View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Open Research Online

Open Research Online

The Open University's repository of research publications
and other research outputs

nQuire: technological support for personal inquiry learning

Journal Item

How to cite:

Mulholland, Paul; Anastopoulou, Stamatina; Collins, Trevor; Feisst, Markus; Gaved, Mark; Kerawalla, Lucinda; Paxton, Mark; Scanlon, Eileen; Sharples, Mike and Wright, Michael (2012). nQuire: technological support for personal inquiry learning. IEEE Transactions on Learning Technologies, 5(2) pp. 157–169.

For guidance on citations see FAQs.

© 2011 IEEE

Version: Accepted Manuscript

Link(s) to article on publisher's website:
http://dx.doi.org/doi:10.1109/TLT.2011.32

Copyright and Moral Rights for the articles on this site are retained by the individual authors and/or other copyright owners. For more information on Open Research Online's data policy on reuse of materials please consult the policies page.

oro.open.ac.uk

Preprint of Mulholland, P., Anastopoulou, S., Collins, T., Feisst, M., Gaved, M., Kerawalla, L., Paxton, M., Scanlon, E., Sharples, M. and Wright, M. (2011) nQuire: Technological support for personal inquiry learning. *IEEE Transactions on Learning Technologies*. First published online, 5th December 2011. http://doi.ieeecomputersociety.org/10.1109/TLT.2011.32.

nQuire: Technological Support for Personal Inquiry Learning

Paul Mulholland, Stamatina Anastopoulou, Trevor Collins, Markus Feisst, Mark Gaved, Lucinda Kerawalla, Mark Paxton, Eileen Scanlon, Mike Sharples and Michael Wright

Abstract— This paper describes the development of nQuire, a software application to guide personal inquiry learning. nQuire provides teacher support for authoring, orchestrating and monitoring inquiries as well as student support for carrying out, configuring and reviewing inquiries. nQuire allows inquiries to be scripted and configured in various ways, so that personally relevant, rather than off-the-shelf inquiries, can be created and used by teachers and students. nQuire incorporates an approach to specifying learning flow that provides flexible access to current inquiry activities without precluding access to other activities for review and orientation. Dependencies between activities are automatically handled, ensuring decisions made by the student or teacher are propagated through the inquiry. nQuire can be used to support inquiry activities across individual, group and class levels at different parts of the inquiry and offers a flexible, web-based approach that can incorporate different devices (smart phone, netbook, PC) and does not rely on constant connectivity.

Index Terms— Fieldwork Learning, Nomadic Learning Environments, Learning Management Systems, Instructor Interfaces, Collaborative Learning Tools, Authoring Tools, Mobile and Personal Devices.

1 Introduction

Inquiry learning involves learners designing and carrying out investigations in order to acquire knowledge about the domain under study as well as developing skills in the application of the scientific method [1], [2]. Learners however, may have difficulties in undertaking inquiry learning and require additional support [3]. Quintana et al [3] identify three broad aspects of inquiry that can be supported by software: sense-making, process management, and articulation and reflection. Sense-making refers to what they term the "basic operations of scientific inquiry" (p. 344) such as generating hypotheses, designing the experiment and collecting data. Process management describes the means used to plan and keep track of the inquiry. Processes of articulation and reflection include building and critiquing arguments and identifying their strengths and weaknesses. van Joolingen et al [4] identify a need to support regulatory and transformative processes in inquiry learning. Transformative processes are those that yield knowledge and are equivalent to Quintana et al's [3] categories of sense-making and articulation and reflection. Regulatory processes are those concerned with planning, monitoring and evaluation and align with Quintana et al's [3] process management category.

nQuire was developed to provide support for inquiry learning and its identified constituent processes, but more specifically for *personal* inquiry learning in which the interests and concerns of the learner motivate how the inquiry is designed and carried out. This work was conducted in the Personal Inquiry (PI) project. PI was a collaborative research project between the University of Nottingham and The Open University supported by the UK research councils. An overall aim of PI was to design, deploy and evaluate a combination of technology and education for evidence-based learning of personally relevant topics in a scientific way.

- *Mulholland, Collins, Gaved, Kerawalla, Scanlon are with The Open University, Milton Keynes, UK. E-mail: author@ open.ac.uk.*
- *Feisst, Paxton and Sharples are with the University of Nottingham, Nottingham, UK. E-mail: author@nottingham.ac.uk.*
- *Anastopoulou is with the University of the Aegean, Greece. E-mail: author@aegean.gr.*
- *Wright is with the University of Bath, UK. E-mail: author@back.ac.uk.*

Designing and carrying out inquiries that are of greater personal relevance involves taking as a starting point topics and themes of interest to the learner that have an impact on their lives and then formulating inquiries that resonate with these. Inquiry formulation could be carried out by the teacher, drawing on topics of relevance and interest to the students or be more student-led, guided by discussions with the teacher. Personal inquiries incorporate data collection techniques accessible to the students with which they can interrogate their own environment or themselves. This might involve taking sensor readings, collecting interviews or taking photographs. Personal inquiries can encompass familiar contexts such as the home and the local neighbourhood as well as the school and field trip locations. Personal inquiries might involve working with others on shared interests, or individually.

The resulting inquiries are therefore imbued with personal context, in terms of their motivation, how they are conducted and the physical environment in which they are situated. These contrast sharply with many other research initiatives within inquiry learning that tend to focus on simulation environments [5] that can facilitate learner access to and manipulation of more idealised models of behaviour.

Within the PI project we developed nQuire, a web-based software environment to support personal inquiry. As the inquiries are personal, rather than off-the-shelf experiments, support had to be developed to allow teachers to author new technology-mediated inquiries and for students to configure inquiries to meet their own needs. We use the term 'script' to refer to a specification of an inquiry that can be implemented in software and used to guide teacher and student inquiry activities. This draws on prior use of the term to describe learning processes such as collaboration scripts [6].

The authored inquiries needed to provide support for regulatory and transformative processes, appropriate not only for the classroom but also the home and other contexts that may not allow direct teacher intervention. nQuire also needs to provide support for collaboration and sharing as well as working individually. Finally, since inquiries can span contexts, such as school, home and field locations, software support needs to handle mobility, potentially including locations in which network connectivity cannot be guaranteed [7].

The rest of this paper is structured as follows. Section 2 outlines related work in inquiry learning, learning design and scripting. Section 3 describes the design aims for nQuire. Section 4 presents the main features of nQuire and section 5 discusses examples of its use in practice. This is followed by a summary and outline of future work.

2 Related Work

Inquiry learning is a process by which learning results from designing and carrying out investigations. There have been a number of formulations of the inquiry learning process. Bruce and Bishop [8], drawing on the work of Dewey [1], propose a cyclic model of inquiry in which the learner should progress through the phases of asking, investigating, creating, discussing and reflecting. The learner's reflections may lead them to ask a new question and perform a further cycle of inquiry. White and Frederiksen [2] also propose a cyclic inquiry model comprising five processes: question, predict, experiment, model and apply. Their model was used within the ThinkerTools curriculum to guide students in learning Newtonian models of force and motion using a computer simulation. Co-Lab [4], also developed to guide inquiry learning from a computer simulation, identifies five inquiry phases: analysis, hypothesis generation, experiment design, data interpretation and conclusion. Within the PI project, Scanlon et al [9] propose an eight phase octagonal model of inquiry that also introduces inquiry phases related to initial topic selection, communication of findings and reflection upon the method of inquiry.

Variations among these proposed models of inquiry originate from their intended contexts of use, such as whether the inquiry is being conducted in a real or simulated environment, the extent to which the domain and methods of inquiry can be manipulated by

the learner and the importance given to the communication and presentation of findings. These variations suggest that there cannot be a single formulation of inquiry learning appropriate across all contexts.

