Technology at work to mediate collaborative scientific enquiry in the field

Hilary SMITH*, Rose LUCKIN, Geraldine FITZPATRICK*,
Katerina AVRAMIDES, Joshua UNDERWOOD
Interact Lab, IDEAS Lab*
Human Centred Technology Group
Department of Informatics, University of Sussex
Brighton, BN1 9QH, UK

Abstract. This paper describes and contrasts findings from two related projects where groups of science pupils investigated local air pollution using a collection of mobile sensors and devices. Both projects however played out in different ways. A qualitative analysis of the projects points to the various issues that contributed to the different experiences despite similar technologies for a similar task. These include: project focus; type of facilitator input and the benefits of in-situ data collection combined with subsequent review and reflection. We point to specific relationships between technologies and context of use, and building on this draw out recommendations for the design of in-context, science learning sessions. This work contributes to the growing conceptual understanding, based on 'real world' experiences, of how mobile and ubiquitous technologies can be appropriated in context to support learning. It contributes to an increased understanding of the types of collaborative scientific activity that are supported by different technology configurations, and the roles that human and system facilitators can play in this process.

1. Introduction

Wireless, mobile and ubiquitous technologies are generating a profusion of potential new ways to engage a generation of inquisitive, technology-savvy students [3, 6]. Combined with exploratory styles of learning, they could support a variety of activities employed by teachers in inspirational, novel and real world learning situations [e.g. 8]. While this potential is widely acknowledged, the question of how best to apply these technologies in learning contexts is still open for discussion and exploration, with relevant concepts, theories and guidelines only starting to emerge. We compare and contrast two studies in which sensing technology was used to afford learners a combination of automatic and manual data collection in two different locations. In this way we can take good account of the contextual factors (e.g. in-situ data collection, type of facilitator input) that influence the ways in which learners and devices interact and also abstract away from the specifics of any single context to contribute to a more general understanding about how we might best use and integrate devices into learning tasks and contexts.

Specifically, we report on two related projects that explore issues around public understanding of e-Science, mobile technologies and learning. We used an exploratory research approach to understand the potential of mobile devices when used as part of a collaborative data-collection process. The emphasis of the first (e-Science) project was on a loosely structured, technology rich session with young students collecting pollution data on a university campus. The second (SENSE) project focussed on a complete scientific enquiry lifecycle, where students explored pollution in their school locality. Both projects used the same suite of data gathering devices, e.g. a Carbon Monoxide (CO) monitor and both had small teams of young scientists working with an adult facilitator.

Our interest here is that even though they utilised the same equipment, the data-logging sessions within each study differed in the level of structure, whether they were single sessions or part of a series of sessions, the role of the facilitator, the type of device/task given. Through qualitative comparative analysis of video and log data, we identify the main issues that arose during the different data collection sessions (task focus, pre-session activities, device control, review activity). These issues point to the ways that the contextual factors contribute to the appropriation of similar tools for similar tasks in different ways. Based on this, we report recommendations for the design of technologies and their use in the educational field-work setting. We conclude by identifying opportunities for focussed studies in this area.

2. Related work and theoretical grounding

Support for collaboration and communication across time and space represent key potential benefits that should be gained from the development of mobile and ubiquitous technologies. These technologies should also allow learners from the nursery to university and beyond to access resources, such as information, software and experts or more knowledgeable peers, to enrich their educational experience and increase their understanding. However, to make the most of what this technology has to offer we need to understand the contextual and social as well as the cognitive (and meta cognitive) aspects of the learner's experience. We have seen that a hands-on experience can lead children to be more imaginative in their understanding of the inter-workings of a living woodland [7]. Both motivational and cognitive benefits have been found when students have greater ownership of their data through data-logging (e.g. see [9]: students learn to focus more on content than the logistics of manual data capture, thus freeing them to interpret and theorise what the data means [10]). It is not surprising then that data-logging is now part of the school curriculum for England and Wales at Key Stages 1-3 (ages 5 to 14 years) [1].

Research within the AIED community has explored how we can design adaptive technology that takes learners' context and potential collaborators into account [2, 5]. Much of this work, grounded in a socio-cultural approach to understanding the learning process, has explored the ways in which technology can adapt to scaffold learners' collaborative interaction [e.g. 2]. We have also noted previously that the introduction of tangible interfaces to collaborative interactions can increase the level of social interaction between collaborators beyond that observed with purely desk-top screen based interfaces [4]. Wireless mobile devices should also allow learners to complete activities, thus freeing them up to think about the underlying scientific concepts and processes.

