# Designing Educational Systems Fit for Use: A Case Study in the Application of Human Centred Design for AIED.

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**Abstract**. Designing new educational experiences, which utilize novel technologies, are usable by teachers and learners and integrate well into existing, everyday educational contexts is extremely difficult. In this paper we describe the process of Human Centred Design as a cyclic process of evolution. An initial system design vision is communicated to a range of stakeholders and revised as informed by feedback from these users to produce a modified vision. A cycle of presentations of the vision and modifications lead to the creation of system prototypes that are increasingly grounded in a genuine understanding of user needs and context. The latter stages of this process employ contextually evaluated semi-functional and functional prototypes, associated documentation and an iteratively refined framework for data capture and analysis. We use the HOMEWORK system development as a case study to demonstrate the use of this approach and to illustrate the benefits that user involvement in the design process can bring to bear upon the development of an Interactive Learning Environment. We describe the type of methodology that can help designers to reap these benefits and the resource implications arising from this work. We conclude that the key output from the design process at each phase is more than the latest version of the system prototype and a modified system vision; it is also the analytical methodology that has been iteratively developed in parallel to the system software. It is this meta level analytical map that can add rigor to the design process and help to make the findings generalise beyond the particular users involved in the design process.

**Keywords.** Three or four keywords

## INTRODUCTION

Designing new educational experiences, which utilize novel technologies, are usable by teachers and learners and integrate well into existing, everyday educational contexts is extremely difficult. Educational designers need to take the complexity of the overall context into account, including the sometimes conflicting goals and expectations of the main players: the teachers, children, parents and schools; the differing constraints under which they all have to operate, such as time, age, resources and cognitive limitations; and the physical and organizational contexts in which the system is to be used. The design process has to find a path through this difficult and complex space.

A key issue for educational systems in the area of AIED concerns the role of AI. From the students' point of view educational tactics and strategies that they might be very willing to accept in the hands of a human teacher may cause problems when implemented in an IT system (du Boulay &

Luckin, 2001). From the point of view of the teacher, there is the question of the balance of agency and professional judgment to be exercised between the system and the teacher. Even if the system could in principle take more control, there may well be very good reasons to hold back on this automation in order to maintain the teacher's overall sense of ownership of the educational process in her own classroom. These two issues raise design questions, not of *how* a system could be designed, but of what *should* be designed. To answer that category of question one needs the kind of Human Centered Design (HCD) methodology described here.

A HCD approach should provide us with the tools both to negotiate this complex design space successfully and to arrive at a fitting design. Such an approach must ensure both the involvement of users in the design process and a proper consideration of context. However, this type of approach is time consuming, resource intensive and brings with it some additional difficulties that must be addressed. The danger of optimizing the design for a particular set of participants and contexts, and so designing an idiosyncratic system suitable only for the context and people with whom and in which it was designed and evaluated, is one such difficulty. A second difficulty is managing the communication between participants with disparate experience, preconceptions, perspectives and abilities. Naturally, educational technology designers will have their own vision about what they are trying to achieve founded in theory and their own views of where technology might be taken. These views will likely be quite novel to participants such as parents, teachers and children, and make it difficult to establish a shared understanding, let alone move people away from their comfort zones. Likewise, bringing designers to a real understanding of the users' requirements and the contexts of use can be difficult. The various representations, such as scenarios, storyboards, low and high tech prototypes and activities in the form of focus groups, ethnographic style studies and in-context evaluations provided by HCD can facilitate this shared understanding of the problem space and technological opportunities. The HCD process can be seen as the method through which the developers' initial design vision, grounded in theory and intuitions about the opportunities afforded by new technologies, is evolved into a validated design grounded in a genuine understanding of the users' needs and the constraints imposed by the physical and organizational contexts they operate in.

In this paper we present a case study describing the Human Centred Design of the HOMEWORK system: an exemplar system to test out a Divergent Television model for the delivery of adaptive, interactive numeracy education for children aged 5 to 7 years at home and in the classroom. The Human Centred Design of technology is central to the work of the ideas lab at Sussex where the HOMEWORK project is based. This process ensures that the technology developed is not only useful and usable but also well suited to the context of use. We provide an exemplar of this process and describe the range of activities employed in ensuring the validity of our design both in terms of the users' needs and the constraints imposed by the contexts of use.

The main contribution of this paper is the presentation of an example of how the HCD process has been used to design a system that we intend to be adaptive and intelligent. We show how this process has guided us in deciding *what* should be built, not just *how* it should be built, and has helped us to identify the ways in which AIED techniques would best contribute to the system being designed. Whilst the HCD approach itself (keeping the user at the center of the design process) is not new, the way we describe this process and the number of details provided is unusual and worth offering to others. The work itself is also novel and timely in its description of the design process for a mobile learning system working across school and home contexts. We show how we have involved many categories of actors (teachers, children and parents) and describe what their participation brought to the design at each phase in development. We also describe the work we have done to identify contextual issues impinging on design both in school and out of school.

In HOMEWORK, we started with a vision that was grounded in theory and the prior experience of the designers. This vision illustrates a perceived opportunity for new technology to support and improve learning and, as is typical at this stage of the design process, can be represented in written scenarios. The HCD process we follow proceeds to identify the users (learners and others) and involves them in modifying and validating this vision using a variety of representations (scenarios, storyboards, prototypes) and activities (focus groups, workshops, interviews, in context evaluations, for example). This cyclic process of communication of vision and revision, as illustrated in Figure 1, results in an evolving vision increasingly grounded in a genuine understanding of users' needs and context and as such has greater validity. In these later stages of the process, communication of the revised vision is supported by increasingly hi-fidelity contextually evaluated prototypes and associated documentation. This process is one that has been informed by previous work in participatory design such as that conducted by Scaife, Rogers, Aldrich and Davies, 1997, and Druin, 1999 for example. The process has and is being used by the Human Centred Research group at University of Sussex to develop and evaluate educational technology.