A number of current projects are developing technology support for various forms of scientific inquiry. As part of the LETS GO project, Vogel et al [10] focus on the integration of sensor data within scientific inquiries. Their software, running on Windows smartphones, can be used to integrate sensor streams with time and location information. Web APIs (from e.g. Google Maps) can then be used to construct map and timeline visualisations of the data to support the learner's analysis.

The SCY (Science Created by You) project aims to develop new approaches to inquiry learning in science for students aged 12 to 18 years [11]. A key concept of SCY is Emerging Learning Objects which are created and shared by learners in the process of inquiry. Students work individually or collaboratively on "missions" such as "how can we produce healthier milk?" that draw on knowledge from different domains, such as mathematics, biology and engineering.

Zhang et al [12] and Looi et al [13] describe a mobile inquiry learning curriculum for primary science. During its design, they took as their starting point an existing school science curriculum and "mobilized" it by analysing its existing learning objectives and constructing an alternative, drawing on the affordances of mobile technology. Students were provided with 1:1 ownership and 24/7 availability of a networked Smartphone device for the duration of a school year. The devices were installed with proprietary learning management software that allowed the student to manage learning goals by specifying what they know, what they want to know and what they have learned. Integrated software tools were provided for activities such as drawing and concept mapping. Students participating in the mobilized curriculum were found to perform better in assessment and foster a positive attitude to mobile learning [13].

An important issue for many inquiry learning applications is how the inquiries to be conducted can be defined or authored by a teacher or learning designer. Within the PI project we drew on the notion of a script. Scripts, primarily used in computer supported collaborative learning (CSCL), prescribe how students should interact and collaborate in order to solve a problem [14]. Classic examples of scripts include the Jigsaw script in which each group member has a subset of the required information [15] and Arguegraph in which students providing conflicting responses to a quiz are selected to work together and attempt to reach consensus [16]. A script is made up of a set of phases [14]. Each phase has a task, a group of learners, a specification of how learners are distributed (e.g. who does what, who has what information) a mode of interaction (e.g. synchronous or asynchronous) and a time specification.

Dillenbourg and Tchounikine [17] distinguish between micro-scripts and macro-scripts. A macro-script specifies a pattern of collaboration enacted in order to produce a desired interaction among the participants. A macro-script could be represented in terms of phases and their key characteristics. Most collaboration scripts work by placing an additional burden on 'natural' collaboration. The desired interactions have to be undertaken by the participants in order to compensate for this. For example in the Jigsaw script, required information is distributed, placing an additional burden on participants to explain what they know in order to complete the task. This design principle is known as Split Where the Interaction Should Happen (SWISH) [18]. A macro-script can be contrasted with a micro-script which defines the finer-grained sequencing of operations such as turn-taking behaviour within a dialogue.

Computer support for scripted collaboration needs to be sufficiently flexible to enact the script. Dillenbourg and Tchounikine [17] identify two types of constraint that technology can bring to a collaborative context: intrinsic and extrinsic. Intrinsic constraints are a necessary part of the pedagogy, such as limiting each participants' access to information at the start of

a Jigsaw script. Extrinsic constraints are due to arbitrary design decisions or limitations of the technology. Software support needs to allow for sufficient flexibility in order to deal with extrinsic constraints. Teachers need flexibility over how the generic script is instantiated and students need freedom over how the task is done so long as the intrinsic constraints are met.

Evidence of the need for this flexibility can be found in systems developed to guide the inquiry process. Later versions of the WISE system [19] for planning and carrying out inquiry learning activities allowed for task order not to be strictly defined, facilitating student agency when order was not a pedagogical constraint. Tsovaltzi et al [20] report on scripting support for scientific inquiry that was found to be too inflexible, not allowing access to prior inquiry phases for review purposes. Therefore, there is a need to allow for inquiries to be specified and presented in a way that does not impose unnecessary constraints and that leaves appropriate options open to the learner.

As well as the potential for introducing extrinsic constraints, the formal specification of a runnable script raises further issues concerned with the expressivity of the notation used to define the script and potential mismatches with how the script is conceptualised. Miao et al [21] identify a number of difficulties with the formal specification of collaboration scripts, including modelling changes in groups over time and modelling artefacts that are created by groups of learners and then shared across activities. Weinbrenner et al [22] discuss their ongoing work in developing ontology support for the formal specification of inquiries in the SCY project. A key feature they identify as not being supported by existing authoring or scripting formalisms is the Emerging Learning Object (see previously), which bears similarities to Miao et al's [21] notion of learner artefacts shared across activities. This problem also has parallels with previous observations as to the difficulties in specifying data flow in learning design and in particular the passing of student work across activities [23], [24]. A particular challenge in the design of nQuire was how to model and support the flow of data or transformation of objects inherent in inquiry learning, for example from inquiry questions, to experimental design through to interpretations and conclusions.

3 Design Aims

As we aim to support inquiries that are personally relevant, the nQuire software cannot just contain a repository of prepared, off-the-shelf, textbook inquiries but rather needs to provide functionality for the scripting and flexible implementation of inquiries accessible by teachers, learning designers and even students. Teachers can be expected to use functionality for authoring new inquiry structures, monitoring the state of the inquiry for individual or groups of students, and orchestration (i.e. specifying changes to the inquiry state during runtime). Students need functionality for monitoring and carrying out their inquiries and also configuring inquiries such as deciding what to measure and how to analyse the results. However, specific learning contexts may require the teacher to claim or concede more control over the inquiry script. Some examples are presented in section 5. It is also important that this functionality is provided in a way that is flexible and minimizes external constraints, for example by not unnecessarily restricting learner choice.

We know from prior work in inquiry learning that the authored scripts need to support both regulatory and transformative processes, especially as aspects of the inquiry may be carried out in an informal context without available teacher support. The personal inquiry context also necessitates support for both individual and collaborative work on inquiries and the sharing of results. Finally, the software needs to support mobility across learning contexts including the home and school.

In summary, the overall design aims for nQuire are to provide scripting support for personal inquiry learning (for authoring, orchestration, monitoring, configuring and carrying out inquires) that encompasses regulatory processes, transformative processes, collaboration and mobility.

4 nQuire

In this section we provide an overview of nQuire and how it supports each of these four aspects. nQuire is built on the PHP-based Drupal open source content management system [25]. Drupal provides in-built support for handling web forms, content presentation, managing users and groups and storing and presenting media. A series of additional nQuire modules build on this functionality. These can be divided into three types. A set of core nQuire modules provide functionality for scripting, storing, navigating and running inquiries. These are a required part of any nQuire installation. A set of activity modules support specific inquiry activities such as data collection, analysis, voting, and uploading presentations. Existing Drupal modules, such as a voting module, can be integrated for use as nQuire activities. Finally, a set of utility modules offer additional functionality such as import, export and synchronisation of inquiries.

4.1 nQuire Interface

A typical nQuire homepage screen for an inquiry is shown in figure 1. The homepage provides an overview of the phases of the inquiry. The one shown in the figure adopts the cyclic, octagonal representation of the inquiry process developed in the PI project [9]. By selecting one of the phases the learner enters a more detailed view of the inquiry, such as the one shown in figure 2. The representation of the overview of inquiry phases is shown top left This functions as a link back to the inquiry homepage as well as a visual reminder of the inquiry process.