The educational context in which the technology is to be used is an important design parameter, both because of its impact upon device selection and because of its importance to a socio-cultural approach. Previous research in schools has indicated that the impact of technology is heavily dependent upon the specifics of, and extent to which it is embedded in, the educational culture [12]. Adaptive technologies and context of learning research would suggest that a similar socio-cultural underpinning is appropriate for learning situations that combine and match technologies to the learning task and context. However, it is not clear from the emerging research *how* these technologies might be best combined, matched and applied to support teachers and students. There is work that tries to unpack what it is about tangible and hand-held interfaces that makes a difference to a learner's interactions with them and yet progress towards the construction of a satisfactory theoretical framework is slow [6]; understanding the factors with multiple interfaces raises even more challenges. The focus here is not to unpack the process of learning with multiple technologies, but to address some of the important pragmatic questions that need to be explored first such as: What technologies should teachers invest time in? And what benefits do they provide for both students and teachers?

In this paper we report research that explores how multiple mobile devices provided different opportunities for active and hands-on learning, in real-life situations. In addition, we report on ways in which support with using these types of technologies affects the level of collaborative scientific enquiry achieved, as determined by types of explanations provided by students in the different project contexts. This type of investigation is important to the AIED community if we are to develop intelligent ubiquitous systems that can scaffold learners with resources appropriately targeted to both task and context.

3. The projects

The projects described here provide examples of two different groups of learners in two different contexts exploring their understanding of CO air pollution in a local environment. The sensing and data-logging technology used in both projects enabled a combination of automatic and manual data collection when out on location. Each group was given a ‘tea tray’ [11], an anemometer, a video camera and map of the local area (see Figure 1). The ‘tea tray’ was made up of a CO monitor; a Global Positioning System (GPS) location sensor; and a Personal Digital Assistant (PDA) that logged both the CO and GPS data from the other two devices. The anemometer was used to manually collect wind speed, whilst the video camera enabled learners to record their own data collection process.

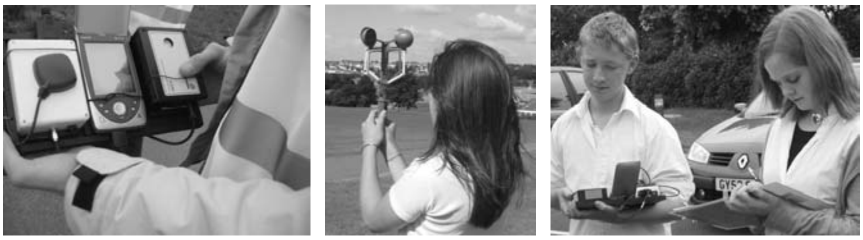

Figure 1 – data-logging technologies

3.1 Project 1 - e-Science

The aim of the e-Science project was to provoke students aged 14-16 years of age to think about how the technologies support their scientific research and learning. Using the domain of CO pollution as an exemplar for this purpose, students learned about factors that might influence local CO levels (e.g. proximity to roads, wind direction and speed, etc.). A guiding principle throughout the sessions was to challenge learners to decide for themselves what e-Science might be. Our intention was for the students’ own interest to drive their research and construction of ideas and knowledge.

A total of 42 students worked in small groups of 2, 3 or 4 accompanied by a facilitator (teacher or researcher), and collected their own local CO and wind readings with the ‘tea tray’ device and anemometer. Students were also asked to make video recordings and were given a map of the campus and locality, around which they could explore. Later in the classroom students reflected on 3D visualisations of the campus overlaid with the CO data they had collected. A total of 12 sessions of 20-30 minutes each took place.

3.2 Project 2 - SENSE

The aim of the SENSE project was to use the exploration of CO pollution to develop scientific enquiry skills among learners aged 13-14 years. Skills included: initial research into a domain; planning an experimental study; articulating hypotheses; hypotheses testing through data-logging; reviewing results and communicating findings to others.

A total of 19 students, working in groups of 3-4, participated in 15 sessions over a 2-week period. Students planned 3 or 4 locations to visit and used identical equipment to the e-Science group (CO 'tea tray', video and wind), with the addition of a paper sheet for logging wind speed and an estimate of its direction. A facilitator (researcher) accompanied each group. In the class-based review sessions, the CO data collected by each group was represented as a graph using a laptop application that synchronised CO readings with video data; students were able to annotate these graphs.