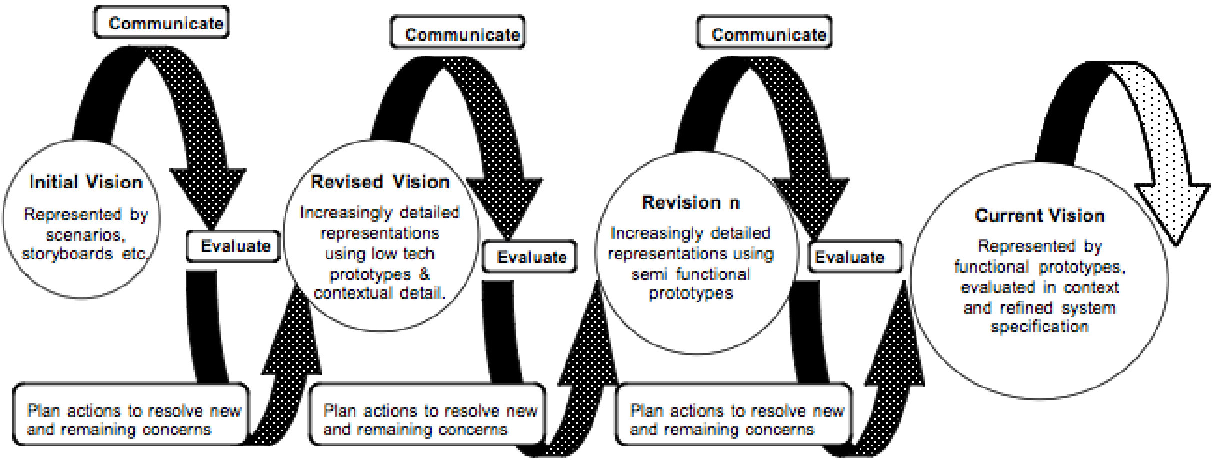


Figure 1: An iterative and incremental Human Centred Design process.

The HOMEWORK project evolved from the initial vision described in the following scenario: *Mary is 6 years old and her school is tuned into the 'Number Crew' from Channel 4. The programme and associated interactive materials are broadcast to the class's set-top box and the children watch Bradley and the crew solve number problems on the good ship Mathematical. Whilst the TV pictures on the large classroom screen engage the class, interactive exercises and activity sheets are transferred from the set-top box to each child's 'digital slate'. These exercises are differentiated and personalised to each child through the Broadband Learner Model maintained by the system for each child. When Bradley and the crew say goodbye each child's slate comes to life and the children can work as individuals (or in pairs or small groups) with the interactive materials on the Number Crew website in the Channel 4 Collaborative Learning Community. Mary and Jo, her classmate, work together. That night at home, Mary switches on her slate and it automatically synchronises with the home set-top box. Mary's teacher had suggested that some consolidation on addition would be good and has made sure that this information was communicated to Mary's slate. When Mary's mum turns on the TV, Bradley engages Mary in some number puzzles that she then completes on her slate with some help from classmate Jo, who lives on the other side of town.*

The story of Mary, her mum, her teacher and her classmate Jo illustrate the participants whom we need to include in the design process and the contexts in which our design solution must operate. Working with children as designers can be difficult. Children are generally less able to express their thoughts and ideas and it is hard to gauge how the design tasks planned might work and whether the children will fully understand what it is that they are required to do (Scaife, Rogers, Aldrich & Davies, 1997). There is an increasing amount of work on designing with children (Druin, 1999, for example). In HOMEWORK we are designing with parents and teachers as well as with the children themselves. Therefore we place greater emphasis here on our work to identify 1) our adult users' requirements and 2) the constraints introduced when designing a system to work across both school and home contexts.

When developing educational technologies for use in the classroom it is essential to engage with teachers, who do not necessarily have technical expertise or knowledge and who will need to be offered access to the design process. For the HOMEWORK project input from parents, carers and other family members is also vital if the system is to work effectively in the home context. In some ways all our user groups are learners, because they are all learning about each other and how to work together using technology to ensure that Mary and Jo progress and succeed. So, in this sense all our work has been learner centred. In particular, for the HOMEWORK project we regard parents and carers as learners and have explored ways in which we can scaffold parents to help their children with their homework (O'Connor, Kerawalla & Luckin 2005). Also, particularly significant in a system designed to work in a variety of locations, is a proper identification of design constraints imposed by the contexts of use. Much of our design process aims to elucidate these contextual issues, which are essential to address in a usable system, but not necessarily revealed simply by engaging with users.

In this paper we describe our design process, illustrating how a wide range of engagements with users and their context contribute to the bigger picture. Through this paper we explore three themes:

1. The benefits such a process can bring to the design of Interactive Learning Environment,
2. The range of methodologies that can help designers to reap these benefits,
3. The benefits of a meta-level analysis of the process (including resource audit).

We start by introducing the HOMEWORK project and describing the evolution of its underpinning pedagogical framework: the Broadband Learner Model, from its roots in Vygotsky's Zone of Proximal Development through early phases of software development in the Ecolab software (Luckin and du Boulay, 1999; Luckin and Hammerton, 2002) to its current generation/manifestation within the HOMEWORK system. Once this background is in place we describe the main components of the HOMEWORK system and present the HCD methodology we are using to continue its development. We highlight the challenges of the HCD approach and illustrate the manner in which we have addressed them, taking care to specify the resource implications. Finally, we discuss in greater depth specific benefits that have accrued from the methodology we have adopted.

