e-Science in the Classroom - Towards Viability

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Abstract

E-Science has the potential to transform school science by enabling learners, teachers and research scientists to engage together in authentic scientific enquiry, collaboration and learning. However, if we are to reap the benefits of this potential as part of everyday teaching and learning, we need to explicitly think about and support the work required to set up and run e-Science experiences within any particular educational context. In this paper, we present a framework for identifying and describing the resources, tools and services necessary to move e-Science into the classroom together with examples of these. This framework is derived from previous experiences conducting educational e-Science projects and systematic analysis of the categories of 'hidden work' needed to run these projects (Smith, Underwood, Fitzpatrick, & Luckin, forthcoming). The articulation of resources, tools and services based on these categories provides a starting point for more methodical design and deployment of future educational e-Science projects, reflection on which can also help further develop the framework. It also points to the technological infrastructure from which such tools and services could be built. As such it provides an agenda of work to develop both processes and technologies that would make it practical for teachers to deliver active, and collaborative e-Science learning experiences on a larger scale within and across schools. Routine school e-Science will only be possible if such support is specified, implemented and made available to teachers within their work contexts in an appropriate and usable form.

1. Introduction: Education, e-Science and The Grid

Engaging young people in challenging and inspiring 'real science' in schools has been the subject of much discussion, with recent reports highlighting both the importance

of doing this (e.g. The Royal Society, 2004; NESTA, 2005; Peacock, 2006), as well as the lack of current opportunities within schools (Woodgate and Stanton Fraser, 2005). Our own work (Underwood, Luckin, Fitzpatrick, Steed, Spinello, Greenhalgh et al, 2004, Smith, Luckin, Fitzpatrick, Avramides, & Underwood, 2005) and the work of others (see, for example, Chin and Carroll, 2000; Hine, Rentoul, & Specht, 2004; Ramasundaram, Grunwald, Mangeot, Comerford, & Bliss, 2005) leads us to believe that the relatively new field of e-Science can provide a real opportunity to transform school science by enabling school children, teachers and research scientists to engage together in authentic scientific enquiry, collaboration and learning. But what is required to make this a reality?

The UK National e-Science Centre asserts that e-Science will change the dynamic of the way science is undertaken describing the rapidly evolving field as being about global collaborations in science and developing the next generation of infrastructure that will enable these (NeSC, 2007). E-Science is about both new ways of doing science and the technologies that allow this. Researchers in education have seen the potential for e-Science to also support new ways of learning and have explored these in several projects. For a review of e-Science in education see Woodgate and Stanton Fraser (2005) who offer the following definition:

> "The use of ICT in education, to enable local and remote communication and collaboration on scientific topics and with scientific data" (p15 Woodgate & Stanton Fraser, 2005).

This definition rightly places the emphasis on the learning activities to be supported while deliberately avoiding mention of specific 'new technologies' to enable these. This contrasts with the wider definition of e-Science which, while still focussing on the activity to be supported, clearly points to the need for new infrastructure to enable this. The infrastructure concept that has been most strongly associated with e-Science is The Grid, described as 'an enabler for Virtual Organisations: An infrastructure that enables flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions and resources' (NeSC, 2007). Many recent science education and technology projects clearly fall within the definition of e-Science in education provided above and are essentially about resource sharing. However, relatively few of these (e.g. I2U2 e-labs and i-labs[1], AstroGrid SchoolSpace[2]) have aimed to explicitly use The Grid for education in the same way that science uses The Grid.

Educational e-Science projects typically have one or more of the following characteristics: access to remote resources, such as sensors (Underwood et al., 2004), electronics laboratories (Burbidge and Grout, 2006) and telescopes (e.g. Faulkes Telescope[3]); collaboration with science projects by contributing computing resources

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[1] Interactions in Understanding The Universe – see http://ed.fnal.gov/uueo/i2u2.html
[2] Astro Grid School Space project proposal – see http://wiki.astrogrid.org/bin/view/Schoolgrid/WebHome
[3] Faulkes Telescope Project – see http://faulkes-telescope.com/

(e.g. climatepredition.net[4], Protein Folding@home[5]); collaboration with science projects by providing human resources to gather data (e.g. Walking with Woodlice[6], The Big Bug Count[7], Springwatch[8]); the use of tools to support communication between remote participants around scientific enquiry activities, e.g. between learners in different schools (e.g. Smith et al., 2005, Pea, Gomez, Edelson, Fishman, Gordin, & O'Neil, 1997, Tinker & Berenfield, 1994) between learners in school and out on field trips (Kravcik, Kaibel, Specht, & Terrenghi, 2004) and between learners, teachers and remote science experts (e.g. Underwood et al., 2004 and The Creative Science Centre[9]).

