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Out there and in here: design for blended scientific inquiry learning

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One of the benefits of mobile technologies is to combine 'the digital' (e.g., data, information, photos) with 'field' experiences in novel ways that are contextualized by people's current located activities. However, often cost, mobility disabilities and time exclude students from engaging in such peripatetic experiences. The Out There and In Here project, is exploring a combination of mobile and tabletop technologies in support for collaborative learning. A system is being developed for synchronous collaboration between geology students in the field and peers at an indoor location. The overarching goal of this research is to develop technologies that support people working together in a suitable manner for their locations. There are two OTIH project research threads. The first deals with disabled learner access issues: these complex issues are being reviewed in subsequent evaluations and publications. This paper will deal with issues of technology supported learning design for remote and co-located science learners. Several stakeholder evaluations and two field trials have reviewed two research questions:

1. What will enhance the learning experience for those in the field and laboratory?
2. How can learning trajectories and appropriate technologies be designed to support equitable co-located and remote learning collaboration?

This paper focuses on describing the iterative linked development of technologies and scientific inquiry pedagogy. Two stages within the research project are presented. The 1st stage details several pilot studies over 3 years with 21 student participants in synchronous collaborations with traditional technology and pedagogical models. Findings revealed that this was an engaging and useful experience although issues of equity in collaboration needed further research. The 2nd stage, in this project, has been to evaluate data from over 25 stakeholders (academics, learning and technology designers) to develop pervasive ambient technological solutions supporting orchestration of mixed levels of pedagogy (i.e. abstract synthesis to specific investigation). Middleware between tabletop 'surface' technologies and mobile devices are being designed with Microsoft and OOKL (a mobile software company) to support these developments. Initial findings reveal issues around equity, ownership and professional identity.

Keywords: *mobile devices, design, distance learning, scientific inquiry, changing environments, access, tabletop systems*

I. Introduction

Educational experiences can occur in a wide variety of locations such as museum visits, theatrical attendance, work-placements and field trips (Lonsdale et al., 2004; Hall et al., 2005, Adams et al., 2005). In this project, our approach is to design hybrid learning experiences supported by a combination of new technologies. The underlying idea is to link students in the field with others situated indoors, supporting a diverse set of learning activities. Elkins & Elkins (2007) identify the cognitive gain of fieldwork by linking theory into practice and translating 2D 'knowledge' into 3D (and even 4D with time) 'understanding'. Collaboration within field studies can also support student identity formation through communities of practice (Wenger, 1998). Through collaboration between both parties, some of the benefits of field activities can be achieved by students who are not physically 'Out There', while those students can be supported by their 'In Here' collaborators. An inspirational analogy is the 'Treasure Hunt' TV game show, where studio-based participants guided a 'skyrunner' over a voice link, searching for clues to lead them to their next location. We propose that having students work together in this interactional way offers new opportunities to synchronously combine field data gathering with research, analysis and reflection. As well as involving students who are unable to go to the site, it can enable more of the inquiry process to happen there and then, rather than field-based students having to hold back on analysis until a later date, away from the actual location

2. Background

Geoscience education emphasises the value of supporting students to develop their expert roles, transferable skills and confidence through collaborative fieldwork (Petcovic & Libarkin, 2007). Mobile technologies can be designed to enrich these 'situated learning' experiences through increased situated data collection, information access and co-located synchronous sharing. Unfortunately, for some, access to such experiences 'in the field' may be limited by disability, cost or timetable. Scanlon et al (2004) argue that students with disabilities are under-represented in higher education science and engineering. It has been identified that remote experimentation can play a key role in increasing accessibility for practical work and experiential learning. However, this work has largely focused on students working in isolation. As collaboration is often a key part of professional learning, this research has sought to uncover how technology can support situated learning experiences through synchronous collaborations that are co-located and at a distance.