## THEORETICAL GROUNDING

### The Broadband Learner Model

The Homework system is built upon a pedagogical framework called the Broadband Learner Modelling framework. This framework is based upon the concept of a Broadband Learner Model which we define as a *learner model created through the use of technology to link a learner's educational experience across time and context.* The term Broadband is influenced by, but not synonymous with, the term as it is applied to network connection speed, we use it to describe the bandwidth of learner experience that we want to capture within the learner model. The term 'context' is used here to include resources both human and artefact, in other words, a learner's context might be a school classroom with a teacher, other learners and some books. The suggestion that digital technology is a fresh form of mediation between a learner and her cultural context: an alternative tool on the all-important interpsychological plane of activity, is not new. It was identified in 1979 by Tikhomirov who saw computers as a "further development of external mediation or interpsychological functioning" (Tikhomirov, 1979). The advent of the Internet and the worldwide web has certainly added weight to this notion, but have we really appreciated the potential power that digital technology, in particular networked technology, might have to re-define educational culture in a way that is as significant as the development of language? It was questions such as this that provoked us to consider how the Law of Cultural Development and the Zone of Proximal Development (ZPD) (Vygotsky 1978; Vygotsky 1979; Vygotsky 1986), introduced in the first half of the twentieth century, could be re-interpreted for a society increasingly embedded with pervasive technology.

In the next section of this paper we describe the evolution of the Broadband Learner Modelling concept from its roots in socio-cultural psychology and the ZPD. Like the ZPD, the Broadband Learner Model is both a concept and a process. It is the process of Broadband Learner Modelling, made possible by a HCD approach that underpins the methodology we use to engage learners in the process of adaptive system design.

## The role of Vygotsky's work in the construction of the Broadband Learner Model

The work of Vygotsky and his colleagues in the socio-cultural school of psychology has influenced educational theorists and practitioners since its publication to the western world in the 1960's (see Gallimore and Tharp, 1990; and Holzman, 1996 for example). The belief that mental functions develop: "first, between people (interpsychological), and then inside the child (intrapsychological)" (Vygotsky, 1978) lead to recognition of the importance of interaction and context. This laid the foundation for the Zone of Proximal Development (ZPD), a concept that has been influential to many interactive technology developers (Laurillard, 1993; Wood and Wood, 1996; Luckin and du Boulay, 1999; Aleven, McLaren, Roll and Koedinger, 2004).

The ZPD is more than a spatial metaphor used to describe the difference between what a learner can currently achieve and their future potential (Vygotsky, 1986). It is also the process through which learning takes place as a collection of social, contextualised interactions. A key feature for successful learning is therefore collaboration in the form of assistance from other more able partners. Learning can be conceived of as a process of engagement, participation, challenge and flexible support. A more recent interpretation of the ZPD can be found in the scaffolding work of Wood (Wood, Bruner and Ross, 1976). The concept of scaffolding articulated learning as the bridging of the gap between a learner's ability to recognise a satisfactory solution and her ability to produce it. This bridging is achieved through the use of contingent support, which has been shown to be effective whether offered by human, or machine (Wood, Wood, Ainsworth and O'Malley, 1995). We have found the use of software scaffolding to be productive for the development of Interactive Learning Environments such as Ecolab I & 2 (Luckin and du Boulay, 1999; Luckin and Hammerton, 2002) and Galapagos (Luckin, Plowman, Laurillard, Stratfold, Taylor and Corben, 2001). These systems were based upon a combination of Vygotsky's ZPD and Wood's notion of Software Scaffolding. They embodied a variation upon the framework for Intelligent Tutoring System design originally presented by Hartley (1973) in which the system components are defined in terms of the system's need to have access to knowledge about the learner, the domain being studied, pedagogy and the way to interface technology and learner in a manner that supported collaboration. Although these early systems were relatively successful, they could only tackle a very small part of the curriculum and be used by a small number of learners on a restricted technology platform in a particular context, and not across multiple contexts or through a network. They represent steps along the way to the formation of the Broadband Learner Modeling framework.

Three guiding principles can be extracted from the ZPD in order to direct the further development of this design framework (Luckin and du Boulay, 2001).

. **Principle 1** *Create networks* of learners in existing, self-selecting and emergent communities that are conceptually grounded and share the same space in terms of their common knowledge even if as individuals they are physically and geographically distant.

. **Principle 2** *Provide technology to support conceptual interactivity* between people and between technology and people.

. **Principle 3** *Offer conceptual bridging* between the already known and the to be learnt through Task Focused and Learner Focused Scaffolding at both the domain and Meta level.

These three principles have been used to guide the identification of the types of knowledge that a system based on the BLM framework would need to have:

- Knowledge of the learner
- Knowledge of the domain of available educational resources
- Knowledge about pedagogy and scaffolding
- Knowledge about how to support collaboration

The term *system* here is used to describe the entirety of the system though which the child will participate in a learning experience, not merely the software and hardware technology being used.

## THE HOMEWORK SYSTEM INITIAL VISION

The three BLM principles above are clearly present in the *"Mary & Jo scenario"* (Section 1) and this scenario in turn led to the following knowledge requirements specification that was adopted when we started designing the HOMEWORK system (see below).

- Knowledge of the Learner will take the shape of dynamic, updateable, collaboratively constructed profiles of individuals and groups. Accessible from multiple devices and across multiple contexts.
- Knowledge of the available educational resources will be in the form of a store of tagged (dynamic and static) rich media with specification of the relationships between these content elements. Mechanisms will be needed to locate, match and compile resources into an intelligent lesson planner or coherence compiler (Luckin, Underwood, du Boulay, Holmberg and Tunley, 2004). The design of the content metadata tags needs to be driven by and compatible with the elements in the user model so that learners can be matched to relevant resources (Tunley, du Boulay, Luckin, Holmberg & Underwood, 2005).
- Knowledge about Pedagogy is to be used to specify the way the resources are described, the design of the learner profiles and the way in which resources are combined into learning activities.
- Knowledge about how to engender Collaboration. The learner profiles are to be collaboratively constructed between learner, teacher, parent and system. The way the resources and learners are described and the way resources are combined into learning activities or lesson plans should promote collaborative learning.