Some of these projects illustrate how e-Science can facilitate mutually beneficial collaborations between 'real' science research projects, school scientists and the public. Such projects are typically large scale and use technology to co-ordinate the individual effort of large numbers of resources to collaboratively solve big tasks that would be impossible with smaller numbers. Examples are use of the public to collect large amounts of data over wide geographical regions (e.g. Springwatch) or to provide computer-processing time (e.g. climateprediction.net) to help solve massive computational problems. Typically these projects provide accompanying educational resources that can support learning. Other projects have less clear benefits for the participating scientists but learners gain access to advanced science resources (e.g. Faulkes Telescope) and scientists (e.g. The Creative Science Centre). It is often claimed that such collaborations can lead to improved learner attitudes towards science and understanding of real science and scientists (e.g. Scherz & Oren, 2006, Beare, 2007).

1.1 Moving to a Vision of Everyday e-Science in the Classroom

However, realising the benefits of e-Science for education is not simply a question of providing access to technology. Teachers and learners need to have the knowledge and skills to make use of the technology within practical time and resource constraints of school life. Further, many of these projects are set up as unique events by dedicated teams of researchers or scientists involving a considerable effort; they are researcher led. If we are to move e-Science into the classroom as a routine feature of learning science, it is timely to turn our attention to the questions of what support is needed to enable teachers to take up the potential offered by e-Science. Without understanding this, large-scale teacher led educational e-Science will not be practical.

Our experiences to date of using ICT in education, to enable local and remote communication and collaboration on scientific topics and with scientific data, reveal some of the difficulties and the large amount of work required to make this successful in existing educational contexts (Smith et al., In preparation). We envisage a future in

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[4] Climate Prediction Project – see http://www.climateprediction.net/
[5] Folding@home distributed computing project - see http://folding.stanford.edu/
[6] The Natural History Museum's walking with woodlice project – see http://www.nhm.ac.uk/woodlice/
[7] An RSPB survey – for more information see http://news.bbc.co.uk/1/hi/sci/tech/3618332.stm
[8] Springwatch Survey 2007 – see http://www.bbc.co.uk/nature/animals/wildbritain/springwatch/record/
[9] The Creative Science Centre, http://www.creative-science.org.uk/main.html

which an educational e-Science infrastructure enables easy and ubiquitous collaboration and resource sharing around scientific activity, accessible to research institutions, schools and potentially the interested public, as illustrated in the scenario in table 1.

Table 1. Future Educational e-Science Scenario

A primary teacher preparing work on plants and animals in the local environment enters information about learning objectives and her timetable in an educational e-Science portal. She finds a match to a national project gathering data on insect activity and plant flowering and follows links to related lesson plans. Materials include advice about field trips in the local area, a suggestion for a videoconference with an environmental scientist, and recommended equipment. She uses tools provided by the portal to arrange the loan of some digital cameras and GPS loggers and to adapt the materials for her class. Following a preparatory session in school the class go on a field trip and use GPS loggers, digital cameras and their notebooks to gather data on plants and insects. After the field trip the teacher has scheduled a quick video chat with the participating scientist to exchange expectations for the class videoconference. At school, children upload their data. Their photos are automatically geo-tagged and displayed on a map of the area they visited. They can explore the map and add annotations. They can also view data layers contributed by other schools and make comparisons with data recorded at other times of the year and in other parts of the country. During this activity they make notes for questions they would like to ask the scientist from the project. Later, they videoconference with the scientist and ask her their questions. After a while they start asking how she became a scientist and what it is like to be a scientist. At home in the evening, a parent asks about the field trip. The child uses a home computer and the portal to show the annotated field trip map and to playback a recording of the videoconference. At the weekend the family notice some weird looking caterpillars in the park. They take a photo on a mobile phone and MMS a question about them to the project. The photo is automatically tagged with location and added to the project database. Sometime later, the family receive an SMS with the answer to their question.

The contribution of this paper is to articulate, based on grounded experiences a framework for identifying and describing the supporting infrastructure that needs to be put in place to make this vision a reality. Using this framework we describe examples of the resources, tools and services that could constitute an infrastructure, which would help move e-Science into the classroom. A resource in this context is any asset that can be made available to users e.g. data collections, computational resources, knowledge, learning objects, remote sensors, etc and includes humans (scientists, teachers, learners). Tools are a class of resource operated by users to facilitate their work (e.g. word processing software) while services require less expertise, take on more of the work for the user and just deliver results (e.g. a search engine).

We are not claiming technology can take on all the work required to set-up and run educational e-Science sessions. Rather, we envisage technology facilitating the efficient distribution of the work required across the available resources, including humans. Our framework assists in identifying these resources, and the tools and services required to manage interactions between them. For us, educational e-Science is primarily about enabling scientists, teachers and learners to create collaborative, engaging and realistic science activities, and furthermore about defining and building the infrastructure that will make this easier and practical on a larger scale and in everyday contexts.