[Insert figure 1 about here]

The navigation panel on the left provides a linearised view of the phase diagram where each phase can be opened, like a file browser, to reveal and link to the constituent activities. Thus it functions as a dynamic 'to do list' for the user. The current activity (in this case to enter a hypothesis for the inquiry) is displayed in the main area of the screen. The "My progress" bar in the banner at the top represents the temporal stages of the inquiry which could for example correspond to school lessons or homework assignments. The current temporal stage (in this case stage 1) is shown in bold. In figures 1 and 2, three phases of the inquiry are marked with an asterisk. This indicates that each of these phases contains one of more activities that should be undertaken during this stage, in our terminology they are "focal" to this stage.

[Insert figure 2 about here]

4.2 Regulatory Processes

Regulatory processes are concerned with managing and understanding flow through the learning activities. For the teacher this generally involves scripting learning flow, making adaptations during the running of scripts and monitoring progress through the script. For the student this involves understanding their current state within the script, reviewing progress so far and planning future activities. Within our approach, each scripted inquiry is comprised of activities. As we have seen in the interface above, activities are organised according to phases of the inquiry. The number of phases and their names is specified in the script. Scripting the inquiry is via a forms-based interface. Figure 3 shows a form for specifying a phase within an inquiry.

[Insert figure 3 about here]

The authoring environment provides an interface for viewing and modifying how the activities are structured by the phases and stages of the inquiry (figure 4). In the first column, the activities are organised into phases. Subsequent columns represent the stages of the inquiry with an "edit" link, indicting that the activity represented by that row is focal for that particular stage. The stage and phase structure shown in figure 4 specifies a linear progression through the phases. The activities of the first three phases are carried out the

in first “Preparation” stage. The activities of the “Collect my data” phase are carried out in the second “Run” stage. Activities of the remaining stages are carried out in the “Conclude” stage. The structure of the inquiry may specify activities as being focal for any number of the stages. The inquiry structure may also specify different activities of the same phase being focal in different stages.

[Insert figure 4 about here]

The activities contained within the inquiry can, at any time, have one of four statuses: start, edit, view or unavailable. The status of an activity is represented to the learner in the interface using one of the icons shown in table 1. Each activity has a pre-defined status at the start of the inquiry. For example, some teacher-prepared instructions could have a status of ‘view’, some initial activities may have a status of ‘start’ and others may be unavailable. There are three ways in which the status of an activity can change during the running of an inquiry: when an activity is started, when the inquiry stage is changed, and manually by the teacher.

[Insert table 1 about here]

First, the inquiry script, as well as giving the initial status for each activity, specifies for each type of activity how its status changes once it has been started. Generally, an activity can be expected to move to edit status once started. For example, a student might start their hypothesis activity by entering an initial version of it. The hypothesis then changes automatically to edit status and can be modified by the student later.

Second, the status of the activity may change depending on whether it is focal for the current stage. When the teacher changes the inquiry stage (e.g. from lesson one to lesson two), the status of activities is updated depending on whether they are focal within the new stage. By default, activities have a status of ‘start’ or ‘edit’ when focal for a stage and ‘view’ or ‘unavailable’ when not, with edit-view and start-unavailable being paired states. Specifying activity status (and therefore access) in this way has two advantages. First, the teacher can make any number of activities available at one time, leaving choice for the learner. Second, it naturally distinguishes between doing and reviewing the activities of an inquiry, allowing teachers to maintain access to non-focal activities for review by students while undertaking their current activities.

The third way in which the status of an activity can be changed is manually by the teacher. The default changes in activity status can be customised in the script for any particular activities or types of activity. For example, the teacher may specify a data collection stage in which data points can be added and edited (e.g. while on a field trip). When moving onto the data analysis stage, the teacher may choose to keep the data editable (though not in focus) in order that the student can fix errors in the data spotted during analysis. Figure 5 shows the interface available to the teacher to change stage during the running of the inquiry. The teacher can select a single stage (from the pull down menu) as being current. The teacher can also choose to keep additional stages within focus. This is part of the intended flexibility of the system and allows the teacher to open multiple stages of the inquiry to allow some students to catch up or move ahead within the inquiry. By selecting on an activity the teacher can also see the status of each participant (whether an individual or group of students) and manually change their status (figure 6).

[Insert figure 5 about here]

[Insert figure 6 about here]

In summary, the nQuire approach to scripting regulatory processes allows the inquiry phases, their presentation and the temporal stages to be defined. Activities are organised according to stages and phases though there are opportunities to improvise around this by, for example, keeping multiple stages in focus and manually changing access for particular students. Scripting support for focal and non-focal activities recognises the importance of allowing students to review and orient themselves within the inquiry process as well as highlighting access to current activities.

4.3 Transformative Processes

Activities are used to generate artefacts during the inquiry, such as notes, questions, data, graphs and presentations. There are two main types of activities. First, there are generic activities such as making notes, sharing a presentation or uploading media related to the topic. Second, there are activities specifically related to inquiry such as data collection and interpretation – in line with Quintana et al's [3] "basic operations of scientific inquiry". The generic activities create artefacts, such as presentations and notes, but are stand-alone, and do not automatically pass content to other activities. The inquiry-related activities share data according to an underlying data model of the inquiry process. This allows, for example, for the selection of measures when designing the investigation to configure data collection activities in order to reflect the choice made by the student. Similarly, the model allows the results of data collection activities to be made in available in an appropriate form within data analysis activities. Similar to Roschelle et al's [26] T-Spaces it provides a shared memory across activities, though with a structure specialised for inquiry learning.

The underlying data model is shown in figure 7. Each inquiry may use a hypothesis activity that the learner can use to create, edit and view their hypothesis. A single conclusion can be associated with the hypothesis. Each hypothesis can be associated with a number of key questions. These can be used to help the student to break down and operationalize their hypothesis. Each key question can be associated with a number of key answers.

[Insert figure 7 about here]

A personal inquiry is defined by selecting and organising measures made available to the inquiry. Available measures could be sensor readings, interview questions, image upload, audio recordings, et cetera. Each available measure has a data type (e.g. number, text, list of options) and a mode of presentation (e.g. single or multi-line text box, pull down menu, file upload dialogue). For available measures that are a list of options, additional data can be associated with each option. For example, if the options are a list of locations at which climate readings can be taken, then GPS location data could be associated with each option. This would allow the students to visualise the data on a map without entering coordinate information themselves. Similarly, if the inquiry involved selecting foodstuffs that had been eaten (e.g. cereal, apple, cola, etc.) as part of a dietary analysis, each food item could be associated (manually by the teacher or from a database) with information on calories or nutrient intake, without this data having to be entered by the student. This additional information could be summed and presented during data collection and analysis.

Available measures can be created by the teacher or student (this will be discussed in section 5). The same measures may be used in many student inquiries. Figure 8 shows the interface of the activity for selecting measures. Some of the selected measures can be defined as key measures. Operationally, these are essentially the independent variables of the investigation (though the assumption that they are controlled by the experimenter need not necessarily hold) in that they are used to organise the data and used as x-axes when generating charts of the data. An example of this is shown later when discussing how results presentations are generated.

[Insert figure 8 about here]

Data collection activities are structured according to the selected measures. In the example data collection activity shown in figure 9 the measures and their order reflects the choice made in the selected measures activity shown in figure 8. This has similarities to the approach described by Giemza et al [27] in which they provide an authoring tool that is used to generate a data collection form. However, our approach allows the definition of individual measures to be saved as available measures and reused across inquiries.

[Insert figure 9 about here]

By default, the set of collected data items for an inquiry are presented in a sortable list, each data entry having a title reflecting its values for the one or more key measures of the inquiry (figure 10). For many inquiries, one data entry activity may be expected for any combination of values for the key measures, for example, a set of dependent measures taken at each of a number of times and/or locations.