The story of the design process (see following section) illustrates how this vision has evolved and how we are moving towards its implementation.

## HOMEWORK Devices & Technology

Our initial vision imagined large screen televisions, set-top boxes and tablet PCs, with Internet access, being used both at school and in the child's home. The TV would be used for group viewing and the tablet PCs would be used both for individual and collaborative interactive activities. The tablet PC could be used at school and be taken home by each child for use out of school hours. Set-top boxes would be used to distribute high bandwidth broadcast media. Our description of the design process shows how we have moved from this initial vision and developed the tablet PC as the linking technology between school and home, avoiding Internet access and set-top boxes in the home. We also show how the tablet PC has become a way of capturing distributed elements of the Broadband Learner Model across school and home contexts.

## HOMEWORK Content

The main content material used by the project was decided at the projects inception and is based on the Number Crew, a popular television series developed by Open Mind Productions for Channel 4 Learning. This consists of broadcast quality video from 60 TV programmes in which the human crew of the ship, SS Mathematical, looks after a collection of animal passengers. In each programme the crew is challenged with a mathematical problem and children are asked to help solve this through a series of activities supported by animation, story and song. In addition to the video material there are also associated interactive activities, games, printed work sheets and lesson plans. All this material is divided into chunks, each of which is tagged with meta-data according to the schema we have developed as an extension to SCORM (see Tunley, du Boulay, Luckin, Holmberg & Underwood**,** 2005). We envisaged the finished HOMEWORK system helping the teacher select resources for a lesson and distributing these to appropriate devices. For example interactive games, that are more suitable for children to use individually or in small groups, are deployed to the children's tablet PCs and material that is more suited to whole class activity are displayed on a large public display.

## THE HUMAN CENTRED DESIGN METHODOLOGY

At the outset of this paper we alluded to the difficulties researchers face in developing a true understanding of users' needs and use context constraints. Here we discuss these challenges, outline the methodology used by the HOMEWORK project and explain how this methodology has helped us to address some of these challenges. The challenges faced by the HOMEWORK team can be classified into five main categories:

1) Communication of the design vision within a multi-disciplinary development team with a membership drawn from computer science, psychology, education and television production. This team must also include learners, teachers, parents and possibly other family members and will need to effect a balance between expert and novice as well as recognizing and overcoming the imbalances in power between individuals that result from existing relationships, such as that between parent and child or between teacher and parent.

2) Coherence. How do we link together and keep track of the iterative stages in the design process to ensure that they fit together coherently? Most approaches to user centred design involve the generation of a series of increasingly sophisticated and functional prototypes (Preece, Rogers and

Sharp, 2002) but how many iterations of prototype development do we need? What level of granularity of prototype is appropriate? What claims can we substantiate at each phase?

3) Evidence. The effective capture and analysis of data from the design process. At each phase, what data should be collected and how? How do we relate this data to the evolving vision?

4) Resources. How do we marshal all the resources that are needed in the different phases of design and keep track of what they do and what influence they have upon user engagement? This is particularly important with respect to the human members of the design team who are often actively involved in making the prototype work during a user engagement. We need to develop ways of factoring their impact into our analysis in order to avoid systems that will always rely upon an untenable level of human intervention.

5) Limitations: How do we overcome the problem of designing for idiosyncrasy? At the heart of the HCD process is the idea that we need to involve individual users and groups of users in the process so that their input makes a difference to the resulting technology we develop. However, this work is resource intensive and therefore the numbers of individuals with whom we can engage is limited. The existence of large variances in individual differences means that there is an underlying risk that technology developed with a particular group of users may be less effective when used with other users.

These challenges suggest that there will be inevitable conflicts that will need to be resolved: for example, those arising from users suggesting that they would prefer a particular system design when the data about their usage of a prototype suggests otherwise. It is insufficient to adopt a policy that the user always gets what they say they want. Such approaches have been at the root of a certain lack of rigor in some early learner centred design work (Read, Gregory, MacFarlane, McManus, Gray and Patel, 2002). It is this need for rigor that has motivated use of: 1) direct and indirect data collection across multiple contexts, media and tools and 2) a mixed economy of data visualization, representation and analysis techniques, both quantitative and qualitative.

At each stage in the design iteration we pay particular attention to the ways in which the methodology as well as the software under development can be validated and verified. We aim to contribute to a 'body of evidence' to support claims both for the validity of our evolving design and the design methodology. Table 1 (following pages) shows the phases in the HOMEWORK project, an implementation of the HCD methodology represented in Figure 1. We illustrate the cycle of vision specification, communication, evaluation and revision, and show how in each cycle the evolving vision becomes increasingly grounded in an understanding of user needs and use context constraints. At each stage the vision is itself represented with increasing fidelity through increasingly functional prototypes and associated evaluations. And at each stage, data sources and analysis methods are evaluated to inform the next phase of data collection.

