analysis reveals the variety of skills required not only to understand the science content and pedagogical aspects of delivering this but also technical issues: from 'mundane' communications infrastructures (the internet and phone), to PC-based off-the-shelf packages which none the less required significant effort to install and troubleshoot, to more cutting edge sensor-based devices and GPS infrastructures, and to understanding how to integrate data from diverse sources for manipulation and display.

While much of the effort here is admittedly due to these projects still being at a research stage and making use of a user-centred and participatory approach, it nonetheless points to the significant areas that would need to be attended to if teachers are to take on the design and delivery of such experiences. Hence a principle contribution from this work has been the systematic identification, through retrospective analysis, of the key categories of work involved in delivering these experiences, as summarised in Table 3, and of the people and resources involved, as summarised in Figure 2.

Limitations of the methodology

Bringing further data to bear on the work categories and framework will be important because of the limitations of our own methodology. We necessarily used a post-hoc collation and analysis of data because of the emergent nature of our understanding of the issues. While the order of effort involved in creating and running the e-Science G&T and SENSE sessions gradually became apparent to us over the course of the projects, it was only during our post-experience reflections that it became obvious exactly how these kinds of experiences are currently way beyond the reach of teachers due to the order of effort involved.

As such, the methodology we employed has a number of limitations: because we did not collect accurate data about the work at the time there will necessarily be some inaccuracy in accounting of effort; we needed to double up on some of our effort because the SENSE project was running slightly behind the G&T project sessions; and because we only had access to our own archival data we have had to omit accounting for time and resources contributed by others within the experience e.g., scientists, teachers, technicians. In addition an unknown amount of data has been lost from our datasets through the time lapse between data creation and analysis, and natural archiving and deletion activities by the researchers.

In future projects, a priori planning for the systematic capture of hidden work will be useful for both sense-checking the categories and to determine a more accurate reflection of the levels of effort involved. Some more informed ways to proceed for better accuracy in reporting this effort would be to:

- develop a time and skills resource plan based on previous experience design knowledge
- maintain reflective estimates of time spent on each category of work during the creation of an experience, identifying where changes in the new experience will save on or cost more resources
- reflect regularly on project progress and resources demanded by project progress.

Developing these ideas further we can see that a more complete picture would be revealed if all partners, i.e. researcher, teacher and scientist partners, were involved in the reporting of time, skills and resource data, and this would contribute to a team-wide, shared view of the planning and running of the educational experience.

Taking the work forward

Even with these limitations, we suggest that the categories identified in this research can be usefully taken forward in three ways: to help in planning of other e-Science learning experiences, to be further tested and evolved in future research, and as a basis for developing an overall experience framework to capture more of the process-related aspects in which these tasks are embedded. We will discuss each in turn.

Firstly, the articulation of these categories and resources can be useful as a working checklist for the pro-active assessment of future resource and skill needs when planning other learning experiences. This might result in a priori planning for how to manage each category or result in choosing to re-design an experience to manage the work, e.g., not to include a remote collaboration because of the effort involved. The categories identified in Table 3 point to the key types of work that need to be considered for e-Science experiences. However, these categories could also be tested for applicability and expanded for other kinds of technology enhanced learning experience.

Secondly, the categories as articulated can form the basis for more pro-active and a priori data collection by researchers and all stakeholders in future learning experience projects. Since the categories and orders of effort have been constructed by post-hoc analysis it would be important a) to test whether these categories hold across other types of learning experiences and to evolve or expand the categories as appropriate, and b) to collect work data in real-time to validate and expand understandings of the orders of effort involved for different types of work.

The value in doing this is that we may then be able to identify where and how we can make the process easier and provide better support to teachers in designing and running their own learning experiences. This could be through guidelines or technology toolkits (Underwood et al., 2008; Woodgate & Stanton Fraser, 2006). For example, if it is confirmed that coordination with remote collaborators is useful from a learning perspective but takes significant time and resources, we could look at developing a skills directory with associated scheduling tools to make it easier for a teacher to identify a science expert and schedule a class session with them.