The importance of scaffolding for technology enhanced inquiry learning within different contexts is well established in the literature (Rogers et al 2006; Manlove et al, 2006). However, the impact of scaffolding collaborative inquiry-based activities between multiple locations mediated by technology is poorly understood. Moreover, many learners are excluded from field-based collaborations because of physical, economic or social reasons. We suggest that social learning theories ('boundary objects' in particular) are a useful starting point for developing engaging yet applicable technology-mediated scripts to enable co-located and separated group inquiries.

Over recent years there has been an increase in innovative technological approaches to learning in informal and formal field-based situations (e.g. Rogers et al., 2002, Hsi 2003; Lonsdale et al., 2004; Hall et al., 2005, Adams et al., 2005). Some of the questions exposed are being reviewed by previous research on personal scripted-inquiry learning in the 11-14 year group (Collins, T. et al, 2008) and field visualization (Teves, R., 2007). Few of these, however, relate to science learning in higher education (HE) contexts. This project is building on this knowledge base and others to develop inquiry-based activities and visualizations for HE science-based contexts. An increasingly important part of inquiry-based activities is the learner's role and interactions within a relevant community. Latour (1999) talks about this knowledge acquisition as a 'complex process of fabrication and negotiation'. Tuomi-Grohn and Engestrom (2003) argue that it is not knowledge that we are required to transfer from situation to situation but 'patterns of participatory process'. What is agreed between theories, and is a main focus for this research, is the often overlooked importance of collaboration in inquiry-based learning.

In certain communities, collaboration in field-based inquiry is a fundamental part of practice and, accordingly, involvement in field activities makes a significant input to the emerging practitioner identity of the student. However, participation in field work may be circumscribed by issues such as cost, physical access and safety which pose problems in field-based collaboration for some or all students. It is a primary objective of this project to enable equitable inclusion of all learners. To achieve this objective we must review many complicated psycho-social issues surrounding a student's perceived participation within a community.

It is important to understand the role of psycho-social elements in learning. However, it is often cognitive rather than affective issues that are the focus of evaluations. Shulman (2004) argues that emotions are a key element in practice-based learning, with collaboration as the route to overcoming near impossible professional challenges. Some emotions, it is argued, such as anxiety and discouragement (for some closely linked to technology) can be overcome through a collaborative sense of belonging, trust and support. To feel part of a community requires a joint understanding of certain concepts and norms (e.g. roles, relationships, ownership, participation, negotiation, goals). All of these concepts have associated perceived affective connotations relating to levels of participation (e.g. respect, rejection, appreciation, inspiration, deterrent, expectation, reliance, confidence).

This research project uses as a starting point Lave and Wenger's theory (1991) of 'legitimate peripheral participation' and their identification of 'communities of practice'. The theory details how new members are brought into knowledge communities, and how knowledge communities both transform and reproduce

themselves. This participation is at first peripheral, but gradually increases in both engagement and complexity. They go on to argue that the emphasis within learning should be on the whole person, and that learning involves equally the agent, activity and world. Wenger (1999) extends this to a framework in which the two basic streams are *Practice* (from collective social norms of practice to accounts of meanings) and *Identity* (from impacts of organizational power and social structures to those of personal subjectivity). Supporting communities of practice can assist the development of effective ways in sharing knowledge across organizational and situational boundaries, thus promoting collaboration and coordination while also increasing productivity and overall performance (Adams et al, 2005; Millen et al, 2002; Mojta, 2002). However, we also need to understand how disadvantaged groups are pedagogically supported to have equitable interactions within those communities (Shulman, 2004)

Current research into HE elearning communities and their moderation (Preece, 2000; Salmon, 2000), although conceptually rich, focuses on the online context. This project is utilising these knowledge bases and building upon them for the learner transferring between online and offline contexts. Supporting a learner transferring between situations is often left to poorly developed aids (e.g. books, manuals, technology). These items or 'boundary objects' act as an interface between boundaries of domain knowledge and organisational structures (Star and Griesemer, 1989). Boundary objects are often defined as physical artefacts (e.g. technologies, whiteboards) but they may also be 'stuff and things, tools, artefacts and techniques, and ideas, stories and memories' (Bowker and Star, 2000 p. 298). Scripted learning activities, as well as the devices that support them, could equally be considered boundary objects as they move through social networks and communities, playing different roles in different contexts. Mapping boundary object transitions between different community actors can often reflect underlying affective responses, social norms and structures that impact upon learning. Technology is often envisaged and used as a boundary object to support learning within and between communities. However, an understanding of HE learners' affective, cognitive and social perceptions of inquiry-based learning technologies is poorly researched. This project seeks to codify and understand these factors within the context of scripted inquiry-based activities.