Table 1
The phases in the HOMEWORK project, an implementation of the HCD methodology represented in Figure 1

| **PHASE 1 Activity and Aims:** Communicate and assess initial vision. Engage with teachers, explore lesson planning and learner profiling from the teacher perspective. | | | |
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| **Method and duration** | **Resources** | **Data** | **Outputs** |
| 2 * 1 Day Teacher Workshop.<br>Participants asked to:<br>1) Work in small groups to discuss:<br>• the characteristics of individual children that | **Tools**: Flip charts, post-it notes, pens. Laptop, PowerPoint scenario and projector. | **Data Collection**: Video camera for plenary. Digital Voice recorders – one per group. Questionnaires<br><br>**Data:** Plenary videotapes. | **Re-vision/user requirements modification:** Initial learner profiles and content metadata schema updated to |

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| influence the selection of learning activities for that child and<br>• the characteristics that influence the choice of a learning partner for that child.<br>2) To work as a large group and discuss their reactions to our system vision scenario presented as a power point presentation. | **Human**:<br>Facilitator for each group. 'Ringmaster' for Plenary. A recorder. A technician.<br><br>**Participants:** 40 Teachers from 18 schools. | Group audio. Completed Post-it notes, drawings, flip chart sheets. Questionnaires, researcher observation notes<br><br>**Analysis**: Key learning activity characteristics, learners' individual traits and contextual constraints expressed by teachers extracted from notes, transcripts | include teacher specified characteristics.<br><br>**Ongoing** work with teachers to develop first semi-functional prototype demo & school trial |
| **Phase 1 Re-Vision** Modify System Vision with increased detail of teacher user interfaces and updated learner model components and metadata content descriptions. Expressed as an enhanced storyboard from teacher perspective, formal learner model description, summary of expressed teacher opinions and requirements. | | | |

| **PHASE 2 Activity and Aims:** Improve understanding of home context and home users needs. Home contexts, parent engagement, explore current homework patterns, current home technology, location and use, assess family availability and attitudes to tablet activities in the home and related technology attitudes. | | | |
|---|---|---|---|
| **Method and duration** | **Resources** | **Data** | **Outputs** |
| **Diary study:** Adult participants volunteered to record every half hour what they were doing as well as their current enthusiasm level for undertaking a homework activity.<br><br>**Parent interviews:**<br>45 minute interview using a PowerPoint scenario and a semi structured script with a set of questions and optional follow-ups. | **Tools:** Diaries. Interview Script, Laptop with PowerPoint scenario.<br><br>**Human:** Researcher with transport<br><br>**Participants:**<br>Diary Study: 37 parents or carers from 22 families at 2 local schools.<br>Interviews: 12 sets of volunteers from diary study participants | **Data Collection:**<br>Digital Voice recorder<br>Completed diary sheets.<br><br>**Data:** Completed Diaries.<br>Interview audio recordings.<br>Researcher notes.<br>Interviews with 12 sets of volunteers from diary study participants<br><br>**Analysis**: Emergent extraction of themed responses in interview transcripts and diary recorded data | **Re-vision/user requirement modification:**<br>Homework activities need to be designed for use in first hour after children return from school.<br>Homework activities need to be flexible, e.g. different length activities for different children.<br>Parents want to know what child has done at school.<br>**Finding** Large differences exist between different schools studied and between some parents' information needs within the same school. |
| **Phase 2 Re-Vision** A modified System Vision with clarification of: appropriate homework activities, parental expectations and further implications for learner modeling and home interface design. Expressed as an enhanced home context storyboard integrated into classroom storyboard from the previous phase. | | | |

| **PHASE 3 Activity and Aims:** A) First system Demo. Demonstrate revised vision in practice. Emulate the classroom context and reveal unpredicted practical issues. Evaluate technical specification and user requirements. B) Lab session to evaluate tablet PC technology. Further explore technical issues that arose at the demo and reveal and evaluate usability (and other) issues that arise when 6-7 year olds use tablet PCs. | | | |
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| **Method and duration** | **Resources** | **Data** | **Outputs** |
| A) Mock up of the classroom context | **Tools:** System technology ( Interactive | **Data:** Videotapes.<br>Researcher notes. | Video of system vision illustrating use |

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| and system.<br>Consisting of a lesson plan with associated resources including video and activities to be done on whiteboard as a class and on the tablet PCs by individual learners. | whiteboard, 4 tablet PCs)<br>Classroom set up (desks, chairs etc.)<br>**Human:**<br>1 ‘Ringmaster’, 1 Recorder, 1 Technician, 2 Researchers<br>**Participants:**<br>1 teacher, 4 children | Software logs.<br>**Data Collection:**<br>Video camera.<br>Researcher notes.<br>Logging software<br>**Analysis**: Identification new requirement issues invisible before demo played, identify time required for average child to work through an activity to aid planning | across school and home contexts.<br><br>Identification of in class practical issues.<br><br>Validation of initial limited set of user requirements for classroom system design.<br>Identification of potential homework activity content capitalizing on hardware offered e.g. digital camera |
| B) Children worked through a task list of activities to test out tablet PC features in the laboratory with researchers. | **Tools:** 2 tablet PCs with some interactive media.<br>List of activities to be completed.<br>**Manpower:**<br>2 Researchers<br>**Participants:**<br>2 children. | **Data:** Videotapes.<br>Researcher notes.<br>Software logs.<br>**Data Collection:**<br>Video camera.<br>Researcher notes.<br>Logging software<br>**Analysis:** GUI issues highlighted in children using tablet screen, pen, touchpad, on-board camera when seated and mobile | |
| **Phase 3 Re-Vision** The modified System Vision with revised technical specification and video demonstrating practicality. Communication of the vision through storyboards, video presentation and custom built single lesson plan/control interface and small scale (5 user) polling software. List of tablet usage issues that are likely to be problematic for children of this age (e.g. left click right click confusion, handwriting recognition issues, time to learn, impatience with slow start-up and tendency to multiple click, postures of usage, tendency for battery dropout, etc…). | | | |