[Insert figure 10 about here]

For some inquiry designs, multiple data entries may be collected for the same combination of key measure values. For example, a healthy eating inquiry may have date and meal as key measures and record a number of food items and their quantity. nQuire can provide some custom views for entering and navigating this data. Figure 11 shows the custom data collection interface used for a healthy eating inquiry in which the ingredients of each meal can be specified. Additional information associated with the selected food items automatically populates the dietary information table shown at the bottom of the figure.

[Insert figure 11 about here]

Presentations of the results can be generated by specifying and ordering a subset of the selected measures. Each results presentation is associated with a key question. Figure 12 shows a results presentation charting temperature across locations. It has been associated with the key question “How will temperature vary across the locations?” As location was previously specified as a key measure and the temperature measure is defined as numeric data, the results presentation activity automatically provides a bar chart of the results with location on the x-axis and temperature on the y-axis.

[Insert figure 12 about here]

If coordinate information is included in the key measures then the results are also provided in a KML format that can be visualised in Google Earth. Presentation of results can also provide data comparisons. For a healthy eating investigation, for example, the student daily nutrient intake is compared to the recommended nutrient intake suggested by the Food Standards Agency. Data activities also provide support for data import as well as export. nQuire can be used in conjunction with Sciencescope dataloggers to automatically add data into the inquiry.

Where possible the set of inquiry-related activities can still be used when other activities with which they have potential dependencies are omitted. Inquiries can and have been used that omit the key questions and key answers, just having a hypothesis and conclusion. In this case the result presentation activity can still be used, but there is no option to associate each set of results with a key question.

In summary, nQuire contains an extensible set of activities that can be used within inquiry scripts. A set of activities directly related to the inquiry process automatically share data. This facilitates the transformative process of the inquiry from hypothesis, though data collection and analysis, to conclusion. Configuring an inquiry, by adding new available measures and using them to design the inquiry, makes it possible for students to design and carry out a broad range of inquiries within the same overall script. This support for scripting and configuring transformative processes provides teachers and students agency and frees them from an off-the-peg set of inquiries.

4.4 Collaboration and Sharing

nQuire provides support for both working individually and within defined collaborative structures. When defining collaborative learning activities in schools, particularly in terms of collaboration scripts, three social planes on which activity takes place can be identified: individual, group and class [18] in which groups are a distinct subdivision of the class. Groups and their membership can be expected change over time, for example to fit particular group-based activities or in response to student absences from class.

Within nQuire, collaboration is scripted according to these three social planes. The script defines for each activity who can carry it out and who will be able to access the result. This information is displayed to the user whenever they are starting or editing an activity, using messages in the style “Being done by my group. Will be seen by my class.” The example data entry activity shown in figure 9 is both performed and seen on the group level. The group of participants accessing the results can be the same or broader than the group who carried out the activity. For example an individual can carry out an activity (such as entering a piece of data) which then becomes available to his or her group. However, a group cannot collaboratively enter data that is then only accessible to a member of that group.

With generic activities, such as adding a presentation, this functionality can be used to create and publish information within the class. For example, an activity could contain a presentation that can only be created and edited by the teacher but is accessible to the whole class. Similarly, each group could make a presentation about their inquiry that is then visible to the whole class.

When used in conjunction with the inquiry-specific activities (such as selecting measures, and collecting and analysing data), the three social planes can be used to create different distributions of activities across the inquiry, such as the one shown in figure 13. Here, deciding on a hypothesis and data analysis are done individually, data is collected in groups and experimental design is done on a class level. In this case, each group collects data according to the design specified on the class level. Each student then analyses their group’s data individually. Alternatively, activities concerned with defining and choosing measures could be specified on the group level. In this case each group would be designing and running their own experiment. More examples of inquiries differing in terms of the social planes on which activities are carried out can be found in section 5.

[Insert figure 13 about here]

The majority of trials we have conduced with nQuire have involved relatively stable group compositions throughout the inquiry, in which all activities carried out on the group social plane are constituted using the same participant groups. This preference for a more stable group structure originated from the teachers. However, nQuire also allows different group compositions (called groupings) to be used in different parts of the inquiry. The part of the inquiry might be a particular temporal stage, inquiry phase or activity.

This can be used to script SWISH-style collaborative patterns [18]. As described in section 2, membership changes in successive group configurations can be used to engineer splits, in for example goals or background knowledge of group members. These splits require collaboration in order to be resolved. Similar

patterns can be embedded within nQuire scripts. For example, in the first stage of the inquiry, students could be given different background materials to read depending on group composition. Different materials may suggest alternative inquiry methods or questions. In a second stage, in which the students design the inquiry, an alternative grouping of students could be used. Each new group would have to reach a consensus across the background materials presented. Similarly, the script could be used to regroup students between data collection and analysis, this partial rotation of students bringing a fresh perspective to the data during the analysis phase.

In summary, nQuire scripts can be used to represent activities on three social planes: individual, group and class. The script can distinguish the plane on which the activity is carried out from the plane on which the result of the activity is viewed. This supports information sharing and publishing among inquiry participants. When used in conjunction with transformative processes, the script can be used to create different patterns of collaboration across the inquiry. Scripting different groupings allows personal inquiry equivalents of many collaboration scripts to be authored.

4.5 Mobility

nQuire offers an approach to mobility though does not necessarily require constant connectivity. Our experiences, reported by Gaved et al [7], indicate the need to have alternative ways of operationalising the inquiry in terms of devices and connectivity and the ability to flexibly move between these depending on circumstances (e.g. unavailability of a network).

Within the trials of the PI project we used three different kinds of infrastructure. First, when internet connectivity could be reasonably guaranteed, such as in the classroom or in the homes of some students, mobile devices, such as netbooks, or desktop PCs were used as clients to assess the inquiry from a central server. This approach was generally used during the analysis and writing up phases of the larger inquiries which were generally classroom-based. Second, when participants were distributed but did not need to synchronously share information across devices, the local installation of nQuire was used on netbooks, and then later synchronised with the central server. This approach was used for collecting environmental data across various field locations. Third, a mobile server with wireless connectivity was used for some field activities in which all students were contained within a reasonably small and open area. This third approach allows intranet connectivity between the participants (e.g. allowing them to see each other's contributed data) using mobile devices as web clients. The mobile server is then synchronised with the central server after the data has been collected.

During trials, this range of options allowed us to improvise and continue when unexpected networking problems arose. This included continuing to work on an inquiry on the school premises when a power cut prevented connectivity through the school network. The interface snapshots in the previous figures show the nQure interface design optimised for desktops and netbooks. nQuire also has a custom mobile interface with optimised navigation and layout. This can be used, for example, when collecting observational data using a smartphone (see figure 14).

[Insert figure 14 about here]

5 Using nQuire to Support Personal Inquiry

nQuire was developed through a process of design-based research [28], [29] in which our conceptualisation of personal inquiry learning and how it should be supported motivated design decisions in nQuire which were then tested in school-based trials. In total seven major trials were conducted over a 2.5 year period. These covered a range of inquiries within the science and geography disciplines such as microclimates, healthy eating, bird feeding and sustainability. The first two trials focussed on data collection and analysis activities and allowed us to develop and test the presentation and navigation of activities, the design of forms, data entry and the presentation of results in

tables, charts and on maps. The subsequent trials focussed on developing the inquiry structure, in terms of phases and stages and using this for interface structure and navigation. The final trials introduced the underlying data model and the broader range of activities having dependencies to this model.