Within the technical domain the concept of boundary objects has been encapsulated within the concepts of 'shareability'. There have been some innovative technical developments and evaluations in the field of shareability. Hornecker et al (2007) detail a model for understanding shareability based on entry points (design features inviting interaction) and access points (design characteristics enabling collaboration). This model provides a valuable technical perspective on supporting the design of co-located shareability but doesn't relate this to psycho-social elements of collaboration or learning design. This project will seek to build on this knowledge and fill the gap identified.

Many of the starting points for shareability relate to issues of information 'visualisation'. There is a wealth of research into visualisation; its impact on different types of information (Benford et al, 1999), on cognitive functioning and thus learning (Card et al, 1999; Beale et al, 2006). Visualisations of geological information have tended to concentrate on maps. There is, however, a wealth of geological digital resources to which learners need to relate this information. The Delesse project for the NSF was a large scale US based digital library for the earth sciences. The geoscience digital library project (GDL), in particular, highlighted the role of community engagement with the project. However, research is needed into the integrating of these resources and others through visualisations that are both engaging yet support cognition and collaborative investigations. These objectives are a main focus of this research project.

Finally, Church et al (2006) highlight how co-located collaboration through a table-top facilitated collaborative decision-making for a simple design task. Rogers et al (2006), however, have demonstrated a problem of poor awareness for remote participants in a co-located and remote collaboration activity (i.e. designing a garden). Their research reinforced the need to scaffold learning activities. We are using a scripted learning approach which is well suited to scaffolding within scientific inquiry (Manlove et al, 2006). O'Donnell and Dansereau (1992) and Dillenbourg (2002) have identified the potential to scaffold learning while allowing for personal exploration. However, the development of this approach to collaborative exploration requires further investigation and is a key aim of this project.

3. Studies

A number of user studies with traditional mobile to PC based technologies have been completed. The findings from these studies have been fed into current research development using ubiquitous technologies (e.g. Tabletops, sensors, mapping technology) to support distributed activities that are monitored, logged and analysed.

3.1 Research rationale

Our approach is to support collaborative remote experimentation where students work together across different contexts (Rogers et al, 2009; Hornecker et al, 2007; Koleva et al, 2001; Benford et al, 2009). Two high-level research questions are guiding these studies:

1. What will enhance the learning experience for those in the field and laboratory?
2. How can learning trajectories and appropriate technologies be designed to support equitable co-located and remote learning collaboration?

Of importance in developing these systems is the notion of 'shareability'. By this is meant technologies that are designed specifically for more than one person to use at a time, and in so being used can enable groups to collaborate more effectively. In sum, the project involves:

- Interface design for temporal and spatial issues in co-located and remote collaboration.
- Visualisations to support integration of multimedia data from multiple sources on different platforms, input and output devices (i.e. mobile, table-tops)
- Orchestrating distributed interactions to enable equitable co-located and remote data sharing
- Graceful degradation if and when network problems occur (e.g. lost video links to the team automatically replaced with audio or textual communication).