3.3 Students' scientific data collection

By working in groups with a range of devices, the students adopted different roles depending on the device there were using (the 'tea tray', the anemometer, the map or the camera); they were free to swap their device roles if they so chose. The differing goals of each project were reflected in the type of instructions given to students. In general, the groups of students would walk around their survey area, monitoring the continuous read out of CO readings on the PDA. At self-determined intervals they would take a manual wind reading, either stopping to allow their peer to record it, or whilst moving, to check on levels. The CO reading could be automatically noted by pressing a button on the PDA or by writing it on paper, and the wind reading would be written down on a map (e-Science sessions) or wind data collection sheet (SENSE sessions). Maps were annotated by the students to note reading locations as the group moved around.

4. Empirical data analysis

The data collected during the sessions of both projects included video recordings of the data-logging sessions, and logged CO and GPS data. For project 2, SENSE, we also had class based video and annotation data added in the review sessions.

In the analysis of this data, we focus on the following research questions:

- What types of interactions were afforded by the functionality and physical attributes of the different devices?
- What types of group interactions and scientific enquiry activities did students engage in with and around the devices and during subsequent reflective review?

To analyse the videotapes, we produced transcripts and created time-related activity maps (see Figure 2). The activity maps enabled us to build up a picture of the roles played by the different resources, both participants and technological artefacts, in each of the learning situations we investigated. They enable us to unpack indicative ways in which these resources interact and impact upon the nature of the learning activity that occurs; indicative because we are dealing with real world empirical studies rather than carefully controlled lab or classroom based work. However, they are still important for framing the nature of future work, provide guidance for educators wanting to use wireless, mobile and hand-held technology in their teaching and guidance for those involved in the design of such technologies.

Activity maps provided activity overviews that we used to determine patterns and trends in the behaviour of participants. Creation of the maps required charting the learners' interactions with each other and with the data-logging devices. Interactions were categorised to explore the nature of the scientific activities they took part in and the ideas generated whilst using particular types of technology. A segment of an activity map is shown left, superimposed with the actual CO graph, synchronised, at the bottom.

Aspects noted on the maps included: a breakdown of the type of comments made by each person within the group (including facilitator) and different co-operative and collaborative behaviours, e.g. suggesting where to test for CO or communicating readings to the group.

Figure 2 - Activity map

In the following section we discuss the findings from this analysis and the implications arising from them.

5. Findings

The findings covered in this section focus on three areas relating to the research questions above: the nature of the interactions between students and their devices; factors affecting the way groups co-operated around and with devices; and the nature of the scientific inquiry processes that learners engaged in to procure and explain the data-logged results. We discuss examples that illustrate the combined devices' contribution to a collaborative air pollution exploration within the group, and illustrate examples of collaborative behaviour using the devices, combined with levels of facilitator input, to determine effective and non-effective behaviours.

5.1 Nature of interactions between students and devices

Initial analysis of how learners interacted with each device focused on the level of the individual learner's contribution. The patterns of interaction that emerged across all sessions indicated that each device's function and physical attributes afforded a different way of interacting with it.

5.1.1 The importance of the level of control: "Let's note the high readings"

The 'tea tray' PDA automatically logged and displayed CO readings, whilst the anemometer readings were taken less frequently and not always by the person holding it. In contrast with the 'tea tray', students frequently played with the anemometer, blowing at it to get a high wind reading or trying to get the 'spoons' to rotate as fast as possible. Selective sampling also occurred, whereby the highest reading was recorded each time, as the students believed this was the most impressive figure to note. For example, the anemometer holder, on a very windy day, was heard saying: *"It was 6 [metres per second] a minute ago"*, encouraging the noting of that figure rather than the current 0 or 1 reading.

This presents an interesting set of trade-offs for design. Whilst the ability to control and explore a device is important to understand the properties of what is being measured and learn about accurate science data-logging, an automated wind-measuring device would reduce the level of control the wind person has over readings, and would give a more accurate value at the time requested. A digital device would have the added benefit of being more easily synchronised with the CO data for classroom reflection.

5.1.2 The value of a data history: Carbon Monoxide data-logger

The person holding the ‘tea tray’ played a key role since the user-interface of the ‘tea tray’ was only visible to the person holding it and, therefore, the group had to rely on that person to communicate the CO values. Across all sessions then, engagement with the device was high and the person allocated to this device tended to keep the group informed of any changes in CO levels. However, we also saw communication breakdowns occur when there was no change in CO levels to report, and when the person carrying the ‘tea tray’ was too shy to take the initiative and call out a reading without being prompted.