To articulate this agenda for moving to everyday educational e-Science this paper is structured as follows. In the following section we reflect on our own experiences with two e-Science projects that underpin the work of this paper. We overview the projects and sessions run and then provide a summary of the retrospective analysis we conducted to identify and categorise the types of work employed in setting up and running sessions (Smith et al., in preparation). Working from these categories, we describe resources, tools and services required to reduce or facilitate this work in order to support repeatable, scalable educational e-Science. Finally, we discuss the limitations of this work and how these might be addressed and our own future work towards defining and implementing useful and usable support for educational e-Science.

2. Reflection on Two e-Science Projects

In this section, we review our experiences with two educational e-Science projects: *Public Understanding for Environmental e-Science* and *SENSE*. In these projects, we aimed to provide teachers and learners with an experience representative of our vision for educational e-Science; in which children and their teachers actively participate in real scientific research, accessing advanced technology and collaborating globally with scientists and other learners. As initial explorations of this vision, we ran a series of e-Science-like experiences in which children, teachers and environmental scientists collaborated around current scientific research: accessing data from remote sensing devices, gathering and sharing data using handheld sensors and the web and communicating using chat and videoconferencing (Underwood et al., 2004; Smith et al., 2005). Our research objectives were to explore the possibilities for educational e-Science and identify issues in delivering e-Science for school children and teachers.

Our work is unusual in combining access to remote science resources, learners collecting and contributing data to science projects, and direct communication with the scientists involved. We provided a sense of active collaboration between real environmental scientists, learners and teachers by using both live and asynchronous communication tools. We also wanted to stimulate and support active involvement not just in data collection but also in its analysis as well as reflection on both the scientific activity itself and, at a meta level, on the use of sophisticated technology to support science learning. This final point leads to the most significant contribution of our work. While learners and teachers were very enthusiastic about how e-Science could be used in school, teachers were deeply concerned about the time, effort and skills required to set up and run sessions. This led to our concern to identify and facilitate the work required to run educational e-Science sessions. Other educational e-Science projects have said very little about the obstacles encountered and the amount and type of work required to make this kind of e-Science learning experience happen.

The *Public Understanding* and *SENSE* e-Science sessions are described in detail elsewhere (Smith, Underwood, Luckin, & Fitzpatrick, 2007). Here we summarise the activities learners, teachers and scientists were involved in order to ground later discussion of work categories and the services to support them are derived.

2.1 Public Understanding & SENSE e-Science Sessions

We ran a total of 21 sessions involving 62 children and 4 teachers as part of two projects in 2004 (see table 1). Both projects made use of environmental e-Science research supported by the Equator research group's e-Science theme[10] to source devices, expert scientists and material for sessions. During these sessions children accessed and analysed data from remote and handheld sensors; collaborated asynchronously and synchronously with remote scientists and other learners; and used advanced software tools to share and review data. *The Public Understanding* sessions made use of existing 'school science labs' for 'gifted and talented' children, which take place in a science laboratory at Sussex University. We worked with the organisers and teachers of these labs to design an e-Science specific session that we ran with 5 groups. The *SENSE* sessions took place after we had completed *The Public Understanding* sessions. These sessions ran in schools during science class time and were developed in collaboration with the teachers to fit the needs of the curriculum. Table 2 lists the activities involved in the sessions and their purpose while Figure 1 shows some of these activities in practice.

Table 1. Summary of e-Science Sessions

	Total Learners	Number of Sessions and duration	Age (yrs)	Learners per session	Subject Matter
Public Understanding Sessions	43 (Gifted and Talented) learners	Same 3 hour session repeated 5 times with different participants	14-16	8-14	Antarctic Remote Sensing CO Monitoring
SENSE Sessions	19 learners	8 sessions involving same participants, and run separately as two halves of class	13-14	8 and 11	CO Monitoring

Figure 1. Left, remote sensing device on Antarctic lake. Centre, in the field collecting environmental data with GPS, CO sensor and PDA. Right, learners explore 3D visualization of their route and CO readings.

