Support for evidence-based inquiry learning: Teachers, tools and phases of inquiry

Scanlon, E., Littleton, K., Gaved, M., Kerawalla, L., Mulholland, P., Collins, T., Conole, G., Jones, A., Clough, G., Blake, C. and Twiner, A.*

*Open University, UK and *University of Jyväskylä, Finland*
e-mail for correspondence: e.scanlon@open.ac.uk

Background

The Personal Inquiry (PI) project (http://www.pi-project.ac.uk/), currently being conducted by the Open University and University of Nottingham, is designed to help school students learn the skills of evidence-based inquiry (Collins *et al.* 2008). Project partners include schools, museums, community education centres, field centres, and a sensor and data logging company.

The broad aim of the project is to understand how effective inquiry learning can be enabled with technology across formal and informal settings. More specifically, the focus is on designing blended support for evidence-based inquiry learning such that pupils can be supported to understand the inquiry learning process. Learners are guided through a process of posing inquiry questions, gathering and assessing evidence, conducting experiments and engaging in informed debate on topic themes of personal relevance within the parameters of the secondary-level UK National Curriculum.

To address the question of how students' inquiry learning can be supported we are developing (through a participatory design process involving both teachers and students) an innovative 'scripted personal inquiry learning' approach. This approach involves young people (aged 15-16 years) in carrying out scientific explorations supported by their teachers and resourced by a personal inquiry toolkit.

The Personal Inquiry project toolkit, which supports inquiry learning, comprises a software application, called an 'Activity Guide' together with the associated hardware support for conducting the inquiry (including a range of sensors for use in collecting data - such as temperature and wind speed). The Activity Guide running on both Ultra Mobile PCs and regular desktop machines supports students in defining, organising and carrying out their inquiry, and resources their decision making and progression through the inquiry.

The Activity Guide is driven by a formal inquiry learning script which specifies how the inquiry is organised and presented, thereby helping the learners to plan and monitor their work. The script enables the teacher to orchestrate activities, for example, through specifying who can progress through a given inquiry and by what means (see Mulholland *et al*. 2009) and by altering both the content and availability of activities (which learners undertake over the course of the inquiry) as it progresses.

Underlying the design of the Activity Guide is a personal inquiry framework (see Figure 1 below) that has been developed by the PI team (see Anastopoulou *et al*. (in preparation) for further detail) and which we have used as an intermediate representation of the inquiry learning process to aid our thinking. This framework is a characterisation of the phases of the inquiry learning cycle that need to be supported:

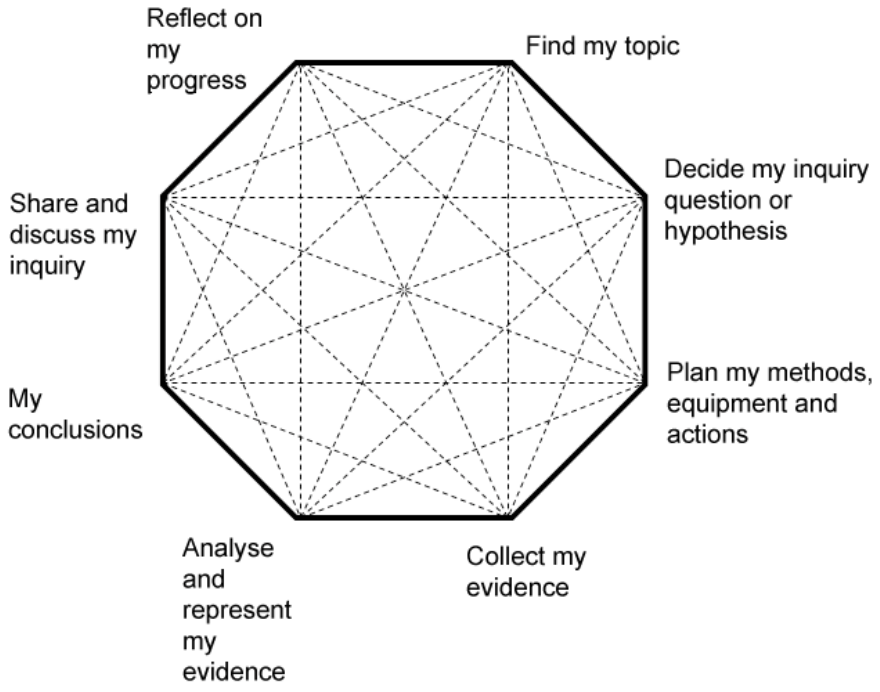


Figure 1: a representation of the inquiry learning cycle

The framework was derived from the inquiry learning literature and pilot studies which identified particular areas of difficulty for young people pursuing inquiries. It fills a gap in the literature on scaffolding inquiry see e.g. Quintana *et al.* (2004). Quintana *et al.* (2004) whilst providing a valuable framework by which software supports for inquiry learning can be considered, do not address the support necessary when data collection episodes are included within inquiries.

The PI project has been running for two years now and during this time we have supported over two hundred students involved in a range of personal inquiries. The students' investigations have concerned topics such as:

- Diet: which involved students in making predictions as to the nutritional quality of their diet, testing these by keeping a diary of their meals and snacks and then using this to calculate their nutritional intake;

- Urban Heat Islands: where students were developing hypotheses as to how temperature varies across an urban area, making measurements and observations, and using these to explain any variations in temperature observed;
- Microclimates: involving students in deciding where in the school grounds would be the best locations for different types of activity, and then collecting scientific data at different locations in order to test their predictions.

The focus for this paper: the Urban Heat Islands intervention

In this paper we focus on the development and trial activities associated with a school-based intervention involving 15 year-old students' use of a location-based inquiry learning toolkit to support a Geography project on the topic of urban heat islands. In particular we will be considering the question: How is cumulative knowledge-building supported and resourced over the duration of the extended inquiry learning activity? The project has been undertaken in partnership with a school in Milton Keynes whose teachers were interested in developing inquiry-based project work which their students could undertake for GCSE coursework.