In all, three main approaches to the authoring and configuration of scripts have been used across these trials. These differ in terms of the level of agency they provide to the students participating in the inquiries. First, nQuire has been used to script inquiries in participation with the teacher. Here, the structure of the inquiry was specified in terms of stages, phases and activities. Activities concerned with experimental design (i.e. the defining and selection of measures) were then used by the teacher to configure the inquiry design on behalf of the class. The inquiry was then conducted by the class. In this context, nQuire is being used by the teacher to completely script the inquiry for the whole class. This approach was used in a climate inquiry which involved data collection by students walking across the centres of two towns [30], [31]. The structure of the inquiry and the experimental design were scripted in participation with the teachers. The prepared structure was then used to guide the students through data collection and analysis.

Second, nQuire has been used to script the inquiry structure and pre-specify available measures and hypotheses from which the students themselves can select. Choices made by the students individually and in groups and key questions added by the student are used to structure their activities concerned with data collection, presentation and concluding their inquiry. In this context, the script is being used to scope the inquiry and provide options for the student that guide their later activities. This approach was used for a climate inquiry around the school grounds in which students made choices in the classroom, used nQuire on netbooks to guide their data collection while walking around the school grounds and then undertook results analysis back in the classroom [32].

Third, we have ran more open-ended inquiries in which the students could pick their own topic, design their own experiment, and collect and interpret their own data. This was carried out as part of an after-school geography club around the topic of sustainability [33]. Here, nQuire assisted the students in formulating their own inquiry design and modified the structure of the inquiry in response to their decisions. In this scenario, much of the inquiry design was done in the after-school club with assistance and input from the teachers. Data collection was carried out independently outside of school by the students, supported by the software and netbooks. In this final case, the initial script provides an inquiry shell and the design of the inquiry is under the control of the students.

This illustrates ways in which the software provides an approach to the scripting and configuration of inquiries that is accessible to teachers and students. Further details on the trials as well as an online demo and software download of nQuire are available from www.nquire.org.uk.

6 Conclusions and Future Work

nQuire provides an approach to scripting personal inquiry learning, with a particular emphasis on regulatory processes, transformative processes, collaboration and mobility. nQuire allows inquiries to be scripted and configured in various ways, in order that personally relevant, rather than off-the-shelf inquiries can be created and used by teachers and students. An important aim of nQuire was to design for flexibility whether through providing access to non-focal activities for review, allowing teachers and students to configure inquiries, or to improvise when network connectivity fails.

Scripting is via a conventional forms-based interface and makes use of a set of constructs such as phases, stages, activities, activity status and groupings. These constructs are relatively atomic and focus on the mechanics of the script. A valuable extension to nQuire would be to devise a way of representing scripts abstracted from the operational level and more focussed on explicating the pedagogical objec-

tives of the script. Drawing on the distinction made in section 2, this new representation could essentially be thought of as a macro-script [17], framing the current nQuire constructs as the language of a micro-script for personal inquiry learning.

The nQuire macro-script could be used in three ways. First, it could be used to provide authoring support for teachers. This would allow the script to be partially specified pedagogically, with further implementation decisions taken on the micro-scripting level. This would bear certain similarities to the Domain Specific Modelling (DSM) approach proposed by Miao et al [34] however, the motivation would be to provide two complementary vocabularies appropriate for expressing pedagogical and operational concerns rather than because the operational level was necessarily inaccessible to end-users. Currently, nQuire can provide this pedagogical layer to some extent through a set of reusable inquiry scripts that exemplify particular pedagogical decisions, though these decisions are not currently explicit within the script.

Second, the macro-script could be used to help the monitoring of inquiries. Currently, the teacher can use tools such as the activity monitor shown in figure 6 to see the status of activities and well as viewing the content of student work. Allowing the teacher to easily visualize during runtime interesting patterns in student behaviour on the macro-script level would allow them to identify and respond to pedagogically significant states. These patterns could be in the state or interaction history of a single student or across a number of students in the class. These could be difficult to identify in-situ from atomic components of the inquiry.

Third, the macro script could assist improvisational, contingent orchestration [35] during the running of an inquiry by not only assisting in the identification of interesting patterns but also in making pedagogically meaningful responses. Often these patterns can be expected to signify breakdowns in the inquiry process that the additional macro-script component would be intended to remedy. This can be thought of as the converse of the SWISH-style script [18] in which a conflict is engineered. As we have witnessed during the extensive trials of the project, personal inquiry learning scenarios carried out in real world settings can often generate their own conflicts. Examples include different students taking wildly different readings in the same context or making conflicting interpretations of the same data. Personal inquiry macro-scripts could be used to identify and turn these situations into pedagogically constructive events. For example, two groups of students with wildly differing data could have a macro-script component added to their inquiry that guides them through investigating differences in how their data was collected.

A pedagogical user community is currently being built around the current nQuire software and lesson plans. This community could allow us to start to explore the value of personal inquiry macro-scripts for authoring, monitoring and orchestration.

Acknowledgments

The Personal Inquiry project was funded by the UK EPSRC and ESRC research councils under the TEL-TLRP programme. We would like to thank the staff and students of Oakgrove School, Milton Keynes and Hadden Park School, Nottingham for their participation. We would also like to thank Sciencescope for their advice and support.

References

[1] Dewey, J. (1933) How we think: a restatement of the relation of reflective thinking to the educative process. Heath: Boston, MA.

[2] White, B. and Frederiksen, J. (1998). Inquiry, Modeling, and Metacognition: Making Science Accessible to All Students. Cognition and Instruction, 16 (1), 3-118.

[3] 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.

[4] van Joolingen, W., de Jong, T., Lazonder, A., Savelsbergh, E. and Manlove, S. (2005). Co-Lab: research and development of an online learning environment for collaborative scientific discovery learning, Computers in Human Behaviour, 21, 671-688.

[5] de Jong, T. (2006). Computer Simulations - Technological advances in inquiry learning. Science, 312, 532-533.

[6] Kobbe, L., Weinberger, A., Dillenbourg, P., Harrer, A., Hamalainen, R., Hakkinen, P. and Fischer, F. (2007). Specifying computer-supported collaboration scripts. Computer-Supported Collaborative Learning, 233, 211-224.

[7] Gaved, M., Mulholland, P., Kerawalla, L., Collins, T. and Scanlon E. (2010). More notspots than hotspots: strategies for undertaking networked learning in the real world. mLearn 2010, Malta.

[8] Bruce, B. C. and Bishop, A. P. (2002) Using the Web to Support Inquiry-based Literacy Development. Journal of Adolescent and Adult Literacy, 45 (8), 706-714.

[9] Scanlon, E., Anastopoulou, S., Kerawalla, L. and Mulholland, P. (in press). Scripting personal inquiry: using technology to represent and support students' understanding of personal inquiry across contexts. Journal of Computer-Aided Learning.

[10] Vogel, B., Spikol, D., Kurti, A. and Milrad, M. (2010). Integrating mobile, web and sensory technologies to support inquiry-based science learning. IEEE International Conference on Wireless, Mobile and Ubiquitous Technologies in Education.

[11] de Jong, T., van Joolingen, W., Weinberger, A. and the SCY team (2009). Learning by design. Computer-Supported Collaborative Learning. Rhodes, Greece.

[12] Zhang, B., Looi, C.-K., Seow, P., Chia, G., Wong, L.-H., Chen, W., So, H.-J., Soloway, E. and Norris, C. (2010). Deconstructing and reconstructing: Transforming primary science learning via a mobilized curriculum. Computers & Education, 55, 1054-1523.

[13] Looi, C.-K., Zhang, B., Chen, W., Seow, P. and Chia, G. (in press). Mobile Inquiry Learning Experience for Primary Science Students: A Study of Learning Effectiveness. Journal of Computer Assisted Learning.

[14] Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. A. Kirschner (Ed). Three worlds of CSCL: Can we support CSCL? Heerlen: Open University of the Netherlands.