While the calling out of CO values depended partly on the personality of the student holding the ‘tea tray’, the addition of a trend graph was found to be particularly useful when the CO person had been quiet or distracted. For example, the wind device holder took on the role of reporting CO in the absence of the CO person or video person doing this:

> Wind device holder comes over to look at CO: *“how come it’s gone up so much?”*
> Camera person: *“it went up to about 6.5 [parts per million] ... yeah that engine…”*
> Wind person [gets Camera person to move camera on to him]: “*The Carbon Monoxide went up greatly because there was a parked van with its engine running still by us*”.

The trend graph in this instance enabled the wind device holder to determine how quickly CO had risen, giving him a timescale for reasoning out why the rise occurred.

5.1.3 The potential for distraction: Video camera

We found the camera person tended to be the least informed about the data readings as they stood back to capture the group. They were often heard requesting readings from the two data-logging device people, and asking *“what are we doing now?”*. We also noted a strong tendency for the camera person (more than the other roles) to be distracted away from their task of filming by other peers, workmen, teachers and members of the public. To reduce this dis-engagement with the task we would suggest the video person is encouraged to take on an 'interviewer' type role. This could reduce the physical space between group and camera person, give more purpose for all members of the group to narrate their activity to camera, and reduce the likelihood of distancing any individual from the group.

5.2 Collaborating and engaging in scientific enquiry

5.2.1 The importance of facilitation

The facilitator role was important in shaping group interactions during the data collection sessions by engaging the group and encouraging critical thinking. The differences in focus of the two projects resulted in different facilitator emphases, for example allowing free exploration (e-Science session) as opposed to the testing of CO at pre-planned locations, interspersed with on-the-fly stops (SENSE session). In particular, effective actions were identified as prompting for CO and wind readings; for hypotheses to explain CO readings; for locations where CO levels would be high; and encouraging students to contrast with previous places visited.

In response to a SENSE facilitator asking why they thought the busy road had not produced as much change as predicted, the students engaged in 4 minutes of discussion, resulting in three hypotheses being verbalised on the effect of cars; buses; and diesel versus petrol engines on CO. These developed hypotheses were not the focus of the e-Science sessions and did not occur in those sessions. Poor facilitation occurred on both projects when the facilitator’s intervention was minimal, resulting in students data-logging without questioning their readings, nor developing explanations or interacting with each other beyond carrying out minimal task activities.

5.2.2 The role of in-situ explanations and reflective review

The effect of environmental context on explanations was salient in both groups. Once the students had started to collect readings, they gave a range of explanatory reasons including reference to the presence (or absence) of wind speed and direction, car traffic, larger vehicles, and proximity to vehicle exhausts. Some groups were further motivated to control conditions to test out their developing ideas: one SENSE group used a pedestrian crossing to stop traffic and see whether a build up of CO occurred. This led them on to consider the direction of wind movement to determine whether they had chosen the best location relative to the queuing traffic, and then reposition the 'tea tray' down-wind. Julie summarised her thoughts: "*at the traffic lights cars stop then they start again so they must go, chuck a lot more carbon monoxide out*."

The technology used by both projects described here enabled students to combine readings from different devices, to pool the ideas they had formed from their different device perspectives, to re-formulate hypotheses and to adjust their data collection plans in order to test these hypotheses. When they did return to the classroom they could reflect upon their experiences, review their findings and their data collection skills. SENSE students reflected upon and learned how to improve the process of collecting data by reviewing their video and data. When making annotations students often referred to their lack of good filming skills, and occasionally found, for example, that a high CO reading had occurred and gone unnoticed. It was instances such as these that encouraged them to revisit parts of the video recordings to identify exactly what was happening. In this way the review session helped students analyse the data in a more productive way than the visual graphing of data points alone [1].

A key value that arose from the review sessions was that groups developed their hypotheses and adjusted predictions for CO levels in preparation for the second data collection session. In the second data-logging session as compared to the first, most students engaged in more narration activities, with spontaneous sharing of readings within the group, more data requests of each other and fewer incidences of distraction. For example one group's narration and direction comments increased by 150%, and their communication of readings increased by 200%.