The project involved students in the development of a personal inquiry on the topic of urban heat islands. It comprised a series of introductory lessons, intended to orient learners both to the project and to the technology, associated group-based field trip activities and an extended set of lessons, and informal after-school sessions, where students generate their personal research questions and associated hypotheses, work through their data, test their hypotheses and produce individual final reports. This project was run over school two years and involved around 78 students for the first iteration and 57 students in the second iteration. We studied this intervention by collecting: interview data, videotaped observations, the data students collected during their investigations and the notes and products created by the learners and teachers during the trials.

The toolkit

The Personal Inquiry project toolkit which supports inquiry learning comprises a software application, called an 'Activity Guide' together with associated hardware for conducting the inquiry including data loggers, science sensors, and cameras.

The Activity Guide uses a content management system built on a database, presenting a web browser to the participating students. A web browser interface was chosen as this is a familiar tool to all school students so little training in its use would be required as a result. The Activity Guide was accessed via a central server at the Open University and local copies could also be run on Asus Eee ultramobile PCs for fieldwork data collection. The Activity Guide structure was devised in collaboration with the school teachers and led the students through the stage of the science inquiry undertaken (in this case an exploration of the urban heat island phenomenon) through navigation tools such as menu bars and tabbed information boxes (see Figure 2). The structure was also informed by the phases of the inquiry learning cycle.

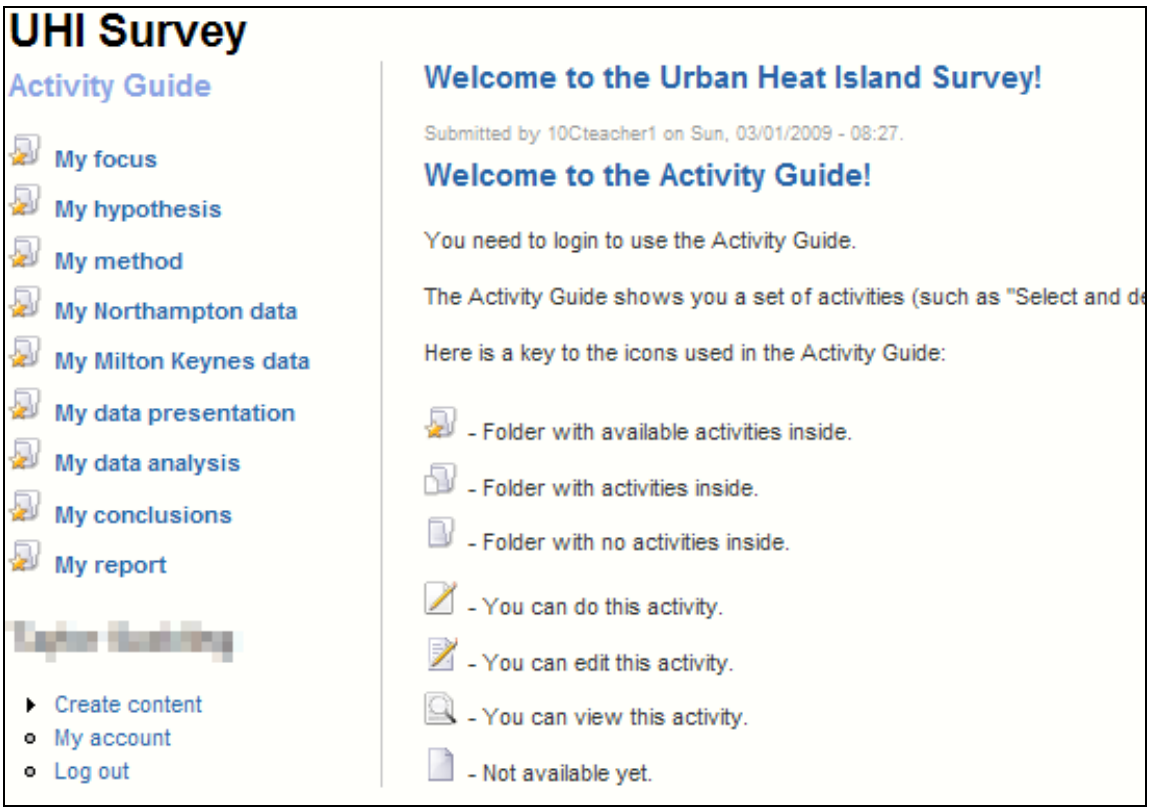


Figure 2: Introductory screen for the Activity Guide showing phases of the inquiry (student logged in)

Data gathering was location based, and this was determined by the use of GPS (Global Positioning System) data receivers. Scientific data was collected using Sciencescope Data Loggers and sensors. Specific sensors used measured:

- wind speed
- air temperature
- infrared irradiance from built environment surfaces
- carbon monoxide

Additionally, students were given cameras to take photos of features of interest.

Research generation

At the beginning of the inquiry, students used the Activity Guide in the classroom to type in an overarching hypothesis and were then prompted by the teacher and the software to break this down into at least two and possibly up to six constituent 'key questions'. This was accessed from a central server at the Open University and students entered their data via school computers logged into this service.

Students then chose from a selection of measures how they would undertake their research, and then considered which tools would be most appropriate to choose to collect data to respond to their questions.