Table 2. Session Activities

Purpose	Activities

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[10] Equator Research Group e-Science Theme http://www.equator.ac.uk/index.php/articles/c66/

Contextualisation	Learners viewed images relating to environmental e-Science projects and were prompted to think about what these showed. They then investigated these research projects online using a structured "Webquest" like activity and formulated questions to ask the scientists involved.
Communication with Antarctic Experts	Learners and teachers asked questions to scientists, located in the Antarctic and Nottingham, using text chat projected on a large screen (figure 1).
Accessing Antarctic Remote Sensing Device Data	Learners predicted the shape graphs of data recorded by the Antarctic remote sensing device would have (e.g. change in ice thickness over the year, variation in UV intensity over a day and at different depths). They then downloaded and plotted the data required to test their predictions from the device.
Mobile CO Data Collection	Groups of 2-4 learners used handheld CO sensing devices (figure 1), video cameras and anemometers to investigate CO levels around the University Campus formulating and testing hypothesis about CO dispersion as they did so.
CO Data Visualisation and Sharing	Learners uploaded their data to a visualisation service that generated a navigable representation of their route and CO readings (figure 1). Learners explored this visualisation and related this to their own experience and observations and to simple plots of the data showing CO levels over time.
Communication with Remote Experts	Learners had the opportunity to text chat with the researcher responsible for development of the CO monitoring device.
Reflection	Learners and teachers were asked to reflect on this experience and suggested how similar technology might be used to support school science learning

SENSE Sessions

1 Contextualisation	Introductory web-based research on air pollution and CO. Designing a small-group study for hands-on data-collection through route planning 3 or 4 locations to visit, and hypothesising about potential readings at locations
2 Mobile data collection	Groups of 3-4 learners used handheld CO sensing devices (figure 1), video cameras and anemometers to investigate CO levels in the school locality.
3 and 4 Data Visualisation and Sharing	Students reviewed data back in the classroom using a prototype CO graphing and video synchronisation tool. Learners annotated these graphs and viewed other group's data.
5 Mobile data collection	Planning and conducting a second data-gathering session.
6 Data Visualisation and Sharing	A similar data annotation and review session
7 Communicating with remote others	Students communicated with environmental scientist about their study and his work via telephone. Reviewed CO data collected by learners in Nottingham and asked and answered questions about experience in both locations.

2.2 Identifying the 'Hidden Work' involved in delivering educational e-Science

Teachers and learners evaluated the sessions very positively in interviews, questionnaires and through informal feedback and expressed enthusiasm for the idea of integrating e-Science activities in school science teaching and learning. However, several teachers expressed concerns about the amount of work and technical know how that would be involved in preparing and running similar sessions in schools. Details of this feedback and our analysis of the activities and implications for learning are described elsewhere (Smith et al., 2005, Underwood et al., 2004). As a researcher-led project, we were also very aware of the considerable effort and resources that we had to put into planning and running these sessions to deliver a successful outcome. We realised that in order to scale up this kind of experience and move towards making participation in

educational e-Science practical for schools we needed: firstly to identify the work, expertise and resources that are involved in delivering such experiences and secondly to reduce and/or facilitate this work. To this end we conducted a retrospective analysis of the project to systematically account for the effort involved. We collated all data relating to the work, resources and any special skills involved in setting up and running the sessions described above. Similar items of work were grouped into categories and a descriptive name for each category was agreed. These categories are: match learning requirements; locate and/or create contextualising materials; coordinate collaboration and communication; data manipulation; equipment management; and testing, breakdowns and fixes. Details of this analysis are provided elsewhere (Smith et al., in preparation); here we summarise the work categories identified with a short description and some illustrative examples in Table 3.

Our audit of the work that went into setting up and delivering the Public Understanding and SENSE e-Science sessions suggests that around 15 person hours of work went into each hour of session delivered (Smith et al., in preparation). This amount of preparation per hour of learning is clearly excessive for what might be expected of a teacher. Even for a researcher-led project, it would be important to look to manage and better support this effort to make repeatable sessions practical and time-efficient. We propose that the categories of work identified from conducting real-world e-Science projects can provide a framework on which to base an agenda of work to practically support moving e-Science into the classroom.
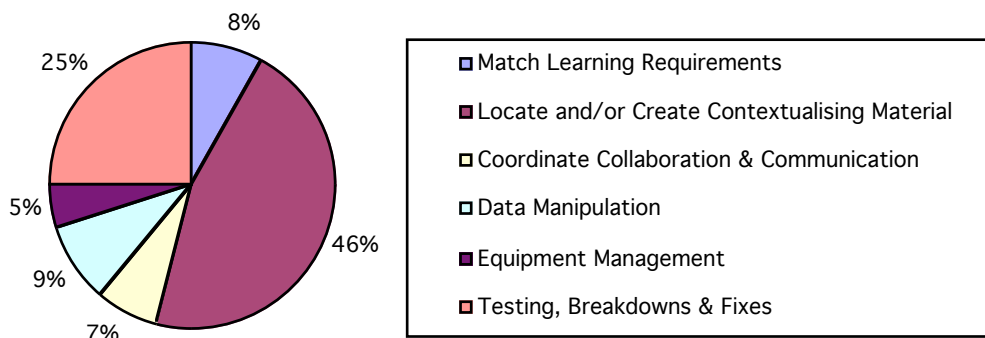

Figure 2. Distribution of work across categories.