[15] Aronson, E., N., Blaney, C. Stephan, J. Sikes and Snapp, M. (1978). The Jigsaw Classroom. Beverly Hills, CA: Sage Publications, Inc.

[16] Jermann, P. and Dillenbourg, P. (1999). An analysis of learner arguments in a collective learning environment. Computer-Supported Collaborative Learning.

[17] Dillenbourg, P. and Tchounikine, P. (2006). Flexibility in macro-scripts for computer-supported collaborative learning. Journal of Computer Assisted Learning, 23, 1-13.

[18] Dillenbourg, P. and Hong, F. (2008). The mechanics of CSCL macro scripts. Computer-Supported Collaborative Learning, 3, 5-23.

[19] Linn, M. and Slotta, J. (2000). WISE science. Educational Leadership, 58 (2), 29-32.

[20] Tsovaltzi, D., Rummel, N., McLaren, B., Pinkwart, N., Sheuer, O., Harrer, A. and Braun, I. (2010). Extending a virtual chemistry laboratory with a collaboration script to promote conceptual learning. International Journal of Technology Enhanced Learning, 12 (1/2), 91-110.

[21] Miao, Y., Hoeksema, K., Hoppe, U. and Harrer, A. (2005). CSCL scripts: modelling features and potential use. Computer Support for Collaborative Learning. Taipei, Taiwan.

[22] Weinbrenner, S., Engler, J., Bollen, L. and Hoppe, U. (2009). Ontology-based support for designing inquiry learning scenarios. International Workshop on Ontologies and Semantic Web for E-Learning (SWEL), Brighton, UK.

[23] Dalziel, J. (2006). Lessons from LAMS for IMS Learning Design. IEEE International Conference on Advanced Learning Technologies.

[24] Palomino-Ramirez, L., Martinez-Mones, A., Bote-Lorenzo, M., Asensio-Perez, J. and Dimitriadis, Y. (2007). Data Flow between Tools: Towards a Composition-Based Solution for Learning Design. IEEE International Conference on Advanced Learning Technologies.

[25] www.drupal.org

[26] Roschelle, J., Schank, P., Brecht, J., Tatar, D. and Chadhury, S. R. (2005). From Response Systems to Distributed Systems for Enhanced Collaborative Learning. 13th International Conference on Computers in Education (ICCE 2005).

[27] Giemza, A., Kuntke, O. and Hoppe, U. (2010). A Mobile Application for Collecting Numerical and Multimedia Data during Experiments and Field Trips in Inquiry Learning. International Conference on Computers in Education, Putrajaya, Malaysia.

[28] Barab, S. and Squire, K. (2004). Design-based research: Putting a stake in the ground. The Journal of the Learning Sciences, 13 (125), 1-14.

[29] Cobb, P., Confrey, J., id Sessa, A., Lehrer, R. and Schaubel, L. (2003). Design experiments in educational research. Educational Researcher, 32 (126), 9-13.

[30] Collins, T, Gaved, M., Mulholland, P., Kerawalla, C., Twiner, A., Scanlon, E., Jones, A., Littleton, K. and Conole, G. (2008). Supporting location-based inquiry learning across school, field and home contexts. Mobile Learning (mLearn 2008). Wolverhampton.

[31] Scanlon, E., Littleton, K., Gaved, M., & Kerawalla, L. (2009, August) Support for evidence-based inquiry learning: Teachers, tools and phases of inquiry, Proceedings of European Association for Research on Learning and Instruction (EARLI) 09, Amsterdam.

[32] Kerawalla, L., Littleton, K., Scanlon, E., Jones, A., Gaved, M., Collins, T., Mulholland, P., Blake, C., Clough, G., Conole, G. and Petrou, M. (in press), Personal inquiry learning trajectories in Geography: technological support across contexts. Interactive Learning Environments.

[33] Scanlon, E., Kerawalla, L., Gaved, M., Jones, A., Collins, T., Mulholland, P., Blake, C., Petrou, M., & Littleton, K. (2010, May). The challenge of supporting networked personal inquiry learning across the contexts of school club and home, In 7th International Conference on Networked Learning, Aarlborg, Denmark.

[34] Miao, Y., Sodhi, T., Brouns, F., Sloep, P. and Koper, R. (2008). Bridging the Gap between Practitioners and E-Learning Standards: A Domain-Specific Modeling Approach. EC-TEL.

[35] Sharples, M. and Anastopoulou, S. (in press). Designing orchestration for inquiry learning. In K. Littleton, E. Scanlon and M. Sharples (Eds.) Orchestrating inquiry learning: contemporary perspectives on supporting scientific inquiry learning. Routledge, Abingdon, UK.

TABLE 1
THE TYPES OF STATUS FOR AN ACTIVITY

Status label	Interface icon	Meaning
Unavailable		Not available yet
Start		You can start this activity
Edit		You can edit this activity
View		You can view this activity

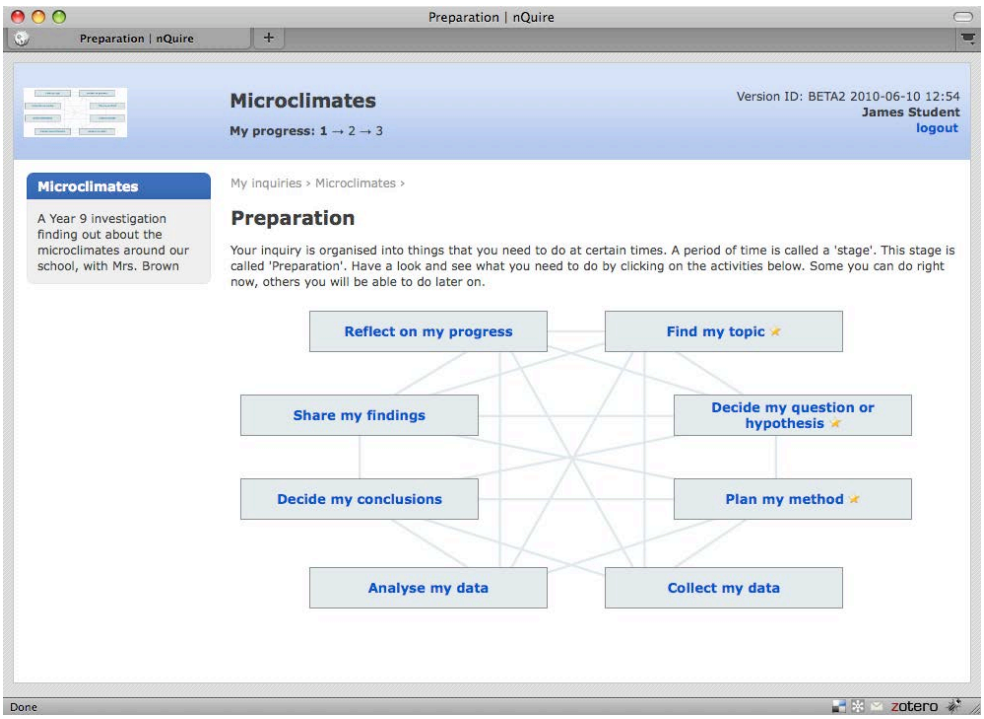


Fig. 1. Home page for a microclimates inquiry showing eight inquiry phases visually represented as a cycle.