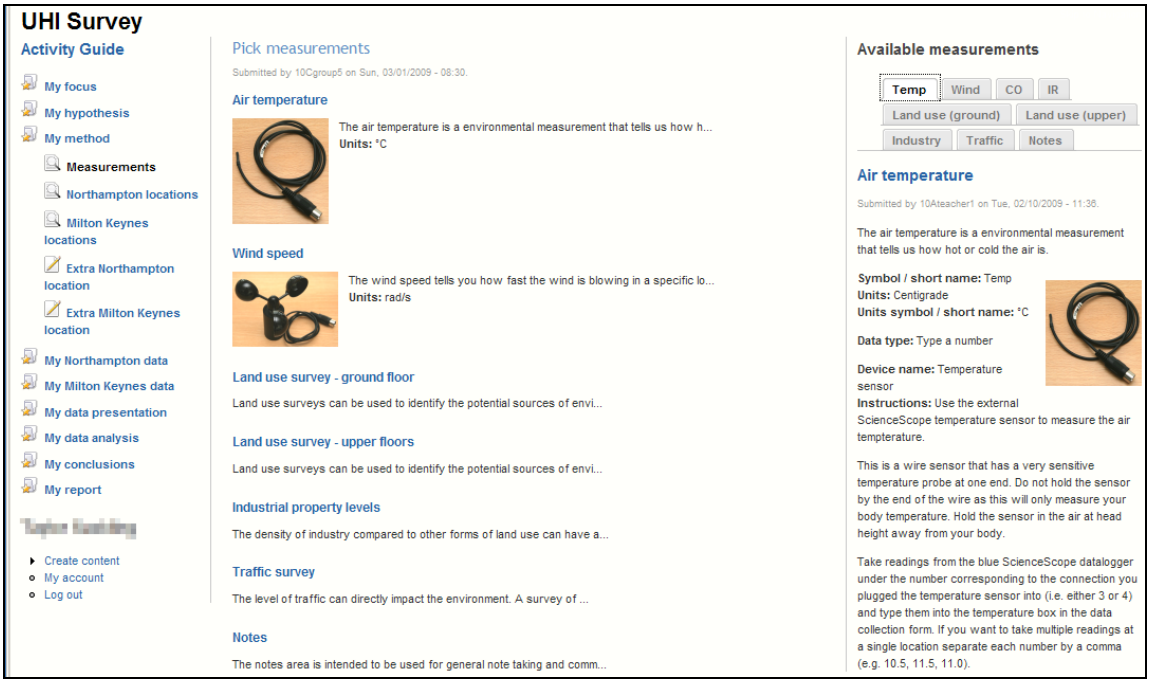


Figure 3: "My method" screen showing measures having been chosen by a student

Students were supported in formalising their inquiry by supporting documents held in the Activity Guide. These had previously been created by the teachers and were accessible to the students throughout the project by clicking on links in the menu bar. Supporting documentation included introductions to the topic, exam board guidelines, and a report writing checklist.

In practice, the teachers introduced the topic to the students before the laptops were brought into the classroom, so the above steps were retrospectively undertaken once the students had returned from their field trip. Teachers grouped students mostly by friendship groups.

Data Collection

The second stage of the inquiry project was for students to go out into the field and collect data by walking on a transect across two towns, Northampton in the morning and Milton Keynes in the afternoon. Data was gathered based on location, determined by the use of a Garmin eTrex handheld GPS (Global Positioning System) receiver. Students worked in groups of approximately four. Each group of students assigned one of their peers to take readings at the locations they stopped at, with the receivers set to display UK Ordnance Survey format readings (a format the students use in the geography lessons).

The central data collection tool was the Activity Guide on the Asus mini-laptops, and one student in each group was designated as the 'scribe' to gather in readings from their peers and add further notes. The Activity Guide ran on the laptops independently, with no connection back to a central server or to other laptops in the field.

Scientific sensors were provided by the PI project partner Sciencescope, and consisted of a Data Logger with digital readout, enabling a number of separate sensors to be plugged in. Data can be captured automatically on the Loggers and later downloaded. In this field exercise, however, it was decided for pedagogical reasons that a student from each group would be assigned to take readings at the chosen locations, and read out the data from the Data Logger's display to another student in the group who would then enter them in to the laptop's Activity Guide software.

As noted above, science sensors used by the students for the UHI2009 fieldwork were selected by the students and their teachers from:

- anemometer (measuring wind speed)
- Infrared irradiance (measuring heat energy coming from surfaces in the built environment)
- Air temperature
- Carbon monoxide levels

In addition to these quantitative data measurements, students also collected observational data, choosing from a selection of surveys built into the Activity Guide (generated from the teachers' guides) including

- traffic volume
- building use
- levels of industry

All students were asked to take field notes and add these into a comments box at each of the locations they visited, noting any aspects of interest, and to also take photographs with a supplied camera to illustrate their points and act as aides-memoire.

Data was collected at twelve locations pre-selected by the teachers having undertaken walkthroughs of the transect across the towns, with the locations chosen for approximately equal spacing though considering places that might be geographically interesting or practically suitable to stop 30 school students. Students were able to add extra locations along this transect if they found additional locations they wished to report on.