Table 3. Categories of Work Required to Support Educational e-Science: Descriptions and Examples.

Work Category	Description	Example Activities
Match Learning Requirements (8%)	Work done to relate a science research activity to relevant National Curriculum or other learning objectives for any particular group of learners.	- Face-to-face meetings and e-mail between researchers and scientists to identify possible opportunities - Reading to understand research & Curriculum
Locate and/or Create Contextualising	Work done to: - Structure learner activity in such a way as	- Make lesson plans - Search for and/or create

Materials (46%)	to lead to the learning outcomes identified above - Make activity accessible, appropriate, relevant and engaging for specific learners.	educational resources e.g. interactive multimedia, structured data gathering activities, worksheets, etc…
Co-ordinate Collaboration & Communication (7%)	Work done to arrange and deliver successful collaboration and communication with local and remote partners (e.g. science experts, other schools, etc…) through appropriate channels (e.g. video conference, chat, e-mail, phone, face-to-face, etc…).	- Find and contact partner schools & scientists - Identify appropriate communication technologies - Establish expectations - Schedule communication
Data Manipulation (9%)	Work done to: - Ensure efficient and secure collection, storage and sharing of data amongst local and remote participants - Enable transfer of data across devices and services in order to facilitate reflection on and analysis of own and others data.	- Access and download data from remote sensor - Retrieve data from handheld device, transfer to PC and upload for visualisation - Transfer video from tape to PC for use in reflection tool. - Establish permissions for use of images and video
Equipment Management (5%)	Work done to identify appropriate equipment for use in activities and to enable access to, and efficient sharing of any 'special' equipment (e.g. high cost and/or difficult to obtain equipment such as the prototype GPS & CO sensors in figure 1).	• Locate and contact owners • Arrange loan and return • Pick up and return equipment
Testing, Breakdowns & Fixes (25%)	Work done to: • Ensure appropriate equipment (software and devices) are ready for use in sessions and work in required contexts • To understand how to recover (including back up plans) and/or who to contact if a problem develops • To record and report problems (e.g. report damage to equipment owners).	• Check required software is available and if necessary install and test • Check 'chat' is allowed on school network • Check devices are working, batteries are charged, etc… • Learn common problems and solutions (e.g. how to wake up the screen on the PDA, how long to wait for initial GPS fix, etc…)

3. Towards supporting Everyday e-Science in the Classroom

The categories of work identified in the previous section reveal many opportunities to facilitate, distribute and greatly improve the efficiency of the work required to run e-Science sessions. Here, we identify resource requirements and suggest how appropriate applications of technology could make it practical to efficiently deliver educational e-Science experiences in schools.

To arrive at an articulation of the ways in which the work could be supported, we worked with the categories and data from the analysis of the e-Science sessions in the following way. First, for each category of work, we examined when the work took place, its significance, and its distribution in terms of who did it, and any special expertise or resources employed. We also looked for opportunities to reduce or facilitate this work. See table 4 for the results of this analysis.

Table 4. Opportunities to Reduce or Improve Work to Support Educational e-Science

Work Category	Significance to Educational e-Science and Opportunities for Improvement
Match Learning Requirements Not specific to educational e-Science. This is a normal part of science teachers' and educational materials producers' work (academic or commercial).	Science teachers typically feel under great pressure to cover curriculum content and it is therefore very important to identify potential learning outcomes of an educational e-Science activity and possible matches to curriculum objectives. This work need only be done once if efficient means to share, reuse and build on previous outcomes are in place. Opportunities for improvement include: - Make curriculum objectives more accessible to non-teachers - Provide tools to help 'tag' and 'describe' science research in terms of the curriculum - Open libraries of 'tagged' educational e-Science activities - Supporting distribution of effort and ongoing e-Science activity description improvement by growing school and researcher communities around the above.
Locate / Create Contextualising Materials Not specific to educational e-Science. Can be part of science teacher's work. Typically make use of existing materials produced commercially, by other teachers, or by science institutions and researchers to support public understanding.	The output of work in this category is highly likely to influence the extent to which the desired learning outcomes identified in the previous category are supported. Creating quality-learning materials is typically very time consuming, particularly if it involves iterative development and testing. Locating appropriate existing materials and adapting them is also time-consuming. In our projects this work typically involved teachers at the lesson planning level, educational researchers in design and implementation of activities and resources, scientists in provision of media (images, video, text, data, etc…) and knowledge, and learners and teachers in evaluation. In other contexts educational media content producers might also been involved. Opportunities for improvement include: - Facilitating access to and management of media (images, text, audio, video, data, etc…) associated with science research projects - Providing templates and pattern libraries for suitable learning activities - Wizards to produce structured investigative activities. - Provide tools to support iterative improvement of resources through evaluation, recommendations and other feedback. - Maximising the potential for re-use of materials produced through libraries and tagging (as described in matching learning requirements category above)
Co-ordinate Collaboration & Communication An important part of work supporting educational e-Science and not usually part of a science teacher's work.	Direct communication (both synchronous and asynchronous) with Science experts was highly valued by learners and teachers and may have particular significance with respect to learners' attitudes to science and scientists (Scherz and Oren, 2006). Collaboration and communication with other learners was considered important for providing an audience for which to prepare presentation and hence promoting reflection. We largely relied on existing contacts with science researchers and schools. So, for us most of work in this category involved identifying available communication channels, establishing expectations and scheduling live communication events. Opportunities for improvement include: - Directories of available science experts and participating schools - Listings of available communication channels and collaboration tools - Example transcripts of science expert and learner collaborations - Provide calendars and associated tools for scheduling collaborations