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| **PHASE 4 Activity and Aim:** First iteration of the home interface linking to classroom activity. Small scale and limited test of tablet based technology in the home and school context. Evaluate participant reaction. Verify findings about homework from diary and interview study. Evaluate home usage, how much, how often, what, when, by whom, etc… Observe classroom usage, integration with ongoing teaching & planning. | | | |
| **Method and duration** | **Resources** | **Data** | **Outputs** |
| Five-day evaluation of HOMEWORK system prototype with a class of children in school and at home.<br><br>Interactive whiteboard teacher led sessions for video, singing and a polling application.<br><br>A different group of 5 children were able to use the tablet in the classroom for practise activities and take it home at the end of each day Tablet used in the classroom and at home for individual activities. | **Tools:** System technology (Interactive whiteboard, 5 tablet PCs, wireless network and classroom server, custom built functional plans for each lesson – 1 each day, functional prototype home interface).<br><br>**Manpower:**<br>1 Recorder, 1 Technician, 4 Researchers.<br><br>**Participants:**<br>32 children, 32 families /homes.<br>1 teacher, 1 teaching assistant, 1 trainee teacher 1 | **Data Collection:**<br>Video camera.<br>Researcher notes.<br>Logging software on Tablet PCs (including screen capture every minute at home and in school).<br>Questionnaires<br><br>**Data:**<br>Researcher notes.<br>Videotapes.<br>Logging software output.<br>Parental diaries.<br>Completed | **Re-vision/user requirement modification.**<br>Further verification of technical specification and additional list of technical issues that need to be addressed.<br><br>**Findings:**<br>Diary and Interview findings verified.<br>Technology welcomed by all participants. |

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| | school | questionnaires.<br><br>**Analysis**: Log data showed length of time used and screens used (indicating parent or child use), verified with diaries | |
| **Phase 4 Re-Vision** System Vision validated in one context on a small scale (both temporal and number of users). Vision revised to support parental issues (e.g. concerns over Internet access – decided this was unnecessary as this phase had managed without) resulting in a modified technical and home interface specification. System can be communicated through rough functional prototypes of home interface and polling software and custom built lesson plans, video and diagrammatic representations of actual usage in this context and evaluation data, feedback quotes from teachers and parents etc… (see figure 3). | | | |

| **PHASE 5 Activity and Aim:** 2nd iteration of in context evaluation. Increase validity through scale up of usage data (number of users and time of use). Validate in an alternative context (different school, different teacher, different parents and homes). Explore system infrastructure capabilities for the delivery of limited personalization through differing curriculum objectives for year 1 and year 2 learners by using a class combining year 1 & year 2. Expand evaluation of home usage and classroom planning and management requirements using interactive whiteboard and a full class set of tablet PCs and improved home interface and custom-built classroom lesson plans. Record the process of collaboratively building classroom and homework plans using the available resources with the teacher and analyse requirements for teacher interface. | | | |
|---|---|---|---|
| **Method and duration** | **Resources** | **Data** | **Outputs** |
| Four-week evaluation of HOMEWORK system prototype with a class of children, in school and at home. System used in class at least 3 x 1 hour sessions per week.<br><br>Interactive whiteboard teacher led sessions for video followed by individual classroom use of tablet PCs for interactive practice activities with differentiate for year 1 & 2 children.<br><br>Children were able to take home the tablet at the end of each day and access video and interactive media related to the classroom activities. | **Tools:** System technology (Interactive whiteboard, 30 tablet PCs, custom built functional plans for each lesson, functional prototype home interface).<br><br>**Manpower:**<br>1 Recorder, 1 Technician, 4 Researchers.<br><br>**Participants:**<br>30 children, 30 families /homes.<br>1 teacher, 1 teaching assistant. 1 school | **Data Collection:** Video camera. Researcher notes. Logging software Diaries, Interviews.<br><br>**Data:**<br>Researcher notes. Videotapes. Logging software output.<br>Parental diaries and interviews. Teacher feedback.<br><br>**Analysis:** Process and time spent lesson planning by teacher specified, lesson management in class issues raised from observation, requirement for IT support in class realized | Video of system vision illustrating use across school and home contexts.<br><br>Identification of in classroom practical issues, updating and distribution of content across 32 devices, robustness of devices, set-up and tidy-up time, home usage issues, amount of required support, parental concerns, actual usage, etc...<br><br>Elucidation of teacher planning issues and requirements. |
| **Phase 5 Re-Vision**. Clarification of teacher planning requirements through assisted planning in context and in real-time, issues involved in identifying and communicating relevant resources to teacher, flexibility to | | | |

| |
|---|
| change plans at short notice, division of control teacher/learner/system issues. Identification and design of solutions to organizational issues (set-up and put away time). System expressed through: video illustrating actual classroom and home usage, summary of parental experience expressed through diaries, representations of usage from logged data, enhanced storyboard of teacher interface informed by planning and delivering 4 weeks of sessions, teacher perspective of experience enhanced through feedback from and additional teacher and teaching assistant. Further requirements for classroom system and planning identified. Substantial burden placed on researchers as technical assistants required by daily manual updates to Tablet PC content |

<table>
<tr><td colspan="3">PHASE 6 Activity and Aim: 3rd Iteration of in context evaluation. Increase validity of teacher interface and classroom system requirements through contextual use and evaluation of semi-functional teacher interface with a different teacher. Test redevelop infrastructure for easing update and delivery of content to tablets. Evaluate redesigned home-interface and automated daily update of home content to match school content.</td></tr>
<tr><td>Method and duration</td><td>Resources</td><td>Data</td></tr>
<tr><td>Two-week evaluation of system prototype with a class of children, in school and at home. System used in class for 3 x 1 hour sessions per week.<br><br>Interactive whiteboard and individual classroom use of tablet PCs for practice activities. Children able to take home the tablet at the end of each day.</td><td>Tools: Interactive whiteboard, 32 tablet PCs, custom built functional plans for each lesson, functional prototype home interface, semi-functional teacher interface.<br><br>Manpower:<br>1 Recorder, 1 Technician, 4 Researchers.<br><br>Participants:<br>32 children, 30 families/homes. 1 teacher, 1 teaching assistant. 1 school</td><td>Data Collection: Researcher notes. Logging software Parent diaries, phone survey and questionnaires.<br><br>Data: Researcher notes, Logging software output. Parental diaries, survey and questionnaire answers. Teacher and T. Assistant feedback.<br>Analysis/Outputs ongoing…</td></tr>
<tr><td colspan="3">Phase 6 Re-Vision An evolution of the current system vision – represented by semi-functional system (home & classroom), videos of usage, accompanying design for integration in organizational context, and evaluation data. Remaining validity concerns/limitations: the kind of school/home context and novelty – what happens with much longer periods of less intensive classroom usage?</td></tr>
</table>