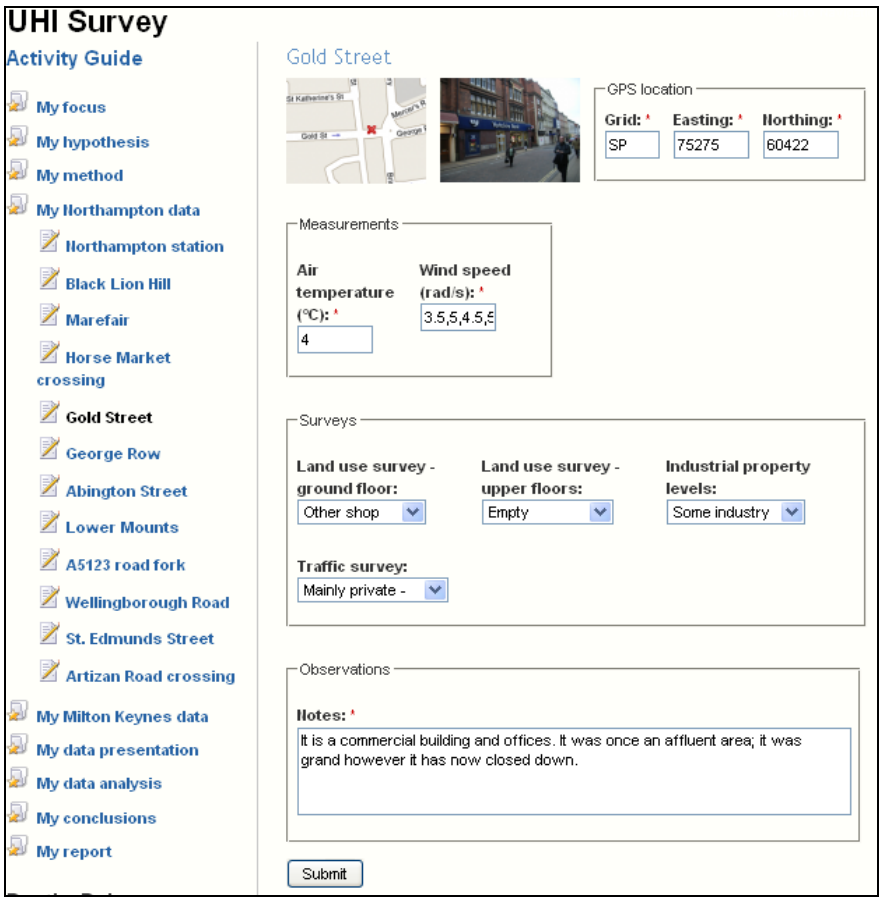


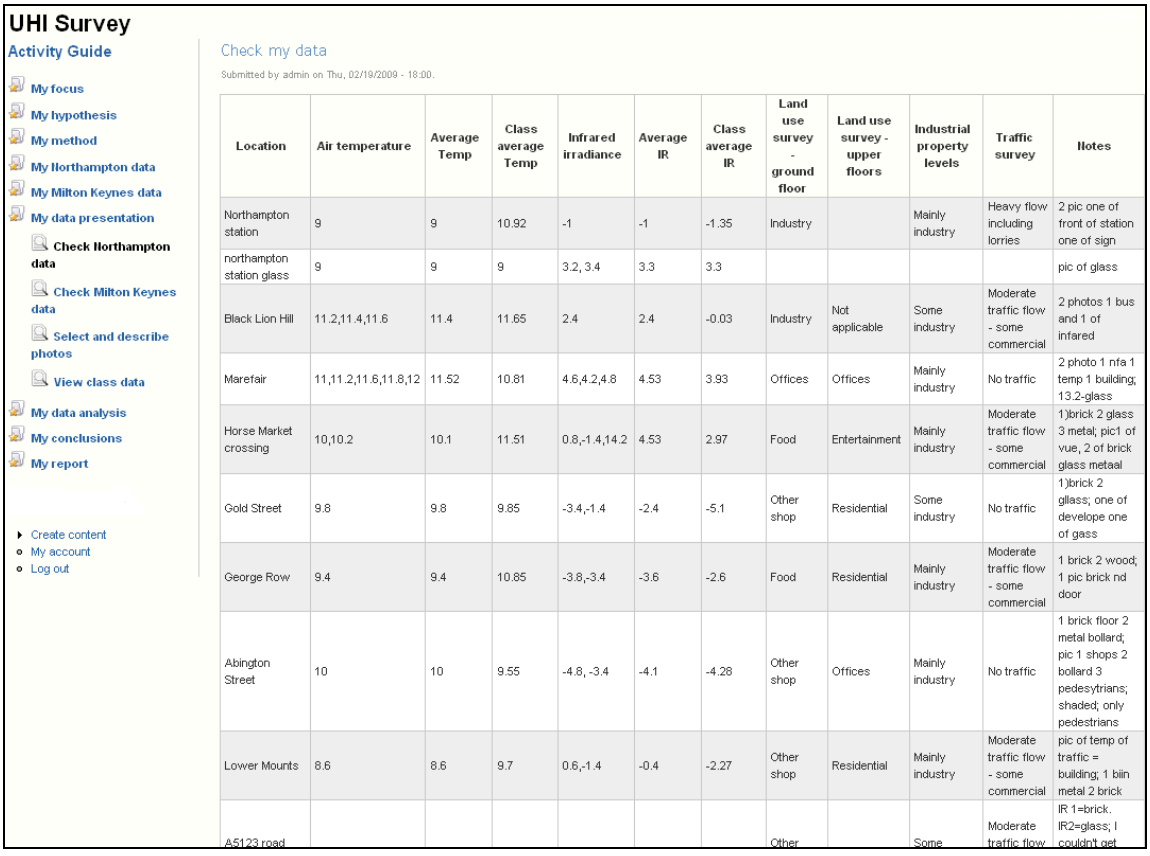
Figure 4: Data Collection screen

Data analysis and report writing

On return, the laptops were synchronised with the central server and the individual groups' data uploaded. From this point the students worked from the server, either through a school computer, the mini-laptops, or their own home computers, all connecting through the internet. Mini-laptops were made available for those students who wished to access the server from home but did not have access to their own computer.

Data was first checked in classroom sessions to correct any mistakes, and also to flesh out field notes. We saw several examples of students revisiting their field notes in the "Comments" boxes and adding more details, as well as correcting errors in data fields and filling in missing data by collaborating with their peers and using their readings. Students were able to compare their data with the class average data as a means of checking their data was in the correct territory.

At this point students were moving from working in groups to working individually, though there was an initial period when students in the classroom referred to the fieldtrip team members to align each others' data and clarify what had been collected; some students had focussed on their role and not been keeping aware of the broader team gathering picture, and required help from their peers to interpret some aspects of the data.