Data Manipulation An important part of the work supporting educational e-Science. This work may occasionally be part of a science teacher's and/or a technician's normal work (e.g. using data loggers in experiments).	Key features of educational e-Science are learners gathering and/or accessing research data and using tools to analyse, reflect on and share these. This sequence often requires data manipulation and manipulating data may sometimes be part of the learning process. In our projects, expertise was required in order to transfer logged data from one device to another, convert data formats in order to make use of tools for analysis and reflection, and synchronise multiple sources of time data. This work often needs to be done in order to progress from one activity to another and hence either needs to be done rapidly during sessions by participants themselves or sessions need to be designed with breaks to allow for this. Transfer of video data from tape to hard disk was particularly time-consuming in the SENSE project as was establishing permissions and the suitability for sharing of such data. Opportunities for improvement include: • Reduce the need for 'human' data manipulation (except for those manipulations that are an intended part of the learning process) by designing smooth integration of data logging, storage, and analysis and publication tools. • Use appropriate technologies e.g. Bluetooth to transfer data between devices, video record direct to DVD or memory stick as opposed to tape. • Ensure 'tips' such as those above are shared • Provide access to data conversion and synchronisation services • Provide accessible, secure content management systems with access controls
Equipment Management May sometimes be part of a science teacher's and/or a technician's normal work but usually within school not across institutions.	Borrowed technology (GPS, CO sensors, wind anemometers) was essential for our sessions. Enabling sharing of resources (advanced devices, powerful computers, software and data) is central to e-Science though special equipment may not always be required to gather data. We had knowledge of and access to equipment through our research contacts and our effort was largely in co-ordinating activities and the borrowing of devices and associated equipment so as to minimise transportation and maximise opportunities for use. Opportunities for improvement include: • List appropriate devices available for loan with owners contact details • List device requirements (e.g. chargers, cables, etc…) and provide manuals • Provide calendar showing scheduled usage, availability and location
Testing, Breakdowns & Fixes May be part of a science teacher's and/or a technician's normal work but the load in this category is likely to be higher in educational e-Science sessions.	Technology breakdowns during sessions are extremely disruptive, and furthermore are frequently quoted by teachers as a main reason for not using ICT in teaching (Education Skills Exchange, 2004). If technology does 'breakdown' during sessions it is unlikely that teachers will have immediate access to appropriate skills or assistance and will most likely abandon activities and resort to back up plans. Consequently, most work in this category takes place prior to sessions and is aimed at checking equipment works in the intended context of use. Frequently installation of new software or equipment will require not only expertise but also authorisation. If problems are encountered in time expert help can be called on to resolve them. However, there are inevitably occasional breakdowns during sessions. Opportunities for improvement include: • Checklists for pre-session testing • Suggestions on how to solve known problems • Provide tools to facilitate sharing of local (on site) expertise • Contact details and communication channels for remote experts • Suggestions for alternative technologies and alternative activities • Changes to organisational infrastructure. For example, it may be the case that teachers (and in indeed learners) have the skills to install and test software but are barred from doing so.

Next, having identified opportunities to reduce or facilitate the work in each category we moved towards identifying and describing tools and services (see table 5)

that could exploit these opportunities. The descriptions of service and tools offered here are hence grounded in our understanding and analysis of the work done to deliver the educational e-Science sessions described in section 2.1.

Table 5. Example Services and Tools to Support Educational e-Science.