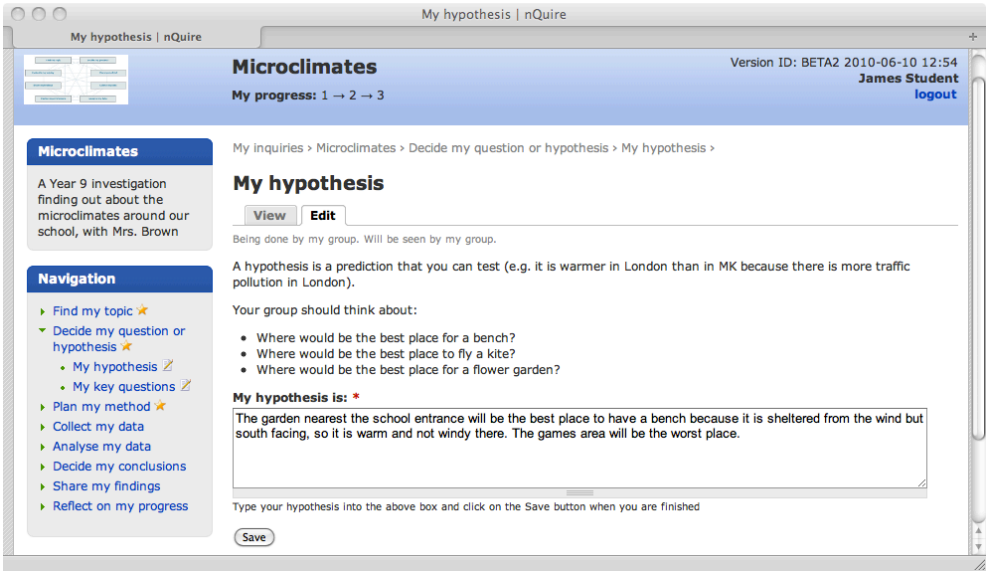


Fig. 2. A ‘Decide by question or hypothesis’ phase with the ‘My hypothesis’ activity being carried out.

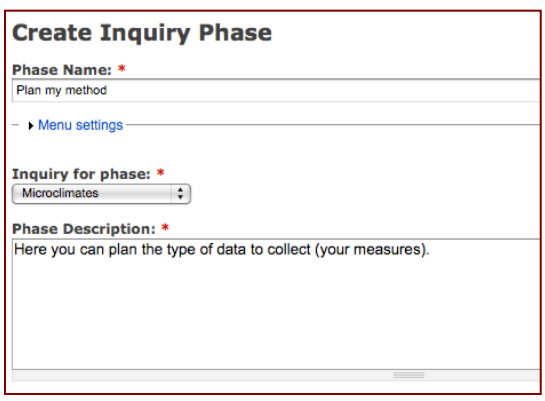


Fig. 3. Specifying a new phase for an inquiry.

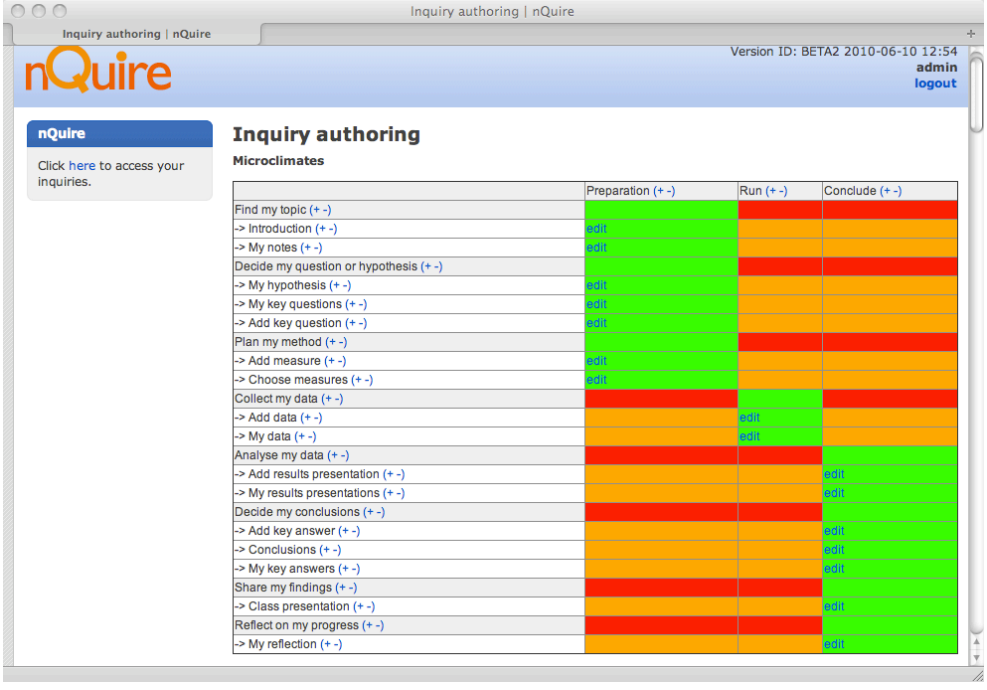


Fig. 4. Defining the phases and stage of an inquiry.

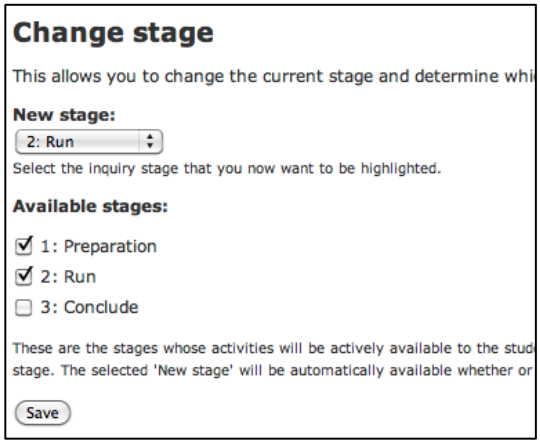


Fig. 5. Setting the current stage and other focal stages of the inquiry.

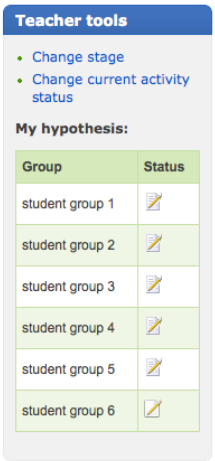


Fig. 6. Monitoring and changing activity status for inquiry participants.

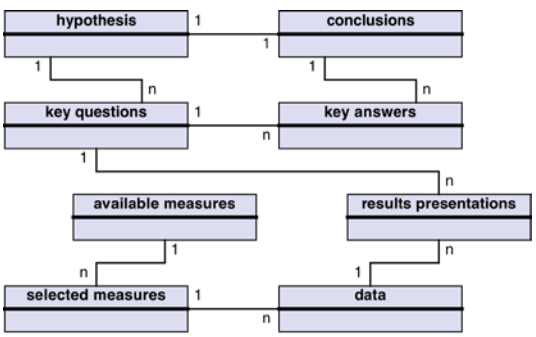


Fig. 7. The data model supporting transformative processes.

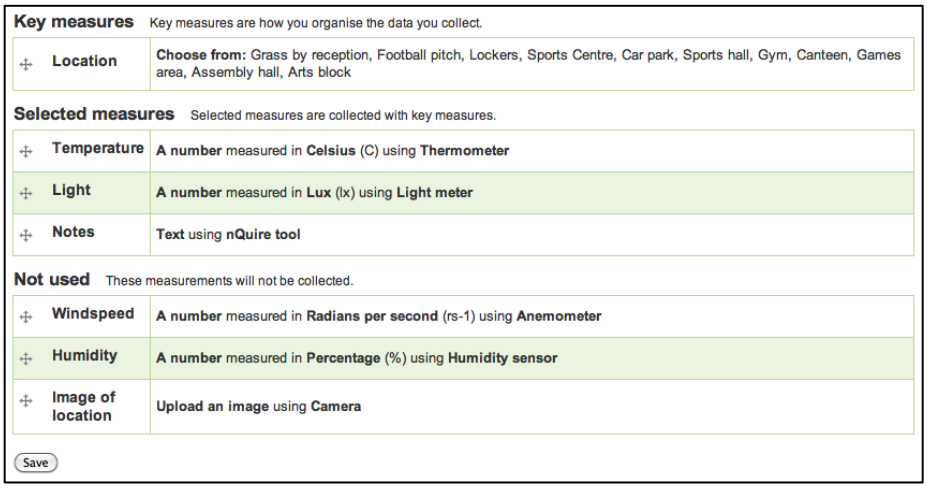


Fig. 8. Selecting from the available measures of the inquiry.