6. Discussion, conclusions and future work

We have presented illustrative findings from two related projects, which identify the factors affecting group interactions around hand-held devices from the perspective of single and multi-session investigations by students. We found that the major impacts on device activity were: the ability to control and explore devices, the availability of trend data and the amount of distraction created by device roles. The type of facilitator input affected group co-operation; and the combination of in-situ data collection sessions interspersed with reflective review produced valuable opportunities to develop group ideas and hypotheses. From our findings we have gained an increased understanding of what needs to be done to facilitate learning around such technologies. We would recommend the following considerations in designing similar data-logging experiences, these include pointers for the development of software enabled scaffolding interventions:

- Consider the trade-offs between a controllable interface versus an accurate data log.
- Provide trend data particularly for variable data such as wind readings.

- Remind learners to vocalise information regularly with peers, which could be given through PDA-initiated prompts to answer related questions.
- Consider the use of larger screens and audio displays to allow all group members to be aware of general trends in data-logged readings.
- Scaffold appropriate facilitator input e.g. via PDA using a suggested question for group discussion, triggered by location, incorporating current data-logged values.

Our experience clearly shows the need for future work to focus on the effects of building 'roles' around devices and of facilitator input. For example, what kind of guidance should facilitators provide, and how much? Could some of this input be mediated by a combination of user modelling, combined with location sensing, and hypothesis knowledge – and should it go directly to the students, or prompt the facilitator to ask students? One aim would be to build relationships within the group over time to create a more talkative, thinking, creative dialogue to enhance learning and collaboration by each group member.

7. Acknowledgements

We would like to thank Danae Stanton Fraser, Sara Price, Ella Tallyn, the SENSE project collaborators at Nottingham, session participants including David Daniels, Steve Rogers, teachers and pupils at Varndean and Hove Park Schools, Portslade Community College. The e-Science project was part of the Equator IRC (www.equator.ac.uk). The SENSE project was funded by the JISC.

8. References

[1] DfES (2005). The Standards Site. Department for Education and Skills, UK Government, http://www.standards.dfes.gov.uk verified 9 February 2005

[2] Greer, J., McCalla, G., Cooke, J., Collins, J., Kumar, V., Bishop, A. and Vassileva, J. (1998) The Intelligent Helpdesk: Supporting Peer-Help in a University Course. In *Proceedings of 4th International Conference on Intelligent Tutoring Systems,* 494-503

[3] Luchini, K., Quintana, C., Curtis, M., Murphy, R., Krajcik, J., Soloway, E. and Suthers, D. (2002). Using Handhelds to Support Collaborative Learning. *Computer Support for Collaborative Learning,* 704-705

[4] Luckin, R., Connolly, D., Plowman, L. and Airey, S. (2003). With a little help from my friends: Children's interactions with interactive toy technology. *Journal of Computer Assisted Learning (Special issue on Children and Technology),* 165-176

[5] Murray, T. and Arroyo, I. (2002) Towards Measuring and Maintaining the Zone of Proximal Development in Adaptive Instructional Systems. In *Proceedings of Sixth International Conference on Intelligent Tutoring Systems,* Springer

[6] Price, S., Rogers, Y., Scaife, M., Stanton, D. and Neale, H. (2003). Using 'tangibles' to promote novel forms of playful learning. *Interacting with Computers,* 15(2), 169-185

[7] Rogers, Y., Price, S., Randell, C., Stanton Fraser, D., Weal, M. and Fitzpatrick, G. (2005). Ubi-learning Integrates Indoor and Outdoor Experiences. *Communications of the ACM,* 48(1), 55-59

[8] Roschelle, J. and Pea, R. (2002) A walk on the WILD side: How wireless handhelds may change CSCL. In *Proceedings of Computer-Support for Collaborative Learning,* 51-60

[9] Sims Parr, C., Jones, T. and Songer, N. (2002) CyberTracker in BioKIDS: Customization of a PDA-based Scientific Data Collection Application for Inquiry Learning. In *Proceedings of Keeping Learning Complex: The Proceedings of the Fifth International Conference of Learning Sciences (ICLS),* Erlbaum, 574-581

[10] Stanton Fraser, D., Smith, H., Tallyn, E., Kirk, D., Benford, S., Rowland, D., Paxton, M., Price, S. and Fitzpatrick, G. (in press) The SENSE project: a context-inclusive approach to studying environmental science within and across schools. Accepted for publication for *CSCL'05*

[11] Steed, A., Spinello, S., Croxford, B. and Greenhalgh, C. (2004) e-Science in the Streets: Urban Pollution Monitoring. In *Proceedings of 2nd UK e-Science All Hands Meeting 2003*

[12] Wood, D., Underwood, J. and Avis, P. (1999). Integrated Learning Systems in the Classroom. *Computers and Education,* 33(2/3), 91-108