Location	Air temperature	Average Temp	Class average Temp	Infrared irradiance	Average IR	Class average IR	Land use survey - ground floor	Land use survey - upper floors	Industrial property levels	Traffic survey	Notes
Northampton station	9	9	10.92	-1	-1	-1.35	Industry		Mainly industry	Heavy flow including lorries	2 pic one of front of station one of sign
northampton station glass	9	9	9	3.2, 3.4	3.3	3.3					pic of glass
Black Lion Hill	11.2,11.4,11.6	11.4	11.65	2.4	2.4	-0.03	Industry	Not applicable	Some industry	Moderate traffic flow - some commercial	2 photos 1 bus and 1 of infared
Marefair	11,11.2,11.6,11.8,12	11.52	10.81	4.6,4.2,4.8	4.53	3.93	Offices	Offices	Mainly industry	No traffic	2 photo 1 nfa 1 temp 1 building; 13.2-glass
Horse Market crossing	10,10.2	10.1	11.51	0.8,-1.4,14.2	4.53	2.97	Food	Entertainment	Mainly industry	Moderate traffic flow - some commercial	1)brick 2 glass 3 metal; pic1 of vue, 2 of brick glass metaal
Gold Street	9.8	9.8	9.85	-3.4,-1.4	-2.4	-5.1	Other shop	Residential	Some industry	No traffic	1)brick 2 gllass; one of develope one of gass
George Row	9.4	9.4	10.85	-3.8,-3.4	-3.6	-2.6	Food	Residential	Mainly industry	Moderate traffic flow - some commercial	1 brick 2 wood; 1 pic brick nd door
Abington Street	10	10	9.55	-4.8, -3.4	-4.1	-4.28	Other shop	Offices	Mainly industry	No traffic	1 brick floor 2 metal bollard; pic 1 shops 2 bollard 3 pedesytrians; shaded; only pedestrians
Lower Mounts	8.6	8.6	9.7	0.6,-1.4	-0.4	-2.27	Other shop	Residential	Mainly industry	Moderate traffic flow - some commercial	pic of temp of traffic = building; 1 biin metal 2 brick
A5123 road							Other		Some	Moderate traffic flow	IR 1=brick. IR2=glass; I couldn't get

Figure 5: Data presentation screen

This was the point at which we saw students reflecting on their collected data, revisiting their Activity Guide notes, improving them and using them as aides-memoire to help remind them of the evidence they had found at each location. Students moved through iterations of improving their recorded data until they were satisfied with what they could save and then present.

Photographs had been uploaded to the central server by the Open University team on the students' return from their field trip and these could now be accessed via the online Activity Guide. Students were encouraged to select from their library of shots, and add captions to chosen photos.

Students would then be presented in a "data analysis" section with their key questions and asked to generate tables with a subset of data, drawing in relevant selection of data to respond to their specific enquiries, e.g. if a student was interested in the possible correlation between levels of industry and CO output, they could select just these data types across all locations. Selections of data were then viewable as tables showing all locations across both towns (one table for each) and the table could be downloaded as .csv format (for automatic import into Excel spreadsheets) or .kml format (and automatic generation of labelled Google Maps).

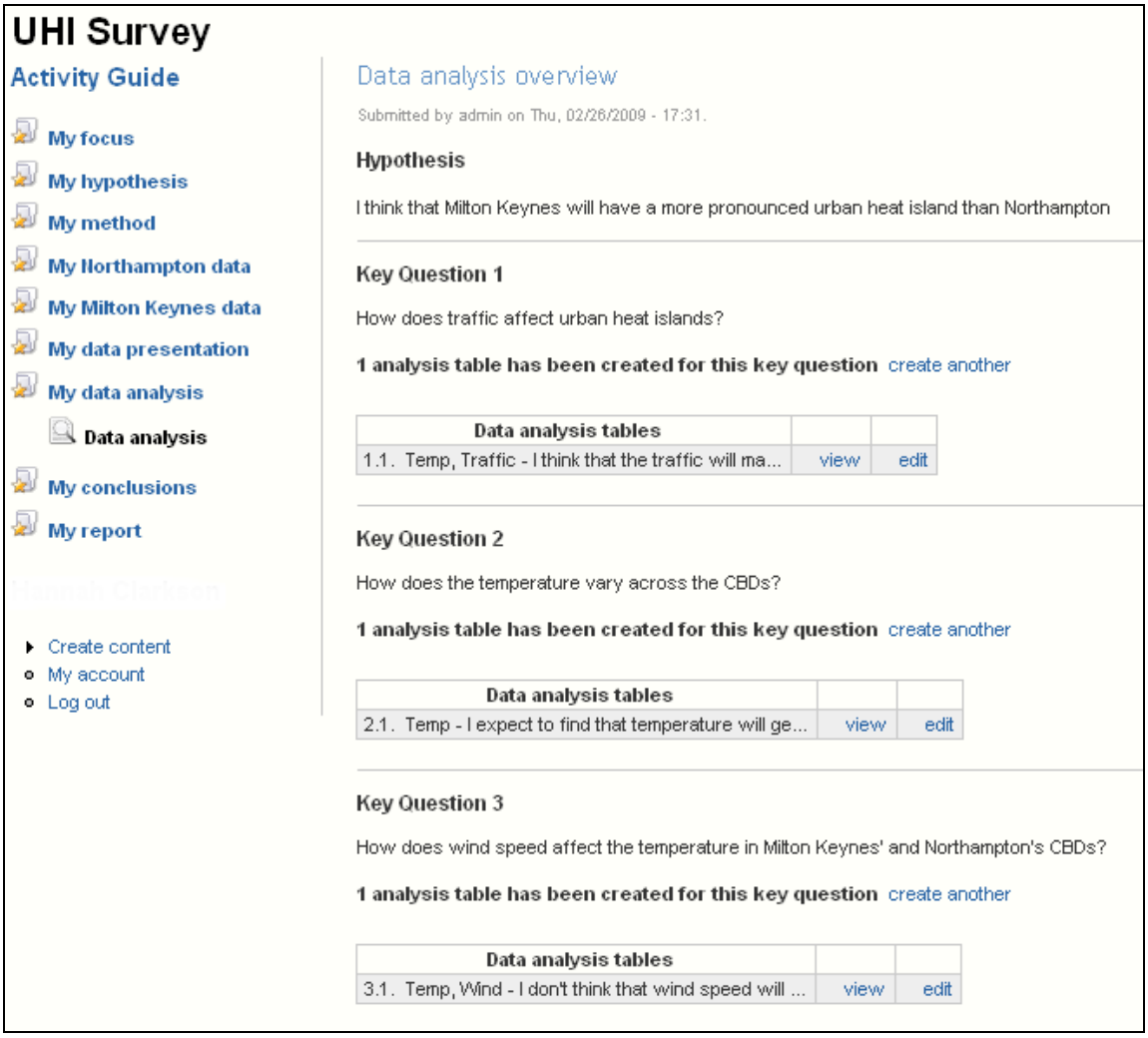


Figure 6: Data analysis overview – student selecting relevant data types to compare for their Key Questions