Service Group	Example Services	Resource Requirements
Match Learning Requirements	Suggest educational e-Science projects matched to learning objectives. Suggest schedule for activities.	Knowledge of current and scheduled learning objectives. Knowledge of e-Science project learning opportunities Tools for tagging resources as above.
Locate or Create Contextualising Materials	Offer appropriate existing learning resources and associated information (e.g. reviews and tips). Facilitate creation of new learning materials and modification of existing materials.	Media (images, video, learning objects, etc…) relating to research projects. Patterns for and examples of successful education materials. 'Wizards' for easy content creation.
Co-ordinate Communication	Introduce teachers and researchers. Facilitate and schedule communication with science researchers and/or other learners.	Knowledge of available communication tools, experts and schools. Knowledge of participants' timetables and time zones.
Data Manipulation	Provide secure data access, storage and access control. Provide tools for data analysis and collaboration (e.g. for shared annotations).	Knowledge of available and appropriate tools to support data sharing, visualisation and reflection. Knowledge of and access to data sources (e.g. remote sensors).
Equipment Management	Suggest and facilitate access to appropriate specialist equipment (e.g. mobile devices, sensors, remote devices).	Knowledge of equipment requirements, available equipment, loan options, transport options, access options, etc…
Testing, Breakdowns & Fixes	Alert users to common problems and requirements associated with suggested technology. Facilitate equipment testing.	FAQs, common problems and solutions, availability of technical experts and communication channel, online equipment tests, etc…

Clearly the services and users of tools described previously need to know, or be able to find out about the resources available to an educational e-Science community in order to efficiently manage interactions between these. For example, a service employed by a teacher to find a science expert able to answer a class's questions about space travel in a live conference amongst other things needs to know: who knows about space travel, their availability, the possible time slots for a video conference, the communication channels available at both ends (e.g. video conferencing software, phone, chat), the time zones at both ends, and the languages spoken by participants. Furthermore, knowledge of the resources accessible through an educational e-Science community may inspire novel science and learning projects. This requirement for knowledge about available resources leads to the next step in our analysis, which is the identification of the resources and knowledge about resources required by the services and tools described in the previous steps. Figure 3 illustrates how knowledge about resources can be structured in a class diagram.
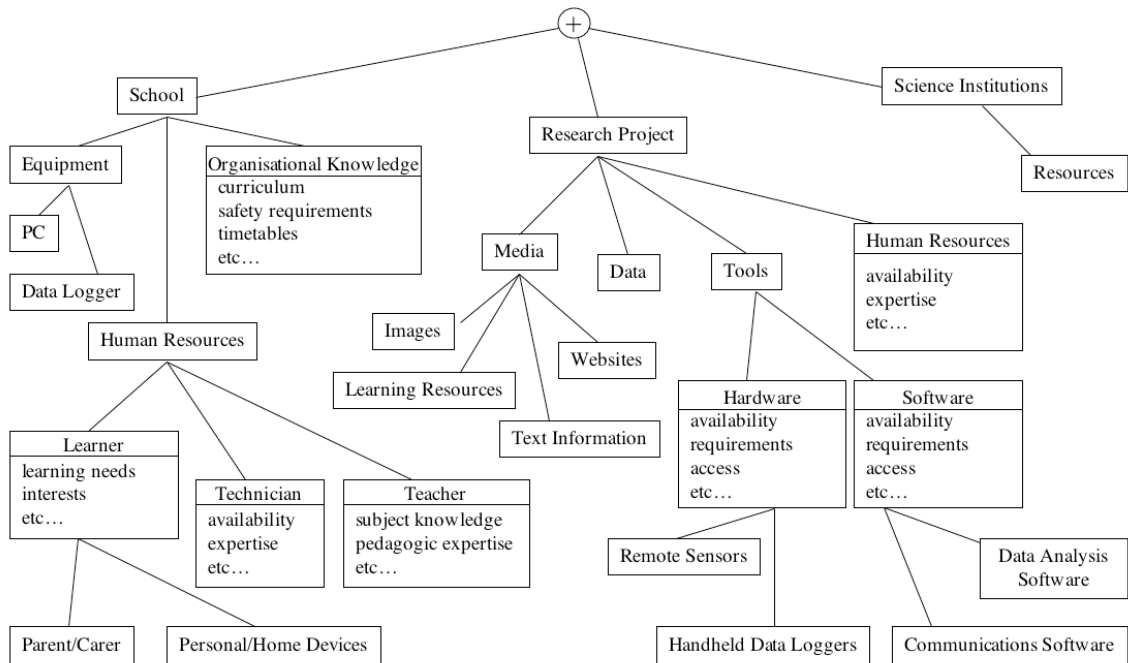
Figure 3. Partially expanded class diagram of resources available in an educational e-Science community

4. Discussion

We have presented a framework for identifying and describing the resources, tools and services necessary to move towards a future in which routine participation in educational e-Science could become practical in school contexts, as illustrated by the scenario in table 1. This framework is grounded in an in-depth understanding of the work required to set up and run our own educational e-Science sessions and the systematic analysis of this work in terms of its significance, distribution and opportunities for improvement. However, many other types of educational e-Science activities are possible and have been, or will be explored. Setting up and running such activities may require different types of work, as yet not contemplated in out framework. Likewise, educational e-Science activities may take place in a great variety of contexts (e.g. at home, in school, outdoors) and the work and resources required to deliver activities can be expected to vary from context to context. We would expect analyses of the work involved in delivering such activities to result in enriched descriptions of the categories of work we have identified and possibly the extension of this framework to include new categories. We would also expect such analyses to lead to the identification of new opportunities to reduce and facilitate work and further suggestions for tools and services. Similarly, analysis of the resources required to support such work may extend descriptions of the resources and knowledge about resources required by an educational e-Science community. The framework provided serves a starting point for more methodical design and deployment of future educational e-Science projects, reflection on which can also help further develop the framework.