3.2 Stage 1: Remote to lab-based collaborative learning

The domain in which we have been designing technology enhance learning system is geology where students visit quarries to examine aspects of the earth, e.g., rocks, fossils, minerals, sedimentary layers. Geologists undertake a range of tasks within a geological or environmental investigation (for example, planning, observing, field identification, sketching, measuring, mapping, data collection and recording, finding information in secondary sources, data analysis, interpretation, drawing conclusions and reporting) and students need to understand the methods of acquiring, interpreting and analysing information alongside a critical understanding of the appropriate contexts for their use. One of the key skills involves collecting and integrating several lines of evidence to formulate and test hypotheses. This involves making connections between information which is often situated in different contexts. The integration of fieldwork, experimental and theoretical investigations is therefore vital to the learning experience. Pilot studies have already been completed with groups of undergraduate students and potential adopters (i.e. HEIs & technical developers) for a number of geology field sites (Gaved et al, 2008). In the first pilot study a co-located field helper and a disabled student took part. The initial system was built using a Wi-Fi network that allowed transmission of data from the field to the student by the roadside. These were loaded onto a field laptop running a web server that could be viewed and downloaded synchronously by the student and their supporting tutor; for analysis. In the second pilot study, student teams on location at the geology field site separately and jointly collected, recorded and synthesised geological data which was then remotely shared with home-based students at the University who debated, synthesised and provided data from other sources e.g. internet, textbooks. In this study the field location and the laboratory were separated by several kilometres. This required a more extended network infrastructure to support synchronous remote synthesis of the data collected and analysed. Subsequent studies utilised VOIP (Voice Over Internet Protocol) handsets with wireless network routers configured as a dynamic mesh network, designed to pick up their nearest neighbour and automatically route the signal forwards.

The findings from the two studies showed that students were able to collaborate effectively. The implications from the remote access trials are that mobility impaired students are empowered through having remote

access to field locations and can complete the practical aspects of geology fieldwork. Moreover, engagement with the technology allowing remote analysis of data was perceived as providing an educationally beneficial experience. Ultimately although a remote experience cannot replace a field-based experience, it can provide an additional experience to those at both locations.

3.3 Stage 2: Analysis and ubiquitous technology development

The project aims to explore issues around geological field trip learning that is 'replicated' for students who are not physically 'Out There'. This requires being sensitive to the experiences of both classes of students and their instructors. As a starting point it is necessary to understand the benefits of field trip experiences, so we have begun a process of eliciting qualitative data from stakeholders (geologists, students, academics) on this topic.

Two activities collected stakeholder perceptions; a set of reflective posters situated in a student / academic common room. These asked for responses to the following questions: 1) "What is it about real fieldwork that makes it such a great learning experience?" 2) "What do students NEED to learn in the field?" 3) "What can students ONLY learn in the field?". The data from this revealed 39 threads for analysis. The second research activity comprised of a day long workshop with 24 stakeholders around field-based learning concepts. Responses from both activities were thematically analysed into these threads:

- Social and collaborative learning (e.g. "People, peers, discussion, combined learning journey")
- Immersion in the subject ("Concentrated. Progression of thought is focussed without distraction")
- Scale ("Context –from hand-lens scale to landscape scale")
- Senses ("All senses come into play (smell / feel)")
- Seeing in reality ("It's different imagining rocks from books and pictures than seeing them in real life")
- Reality is complex, and not like the textbook ("That there's no such thing as a perfect example of a rock type").
- Learning the process from observation through analysis ("How to build up a 'story' from lots of observations").
- 3-Dimensional Comprehension ("Relationships between hand sample, outcrop-scale and terrain scale").
- Essential practical skills like mapping, measurement and reporting ("How to locate features seen on a map in the real world and how to put observations onto a map").