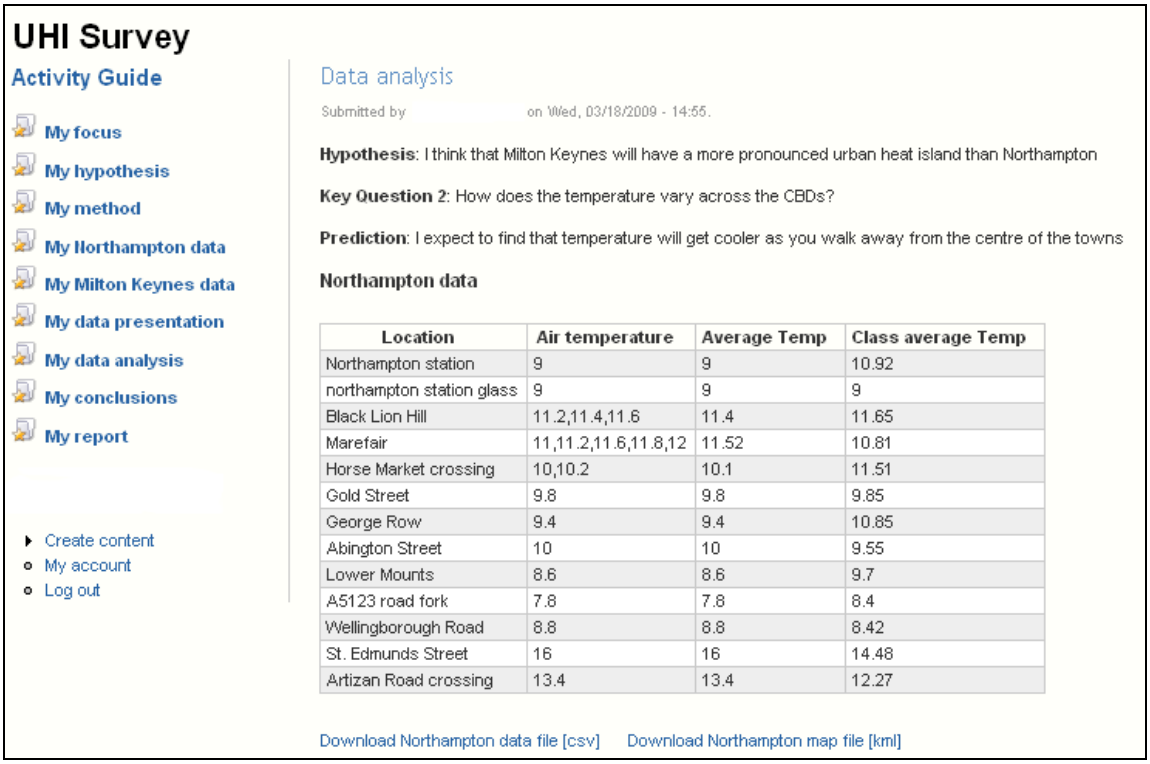


Figure 7: Data analysis table view – student comparing selected measures to analyse Key Question

The Activity Guide enabled students to then add in a conclusion. A screen was presented to the students via the menu bar with their original hypothesis, and their key questions, and a text box to enter their final conclusion. However we found that the students, having downloaded their data analysis to Excel and Google Maps, continued from this point working in other software packages, primarily Microsoft Word, to write up their reports and did not use this function.

The primary write-up tools for the students report were Microsoft Word and Excel and once data had been analysed, corrected, and improved within the Activity Guide we found that students would output their work to these tools and work from there.

We now draw upon interview data, videotaped observations, the data students collected and the notes and products created by the learners and teachers during the trials to explore the following question:

How is cumulative knowledge-building supported and resourced over the duration of the extended inquiry learning activity?

Cumulation

A key educational challenge facing the teachers working on this project, which spread over 12 weeks, was how to ensure that the overall educational experience for the students was one that was genuinely *cumulative and reciprocal*, rather than simply extended in time (Alexander 2004; Mercer and Littleton 2007). As Douglas Barnes has observed: 'Most learning does not happen suddenly: we do not one moment fail to understand something and the next moment grasp it entirely' (Barnes 1992: 123). Thus the teachers involved in the project needed to work hard to create continuity between ideas and events across time and they confronted the complex issue of how to support and resource the development of linked 'chains of inquiry'.

Our initial analyses of the teaching-learning interactions suggest that through a complex series of recaps, elicitations and reformulations (Mercer 1995) the teachers worked, in their talk, to create cohesion and continuity from what might otherwise be seen by students as no more than a series of disparate events. The teachers thus aimed to foster students' understanding of the scientific inquiry process within a 'meaning making trajectory involving the *progressive integration over time* of the diverse semiotic resources and representations that were being (re)constructed and encountered, including those afforded by the use of the computer toolkit. Such trajectories may last mere seconds or minutes or may occur over much longer periods of time, as well as being picked up and resumed across separate occasions (Baldry and Thibault 2006: 116).