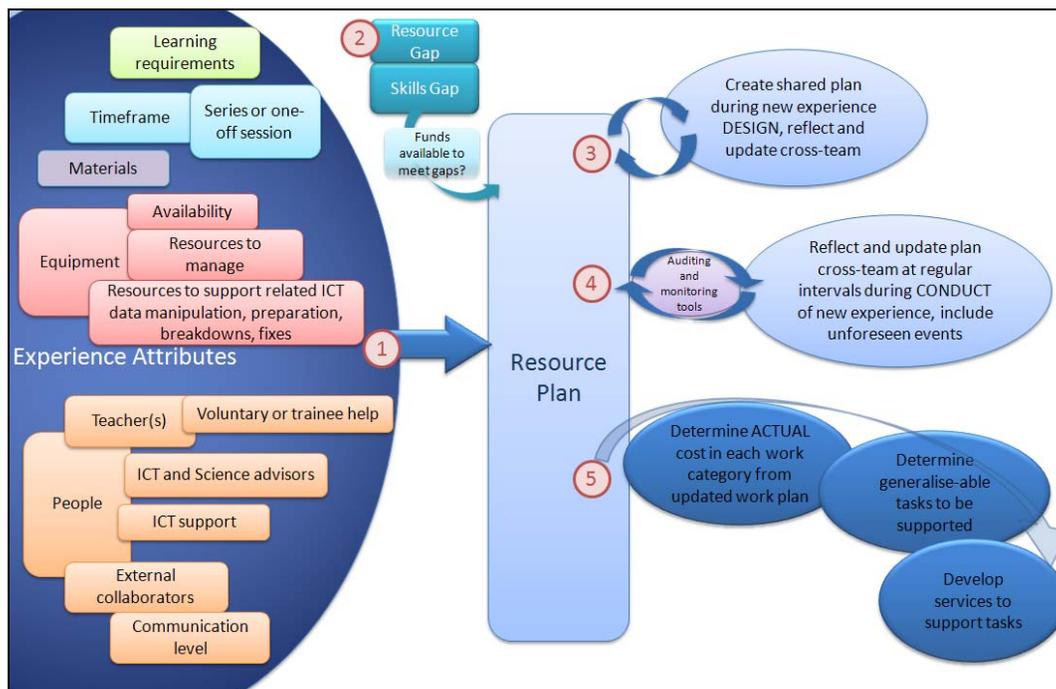


Figure 4 - Experience framework, to plan and analyse e-Science educational experience resource needs (numbers reflect proposed phases of an experience)

Thirdly, we can also use the understanding of the categories, the people and resources involved to develop an overall 'experience framework' to guide the planning process. Koszalka and Wang (2002) emphasise the need for practitioners to consider their learning context when planning technology integration, and for technology developers to gain a better understanding of the challenges of teaching environments. To this end, the experience framework (Figure 4) illustrates the resource and skill implications of technology enhanced educational experiences in school contexts, based on our understandings to date. The formulation of this framework derives from our resource diagram, Figure 2, and categories of work, summarised in Table 3. In pulling together a coherent resource plan for new educational session(s), phase 1 is labelled 'Experience Attributes', it covers the hidden work categories we identified and provides a checklist of all the items we found necessary in our sessions' design, set-up and delivery. The phase 2 items of 'Resource gap and Skills gap' were derived from our data analysis of potential skills and resource shortages

within a teaching unit, and indicate where external skills may be bought in, trained up, or requested from an ICT support unit if funds allow.

Phases 3-5 on the right-hand side of the resource plan indicate how an iterative cycle of session development across team members is created, and could also be validated either by practitioners or by practitioners and researchers. Phase 3 thus results in revisions of the resource plan as a session design is negotiated and agreed with colleagues and potential collaborators e.g. through new knowledge of equipment hire costs, or availability. For additional assessments of hidden work phases 4 and 5 may be performed by researchers or practitioners if data is planned to be collected in an a priori manner.