Clearly much of the work we aim to support (see table 4) is not specific to educational e-Science. Matching learner requirements and locating or creating contextualising material for learning activities are an everyday part of teaching, and much effort has been directed at developing tools to reduce, facilitate and maximise reuse of such work; e.g. Curriculum Online[11] and more generally content management systems, learning object repositories and learning design tools. However, these are largely aimed at users with educational expertise; more work is needed to enable scientists and others interested in public understanding of science to easily contribute and appropriately label content for use with these tools. It may also be the case that new designs for new ways of learning are required in order to fully exploit the affordances of educational e-Science.

Similarly, although co-ordinating and conducting communication with remote participants has not traditionally been part of teaching work, it is increasingly becoming part of modern life. Scientists and others frequently need to communicate and collaborate with distant colleagues, and children and grandmothers are videoconferencing across continents. Tools to support such communication (e.g. Skype[12], FlashMeeting[13]), to schedule face-to-face and virtual meetings (e.g. Meet-O-Matic[14], Google Calendar) and to facilitate building communities of people with like interests (e.g. Upcoming[15], CivicSpace) are in common use outside school and evolving rapidly. The combination of such technologies with the expertise directories[16] and contacts information universities and others already publish online could greatly facilitate the work of coordinating communication for educational e-Science. Technology applications to support work similar to that in the remaining work categories we have identified are also increasingly common and accessible; online services to transform data from one format to another and tools for data visualisation (e.g. GPSVisualizer[17]), spaces for sharing data, media and annotations (e.g. Flickr[18], Google Earth Community Layers[19]), services to access remote devices (e.g. Faulkes Telescope) and to support equipment testing (e.g. Nokia RDA[20]) and fault diagnosis. Services to efficiently manage the physical loan of equipment between institutions might be developed from existing online institutional room booking and equipment booking systems.

Hence the problem for educational e-Science is not so much one of developing new technologies as of binding together existing and emerging technologies so as to deliver integrated access to appropriate resources, tools and services for educational e-Science. Ensuring that these resources, tools and services are usable by the intended

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[11] Tool to find multimedia resources linked to curriculum - see http://www.curriculumonline.gov.uk

[12] Cross platform video, audio and text communication - see http://www.skype.com

[13] Supports audio and video for meetings with replay - see http://flashmeeting.open.ac.uk/

[14] Online meeting planner software – see http://www.meetomatic.com/calendar.php

[15] A social event calendar website - see http://upcoming.yahoo.com/

[16] For example, see http://www.sussex.ac.uk/USIS/experts/

[17] An online utility that creates maps and profiles from GPS data - see http://www.gpsvisualizer.com/

[18] A space to store, share and annotate photos - see http://www.flickr.com/

[19] Databases of geographic information contributed by and shared with users - see http://earth.google.com/

[20] A service that enables developers to test applications on remote devices over the Internet - see http://www.forum.nokia.com/main/technical_services/testing/rda_introduction.html

users (teachers, scientists, learners and possibly the general public) within the constraints of the contexts they operate in (e.g. school classrooms and laboratories, at home, on field trips) is a substantial user centred design task. One direction for our future work involves working with educational e-Science users in a variety of realistic contexts to design, prototype and evaluate access to educational e-Science resources.

Even with the supporting infrastructure in place effort will still be required in order to deliver effective educational e-Science but this will be reduced and more effectively focussed and distributed. Content (e.g. lesson plans, activities, multimedia) will still need to be created by teachers, educational media producers, those interested in public understanding of science and other institutions but the effort required and outputs will be distributed more effectively. Awareness of and access to the right tools and services will enable educational e-Science communities to grow and build the contexts within which they can efficiently share and exploit resources. Knowledge of the resources accessible through such a community may motivate novel science and learning projects. Teachers and learners may be inspired by what the technology can and is doing for scientists and may be prompted to think of and design their own exciting science activities and the appropriate the tools and resources to make these happen. They may also have a say in the nature of the scientific activities and goals of the community as a whole and be able to contribute to the agenda. Such educational e-Science communities could potentially lead to a real difference in the way the public engage with and participate in debate about science by enabling direct participation in scientific research and communication with scientists.

Acknowledgements

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