What was apparent is how the affordances of the Activity Guide distinctively entered into and resourced the processes of *connection building* across phases of activity. From the learner's perspective, the work they were undertaking began to develop a cumulative quality in which specific activities, and their goals, began to form part of a greater whole - a purposeful educational 'journey' through which they came to understand the nature and processes of the inquiry learning cycle.

Consider as a specific example, the students' use of the qualitative free text 'Comments' boxes that were aligned with the numerical and categorical data entry boxes. These were designed to enable students to capture, during the data collection phase of their work, important contextual information that would assist them in the interpretation of their data following analysis. Initially the students used these boxes to 'record' data. In subsequent lessons, however, as they moved towards the individual reporting of their investigation, they began to rework and refine and continually edit and save the text within the boxes. In doing so the text became an ongoing work in progress. It became an iteratively refined aide memoire and repository for capturing emerging ideas and thinking, over time, in respect of the interpretation of their data and key findings. So the initial contextual information recorded in the comments boxes provided an 'anchor' (Schwartz, Lin, Brophy and Bransford, 1999) from which to build knowledge and understanding. This process of reworking using the comments boxes seemed to support the students' in making connections across different phases of the inquiry cycle – work undertaken as part of the data collection phase became connected to and resourced further work in respect of interpretation and reporting:

> *…. when they were out there [on the fieldtrip], it was just something to record their data on…then as the whole thing has progressed, lots of them have started to use it more, like a lot of them have been writing all their Word bits in it, and then copying that into their Word documents….some of them were properly filling in the comments bits, and their introduction bits, so some of them were writing those in... Some of them were really using it, because then, obviously it's really supporting their learning. And those students that have been able to – at the start*

> *it was just something to record the data on, but then when it became apparent what you could use it for then it really has supported their learning.*
> *(Teacher interview)*

So rather than moving through a sequence of prepared screens, with the associated dangers of fragmenting and compartmentalising learning, the students' iterative use and re-use of the comments boxes resulted in the construction of a kind of 'narrative trail', somewhat akin to the workings of a problem, which could be saved, remaining visible to the learner, their former group-mates and the teacher who are able to offer reflections, reactions and comment. The material is thus available for working on in the present, using material generated in the recent past and in anticipation of future use. Similar processes of connection-building and iterative refinement of material were also evident in relation to the students' drafting and reworking of the formulation of their hypothesis and associated key questions as the inquiry unfolded (Figure 8).

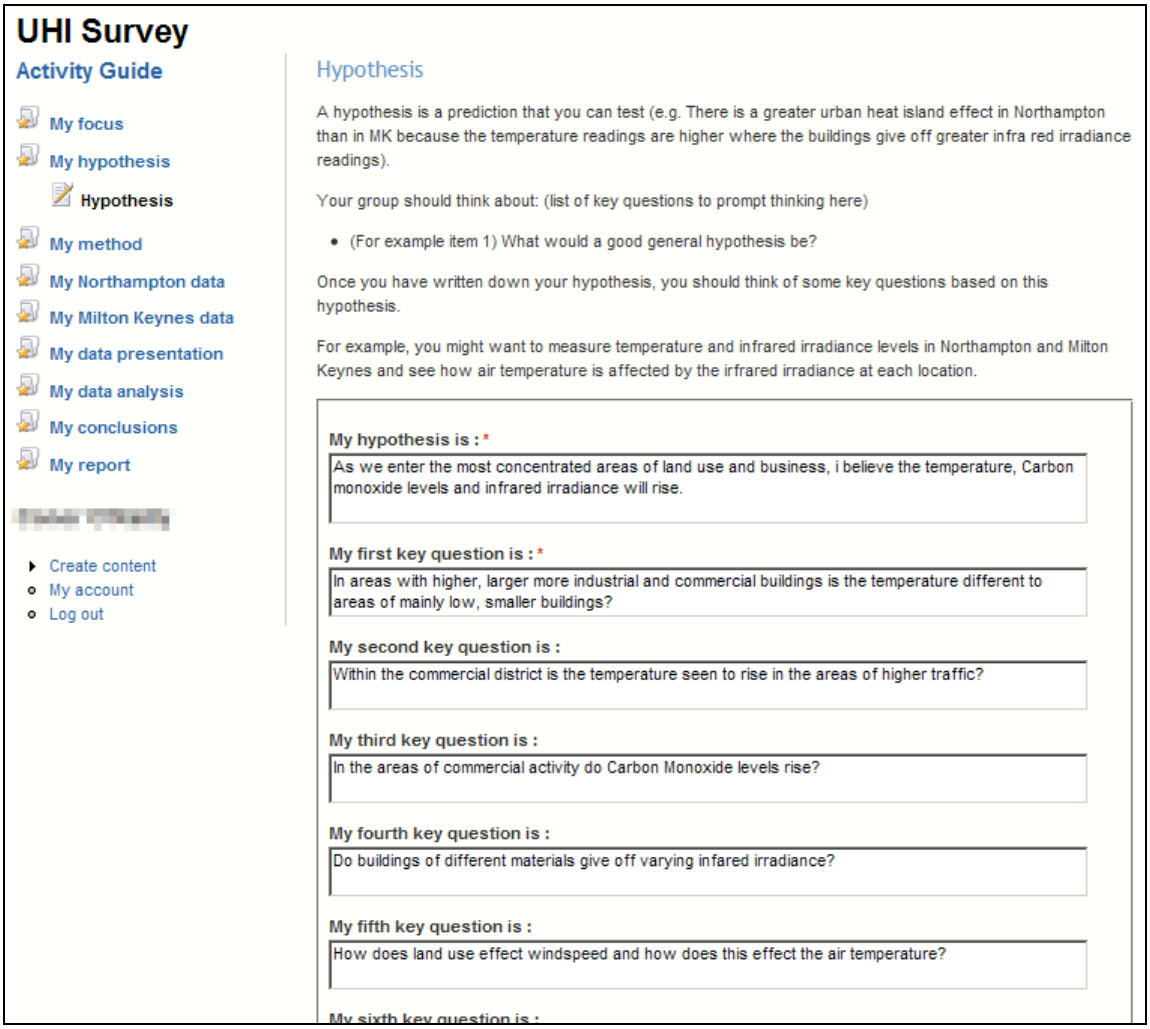


Figure 8: One student's completion of their Key Questions

A further example regarding how the functionality of the system resources connection building, concerns the way in which it enables the student to make a focused selection of data types from within the complete data set to address specific key questions framed by the overarching hypothesis. As part of the development of their inquiry, students are required to generate hypotheses and associated key inquiry questions. The nature of the key questions affects the data that the student should select from within the wider data set collected in order to answer that question.