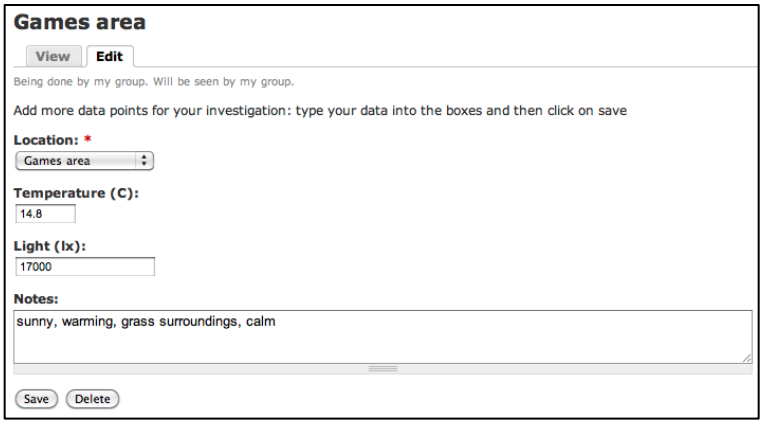


Fig. 9. A data entry activity.

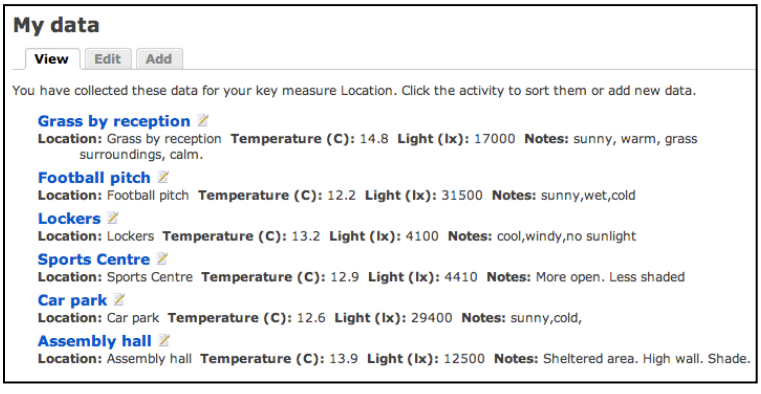
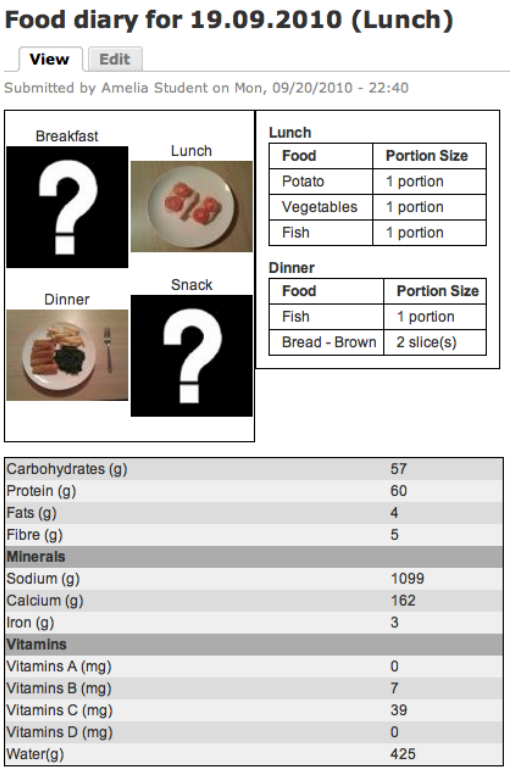


Fig. 10. A generic data management activity.



Food diary for 19.09.2010 (Lunch)

View | Edit

Submitted by Amelia Student on Mon, 09/20/2010 - 22:40

Breakfast

Lunch

Dinner

Snack

Lunch

Food	Portion Size
Potato	1 portion
Vegetables	1 portion
Fish	1 portion

Dinner

Food	Portion Size
Fish	1 portion
Bread - Brown	2 slice(s)

Carbohydrates (g)	57
Protein (g)	60
Fats (g)	4
Fibre (g)	5
Minerals	
Sodium (g)	1099
Calcium (g)	162
Iron (g)	3
Vitamins	
Vitamins A (mg)	0
Vitamins B (mg)	7
Vitamins C (mg)	39
Vitamins D (mg)	0
Water(g)	425

Fig. 11. A custom data management activity used for a food diary inquiry.

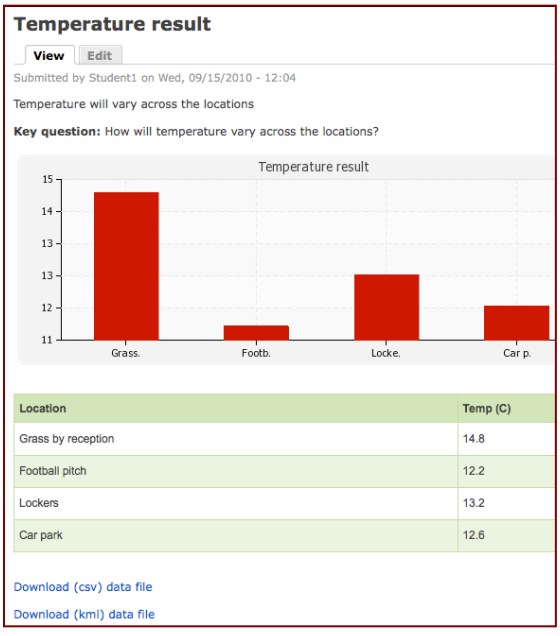


Fig. 12. A results presentation activity.

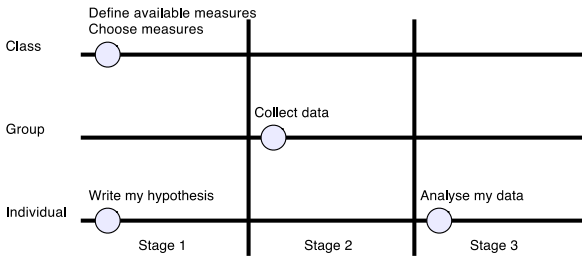


Fig. 13. Example activity distribution used for a microclimates inquiry.

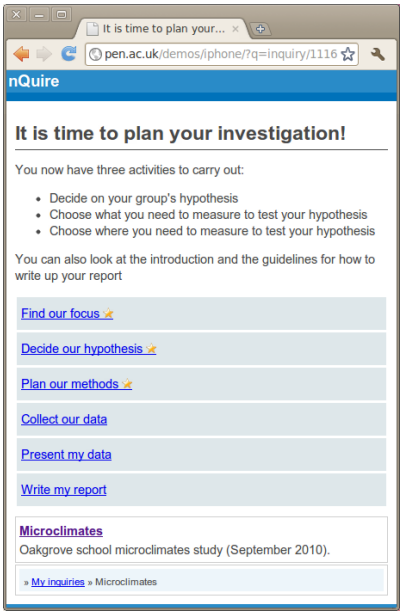


Fig. 14. The mobile equivalent of the inquiry home page as shown in figure 1.