## HOMEWORK GOES TO SCHOOL

Here we describe in more detail the system developments that resulted from our engagement with users across phases 1 – 4 (see table 1) for the school context. In particular this section provides more detail on the evolving teacher user interface and highlights the changes we made to the manner in which we describe content resources and to the specification of the learner model.

### Teacher Concerns

The initial vision for the HOMEWORK system (see System Vision Section) was developed into a storyboard PowerPoint presentation that we offered to teachers at the two workshops we conducted in phase 1 of the design process. This vision was generally well received by the 40 teachers involved in the 2 workshops in phase 1, though specific concerns, such as how it would operate in practice, possible extra time demands on teacher planning, and worries about being tied to planning in school were noted and incorporated in to our evolving vision for the system. This resulted in a clearer specification of the teacher interface components (see below) and our decision to trial the content and technology infrastructure in realistic contexts as early as possible.

## HOMEWORK Teacher Interface Components

### *Lesson Planner*

When each lesson is planned using the HOMEWORK system, the teacher should have access to the full set of meta-tagged resources along with information on the curriculum relevance of a particular resource, its likely duration and learning objectives. The teacher would use the lesson planning software to group learning resources into coherent lesson plans, or use existing plans provided with content or built up previously by other teachers. The system should allow complete flexibility for the teacher to use as many or as few of the available resources as required. As far as modelling the learner is concerned, the teacher will start with basic, stereotyped learner profiles for each learner in the class. Any learners with distinct needs can have their profiles adjusted at any stage. Once choices have been made and a lesson plan constructed, the system should ensure that the optimal version of each resource is mapped to each child's tablet PC by cross-referencing with the individual learner profiles. Any problems should be flagged up for the teacher, the need for subtitles for an auditory-impaired child, for example.

### *Lesson Runner*

A central goal of the system is to ensure that the correct resources are available to each child or group of children at the correct time both in the classroom and at home. Throughout the lesson the teacher will be able to override the system, and/or examine the current progress of any child within the class using the teacher interface on her own Teacher tablet PC. This will allow the teacher to identify and tackle problems a learner is having at an early stage. Throughout the lesson the results of each child's activity will be recorded and it will be possible for the data to be accessed from the teacher tablet and centrally collated for subsequent analysis.

### *Learner Model Profile Updater*

Following a lesson the information from each child's tablet will be used to update their learner profile. Over time, changes within each record of the profile will enable detailed information on the child's progress to be built up for the benefit of both the teacher and the parents.

Section 4.4 describes how these component descriptions have evolved and the extent to which these requirements have been implemented in the prototype teacher interface evaluated in phase 6. However, here we wish to focus on another key output from our phase 1 engagement with teachers. This was the development of a learner model.

## The Learner Model: Pedagogical Adaptation, Collaboration and Context Sensitivity

The learner model used for the HOMEWORK project has been informed by the Broadband Learner Model (BLM) described earlier and has also been influenced by teachers who attended the design workshop mentioned in Table 1. It was considered important to develop a user model that was not only comprehensive, but also practical and accurately reflected the needs, perceptions and interests of practicing teachers. For example, the teachers were interested in including categories, such as “concentration”, which would directly impact on their teaching and the kinds of resources available to them in the classroom, rather than 'academic' categorisations of learning styles, which were of limited practical use. The categories identified by these teachers informed many of the fields used in the HOMEWORK model.

The specification of the HOMEWORK learner model and associated meta data schema evidences the emphasis we have placed on two main areas: Context: in particular, the formal and informal learning contexts of classroom and home; and Collaborative learning with which we associate social and affective issues. This emphasis upon collaboration is a logical progression of our previous work. And as part of the HOMEWORK project we have developed and trialled prototype collaborative game content for the system, designed to support collaboration between adult carers and children in the home context. However, analysis of both of these strands of HOMEWORK is ongoing, outside the scope of this paper and will be reported on elsewhere.

### *Outline of the Learner Model*

The learner model developed so far with the help of teachers is illustrated in the Table 2 below. Some fields have two representations, *formal* (for school-based learning) and *informal* (for home-based).

Table 2.
Learner Model

| **Fieldname** | **Details** | **Purpose** |
|---|---|---|
| Compulsory data | Data in this category must be supplied for all students | To allow user ID to be created and basic details to be stored |
| Name | Name of student, surname and initial | Unique ID for each student, possibly incorporating school name and location |
| DoB | Whatever most suitable format for easy age calculation | Allows age and KS (see Note 1) (if appropriate) to be calculated dynamically as required |
| Gender | Male/female (m/f) | For statistical analysis of data |
| SEN. formal | Checkbox list for SEN (see note 2) categories: learning difficulties (4 levels); behaviour, emotional & social difficulties; speech, language and communication needs; hearing impairment; visual impairment; multi-sensory impairment; physical difficulties; autistic spectrum disorder; other | Ensures that system sends appropriate material to student tablet – e.g. severely deaf student would have no use for voice-over software, a statemented student may have LSA support |
| SEN. informal | As above but within a home context | Certain SEN altered by environment e.g. a deaf child may have access to a signing parent/sibling |
| Learner Category | KS1; KS2; KS3; KS4; etc | Enables best record structure for that student category with respect to the optional/stereotyped data fields. |