This selection tool within the Activity Guide helps render salient the connections between the key question(s) the student has generated and the nature of the specific data that need to be analysed and interpreted in order to answer these questions. Salience is thus given to the important connection that exists between the asking of inquiry questions and the framing of the analysis in order to answer the question posed using the data collected:

> *I think one of the key things …it's the fact that each key question automatically sorts the data they needed…it automatically sorts the data they needed, whereas if If you just had huge tables of data and you had to go through and by hand on that…I think just the whole wealth of information was there.*
> *(Teacher interview)*

Having pointed to the significance of resourcing and supporting the cumulation of understanding over time, it was evident that there were some dilemmas that learners needed to negotiate. One dilemma concerned the different representations of the inquiry activities that were in play in the classroom. The Activity Guide had been carefully designed to resource the understanding of inquiry processes through instantiating these processes (captured in the inquiry framework) in its design. The dominant representation of inquiry circulating and being constituted in the classroom, however, was derived from the assessment criteria being used by the examination board. Here the key parameters, which were identified with and aligned to sections of the final assessed report, were: Introduction; Data Collection; Data Presentation; Analysis and Conclusions. So the salience of generating key inquiry questions and the processes of hypothesis-testing, for example, are not strongly signaled as being of consequence, and this characterization places a different emphasis on what is of significance. How are students to negotiate this difference in emphasis?

Concluding remarks

In this paper we have introduced the Personal Inquiry project – which is a substantive investigation into the role that technologies can play in enabling effective inquiry. The project is exploring how student inquiry-based activities and the teacher orchestration of such activities across time and contexts might be supported and resourced. Our endeavour incorporates a detailed evaluation of technology-mediated learning and is designed to inform broader innovative educational practice.

Our particular interest is in designing blended support for evidence-based inquiry learning such that pupils can be supported to understand the inquiry learning process. This blended support (an example of which is exemplified in this paper) is constituted in the interplay of teacher-student interaction and the orchestration of activity mediated by the Activity Guide software application (the design of which is, and continues to be, informed by both theoretically derived characterisations of effective inquiry and the reported difficulties of students and teachers in respect of inquiry learning.

We have introduced the notion of 'scripted personal inquiry' that supports learners to implement personally relevant inquiries and enables teachers to orchestrate learners' activities in a more learner-centered fashion. In doing so, we have underscored both the necessity and difficulty of supporting processes of connection building between the different phases of activity within the inquiry cycle.

In the work we have conducted thus far, our exploration of the contexts to be supported have involved work in classroom settings and on field trips with a limited amount of attention paid to work by students at home. It is a goal of the project to investigate further the types of support required for inquiry-based learning across a range of formal and informal settings. In the next phase of the project one of the settings we intend to investigate is an after school club, where the intended focus of work will be on the concept of sustainability. In this context support for inquiry will be further explored.

References

Alexander, R. (2004) *Towards Dialogic Teaching: rethinking classroom talk*, Cambridge: Dialogos.

Anastopoulou, S., Kerawalla, L.J., and Scanlon, E. (in preparation) '*The scripted personal inquiry approach: using technology to represent and support students' understanding of personal inquiry across contexts*.'

Anastopoulou, S., Sharples, M., Wright, M., Martin, H., Ainsworth, S., Benford, S., Crook, C., Greenhalgh, C., and O'Malley, C. (2008) 'Learning 21st century science in context with mobile technologies', in *Proceedings of the 7th World Conference on Mobile and Contextual Learning* (mLearn-2008), Telford, UK.

Baldry A. and Thibault P.J. (2006) *Multimodal Transcription And Text Analysis*, Equinox, London.

Barnes, D. (1992) 'The role of talk in learning' in K. Norman (ed) *Thinking Voices: the work of the national oracy project*, London: Hodder and Stoughton.

Collins, T.D., Gaved, M.B., Mulholland, P., Kerawalla, L.J., Twiner, A., Scanlon, E., Jones, A., Littleton, K., Conole, G. and Tosunoglu, C. (2008) 'Supporting location-based inquiry learning across school, field and home contexts', in *Proceedings of the 7th World Conference on Mobile and Contextual Learning* (mLearn-2008), Telford, UK.

Mercer, N. (1995). *The Guided Construction Of Knowledge*, London: Multi-Lingual Matters.

Mercer, N. and Littleton, K. (2007) *Dialogue And The Development Of Children's Thinking: a sociocultural approach*, London: Routledge.

Mulholland, P., Collins, T., Gaved, M., Wright, M., Sharples, M., Greenhalgh, C., Kerawalla, L., Scanlon, E. and Littleton, K. (2009). 'Activity Guide: An Approach to Scripting Inquiry Learning.' AIED Workshop on Exploratory Learning Environments, Brighton, UK, July.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, RG., Kyza, E., Edelson, D. and Soloway, E. (2004) 'A scaffolding design framework for software to support science inquiry', *Journal of the Learning Sciences*, 13 (3): 337-386.

Schwartz, D., Lin, X., Brophy, S. and Bransford, J. (1999) 'Toward the development of flexibly adaptive instructional designs', in C. Reigeluth (ed.) *Instructional design theories and models: a new paradigm of instructional theory* (vol. 2, pp. 183-213), Mahwah, NJ: Lawrence Erlbaum.