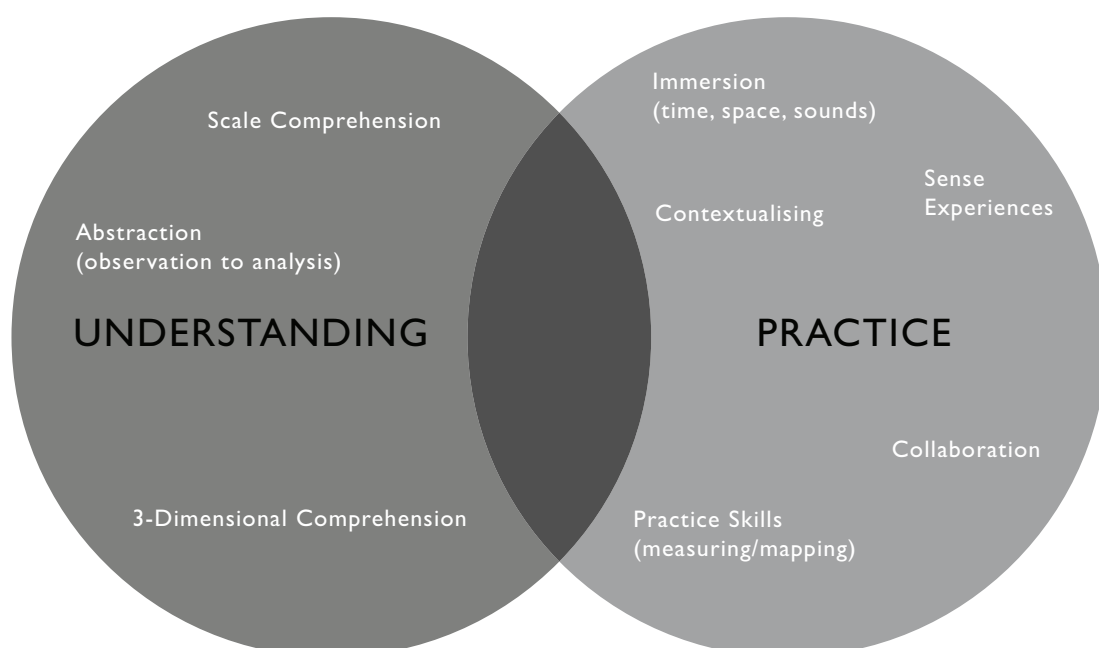


Figure 1. Geologists perceptions of field learning benefits

Figure 1 presents a high-level abstraction of these themes and shows how the benefits of fieldwork can be seen in terms of improved understanding and development of practical skills. Supplemental student learning materials (e.g. fieldwork videos with analyses and conclusions) have also been analysed and fed into an initial model of the experience essentials. Workshops and interviews are being undertaken to develop this understanding further, leading to a detailed set of initial requirements for the system and for complementary activities.

The initial trials have identified that a crucial element of the design process is the importance of technology being led by pedagogical and students' socio-psychological needs. An example summary of a scripted inquiry (see table 1) that has been edited and summarised from the second pilot study illustrates the development of the pedagogy for the next stage of technology development.

Stage	Scripting components	Description
1	Study aim	Interpretation of the past environment through an investigation of the current geological features in a sand quarry.
2	Collaborative Activities	Students are placed into 3 teams to investigate different aspects of the geological evidence: a) palaeontology, b) graphic logging and c) mineralogy and palaeocurrents.
3	Collaborative Procedure	Half the members of each team go into the field and half remain at the 'home-base'. Teams are in communication via audio and video and can exchange digital images.
4	Collaborative pedagogy	Lab and field members of the three teams have scripts (i.e. detailed objectives, stages in the activities, learner role descriptions and assignments, interlinking tool usage) which guide them through a joint investigation with each half of the team using the relevant techniques and tools for the two locations; Lab (e.g. textbooks, identification books and charts, maps, geology software and internet resources) and field (e.g. measuring tapes, trowels, hand lenses, grain size cards, compass clinometers and GPS handsets). Both teams have interlinked tasks requiring communication, collaboration and co-ordination between sites to complete the investigation. Collaborative documents are used to focus on hypothesis generation with evidence e.g. by making and adding to a field sketch and joint voting activities. Throughout the study all the participants debate findings and interpretations, in a group discussion which is mediated by the tutors. Each participant provides information which is then integrated into a shared representation to describe the whole picture. A field and lab tutors will support investigations.
5	Evaluation	Summer 2010: Two field trials will be video recorded, collaboration logs recorded and participants interviewed. Resultant quantitative and qualitative data will be thematically analyzed.

Table 1. Scripted Scientific Learning for Geological site trials (* technology enhanced learning)

The implications from the remote access trials are that mobility impaired students are empowered through having remote access to field locations and can complete the practical aspects of geology fieldwork. Moreover, engagement with the technology allowing remote analysis of data was perceived as providing an educationally beneficial experience.