We propose the ordered phases required for teachers, scientist collaborators and other session planning colleagues to firstly 'build a Resource Plan' for a learning experience comprises the following, as indicated by numbers in red circles in Figure 4:

- Produce an initial resource plan based on the desired attributes of the educational experience at the outset. The experience's timeframe and its nature (whether a one-off session or a series of sessions) are examples here. This initial plan should involve as many intended team-members as possible e.g., teachers, ICT and science technicians, school policy advisors, scientist contacts if known.
- From the initial plan, the identified skills - or resource-gaps – e.g. a lack of science or communication equipment, must be solved through the funds available to meet this gap.
- Iterative development of the design of the experience across the intended team members is then put in place to ensure each team-member has a shared ownership, and equal contribution to the plans.

At the end of phase 3, teachers, along with any collaborators, should be equipped to deliver on the session design, as defined within the constraints of available resources. The practice of review and reflection on technology enhanced teaching can also provide valuable training opportunities. Dawson and Dana (2007) advocate using 'teacher enquiry' as: "a strategy for helping educators systematically and intentionally study their own practice, [and] provides important benefits for prospective teachers participating in curriculum-based, technology-enhanced field experiences" (Dawson & Dana, 2007, p. 656) particularly in challenging perceptions about teaching with technology. Here, for practitioners and/ or researchers to secondly 'review the resources' involved in the session's design and delivery, an audit process, set-up a priori to capture the data for the work categories specified by our data analysis, would use phases 4 and 5 of the framework:

1. During the conduct of the experience plans, the team keeps concurrent records and reflections on skills, time and resources used to feed into phase 5. Communication and time tracking tools that create a shared log of activities can be used from other professions e.g., legal project tracking, or recording tools developed for ethnographic support (Iacucci et al., 2004; Morrison et al., 2006).
2. The final phase, and longer term objective, works towards the identification of generalisable tasks or technology packages from the whole experience, combined with data from experiences others create, that can be better supported by a suite of computational or other support services for teachers, technicians, scientists and others or the development of technology toolkits for the classroom (Underwood et al., 2008) to assist further collaboration.

We have suggested that the work categories and experience framework can be used as a basis for guiding data collection of hidden work in future projects so that they can be evolved to account for more diverse technology enhanced learning experiences. Hence, we present these categories and the associated framework as a starting point for others to engage in this reflection and planning process, and further refine the model depending on the various parameters of their own educational experience design.

Conclusions and future work

Many reports of novel technology enhanced learning projects account for the learning experiences of the students and point to the exciting potential of new technologies to enable engaging hands-on learning but tend to delete from their accounts the work involved in delivering those experiences. We have used the term (from elsewhere) of 'hidden work' to describe this work to put the experiences to work. It is the understanding of this work, and being able to develop the tools and processes to support this work, that will make the critical difference to moving e-Science in the classroom out of the hands of researchers into the hands of the teachers.

To begin this process, we have provided a retrospective account of the effort involved in delivering on two education e-Science projects. From this account, we have suggested that the identified work categories can be used as an experience checklist. We have also included these categories into a broader process-oriented experience framework that can be used as a planning tool. We present the categories and framework for trial and critique by science researchers, educational professionals and others in order to further its development as a methodology for assessing and analysing the types of hidden work we have identified. We believe collecting real-time records of effort will contribute significantly to this aim. As such, we anticipate its use in:

1. helping others to identify realistic costs of creating and running their own experiences,
2. developing a richer understanding of the variety of experience attributes that affect the associated resource and time costs,
3. and obtaining additional reflections from other researchers' uses to further the aim of identifying those tasks which are considered generalise-able across different experiences to warrant design, development and the refinement of support services.

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