A user-centered participatory design approach is being employed for the design and development of this technology enhanced learning system (Muller, 1991; Kiili, 2006). System requirements (i.e. functional and non-functional requirements) have been gathered from user trials (initially from the project pilots) and from participant design meetings with end-users (e.g. students and teachers), discipline experts and stakeholders (e.g. geology academics, technology developers, HCI and elearning experts). These design meetings are enabling interdisciplinary participation in the project throughout its life as the system is iteratively developed, evaluated and re-developed.

The findings from the 1st stage research have led initial design decisions to be based on the importance of a distributed interdependency. The next stage of prototyping proposes to develop new ways of connecting those excluded from participating in outdoors activities with those included, providing enjoyable and equitable roles for all. To this end table-tops and innovative mobile devices will be linked through middleware that has the goal of supporting distributed mixed teams to work together cooperatively. In order for students in the field to progress they need to communicate with and follow suggestions made by students at the home station who use the tabletop. Evaluations are focusing on the benefits and limitations of technology-interlinked with socially interdependent experiences. To aid communication we plan to provide two-way audio and video links enabling participants to talk with one another during their data collection/manipulation activities (see Figure 2).

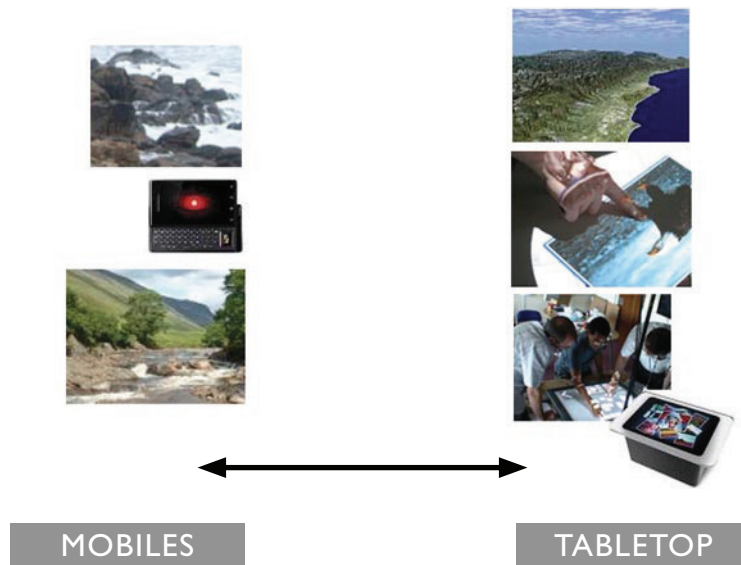


Figure 2. Mobiles and tabletops supporting collaboration and situated learning.

4. Conclusion

The findings to date highlight the value of technology supported distributed collaboration. However, we need to understand better the complex issues of equity in those collaborations. Co-located collaboration in a traditional indoor setting can produce problems with equitable teamwork and shared inputs (Rogers & Price, 2008). Collaboration between distributed teams is likely to increase the inequality of these collaborations. Orchestration of activities and interactions is therefore central. Koleva et al (2001) initially detailed the concept of 'orchestrating' a mixed reality performance where performers orchestrated players' engagement in an interactive experience. They argued that the key factors within orchestration could be utilised in workplace technologies. Benford et al (2009) took these findings further with studies looking at interactional trajectories for tangible interfaces in museums and galleries. Trajectories provide designers with a heuristic to support collaborative experiences over space and time involving multiple roles and interfaces. The current and future research plans of this project are to use the trajectory framework to design the collaborative learning experiences across technologies and locations. These will include determining the timing of interactions, individual roles to encourage collaborative support, different forms of communication for different spaces, establishing appropriate participant expectations and if intervention is needed. The role of a teacher and the student in this trajectory is also paramount. However, a key issue which keeps reoccurring throughout the project is the importance of our understanding of how learning fits with the development of professional skills and identity. The importance, yet complexity, of these issues within technology enhanced learning developments are something that researchers, practitioners and policy makers must understand for future system developments.

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