| | | |
|---|---|---|
| Extensions | Pointer to further records required at a later date | Enables learner model to be extended at any point due to omissions or other factors. |
| Optional data | | Allows exceptional students excluded from all levels of stereotyping |
| Friendships/ collaborators | If entered by user then names (auto updated to IDs by system), system updated entries will be user IDs | Allows teacher and/or system to establish (un)successful groupings of workers.<br>+ID = good pairing, -ID = avoid pairing |
| Interests | Taken from a pre-written list of likely interests with possible extra interests. | Allow particular topics/objects in a learning object to be matched to a particular learner's interest |
| Stereotyped data | Data which could be set at certain levels initially | To avoid the need to fill in all record entries - updatable automatically by system |
| Maths current attainment level | Based on NC-based targets number from 1 to 10+ default to lowest for student's current KS, though could be initially overwritten for those with initial data in their ability record (see Note 3 below) | Important for monitoring student progress and aiding in automatic report writing - using a National Curriculum based approach would aid teachers in report-writing which tends to use NC-based normative data. |
| English level | (As above) | (As above) |
| Reading age | Default to current age (as a decimal). Assumption made that below certain threshold learner is not able to read (see Note 4 below) | This record would inform system of suitable material. For pre-readers voice-over may be required, or more use of graphical resources |
| First language | Defaults to English | Allows for the presentation of assets in non-English language where available |
| Second language | Non-blank indicates degree of bi-lingualism | If English here then an issue with reading age which is assumed to be English reading |
| Confidence level formal | 3 level system: high, average, low. (see Note 5 below) | Establish whether learner would aid in peer teaching or be prepared to tackle work above their current attainment level |
| Confidence level informal | As above but for home context | Some learners are more/less confident in a home environment |
| Collaborative skills .formal (see Note 6) | 3 level scale (see confidence level) connected to number of positive/negative collaborators in collaborators record | Students with high collaborative. skills would be more likely to be included in larger groups during interactive activities. Those with low levels may require further help |
| Collaborative skills informal | As above but for home context | Some children will not have any home-based collaborators (only child/busy parents) |
| Concentration skills formal | 3 level scale (as above) | Useful for younger learners. Those with a low level would require material of a shorter duration than others |
| Concentration skills informal | As above but for home context | Some learners find it easier/harder to concentrate at home – depending on distractions e.g. young siblings |
| Reasoning skills | 3 level scale | Child with lower reason. Skills would benefit from material with a higher amount of explanation |
| Motor skills (see Note 7) | 3 level scale | Ensures that speed of response by learner is normalised for dexterity |
| Oral skills formal | 3 level scale | More relevant to non-computer-based resources |
| Oral skills informal | As above but for home context | Particularly relevant for learners with English as a foreign language with improved oral skills at home |

| | | |
|---|---|---|
| | | through speaking in their native tongue |
| Written skills | 3 level scale | Use of tablets for writing |
| Learner type | Scale (3+ to 3-) for each of the following: kinaesthetic; oral; visual; tactile; aural | Useful for choosing the type of resources best for a child – obviously important in SEN e.g. tactile rather than visual for a visually-impaired learner |
| ZPD | Derived measure of learning represented as a number triple | |

***Notes on Table 1***

1). KS refers to Key Stage. In HOMEWORK we are working with children in Key Stage 1, which refers to the National Curriculum objectives for children of age 5-7. 2). SEN refers to Special Educational Needs. 3). When dealing with attainment level, there could be a need to have separate values for different subjects (e.g. Mathematics and English) and again within the subject. Children who are good at one aspect of a subject are not always good at other areas, e.g. in Mathematics some who are good at Number are not always good on Shape and Space. Similarly in English some are great orally but bad at writing. 4). For a student with English as a second language the reading age may be lower, though the system should be able to assess this and adjust the age accordingly. Emphasis needs to be placed on establishing the correct level as quickly as possible to ensure that the correct level of material is supplied to the user. 5). As with attainment level there could be a need to supply different levels of confidence in different subjects – one for Mathematics and one for English. 6). Collaborative skills are important for learners of all ages. Within young learners this record can be used to flag up particular strengths and weaknesses so that on occasions students with low skill levels could be paired with particularly gifted collaborators. 7). Motor skill level is particularly relevant for very young children who may not be used to computer technology. A slow response to a question may be linked to this factor rather than a low reasoning/understanding of the task. A learner might have a physical condition, such as arthritis, which again could affect speed of response. In all cases it is important to ensure that the reaction time recorded takes such conditions into account.

This list of features combines areas we are concerned to model and those that teachers felt to be most significant. As such it represents a shared understanding of what might be desirable and useful to model. We acknowledge that it is easy to create a knowledge representation scheme where you have more variables than you know what to do with, and this may be the case with respect to our current implementation of the HOMEWORK system. However, we see no disadvantage in maintaining, refining, expanding and making public this learner model whilst the system is under development. We or indeed others may find ways to effectively measure and input to some of these categories (motor skills, confidence, for example) and make use of them in adaptive systems.

## The Teacher Interface Prototype

The teacher interface prototype developed out of the requirements arising from Phase 1. Storyboards and mock-ups where used to engage with and elicit feedback from participating teachers in Phases 4 and 5 and in Phase 6 a semi-functional prototype was developed and used in the planning and execution of 6 one hour numeracy sessions over a two week period. Analysis of data from Phases 5 and 6 is ongoing, here we describe the teacher interface prototype (Figures 2 & 3) and how it was used in Phase 6.

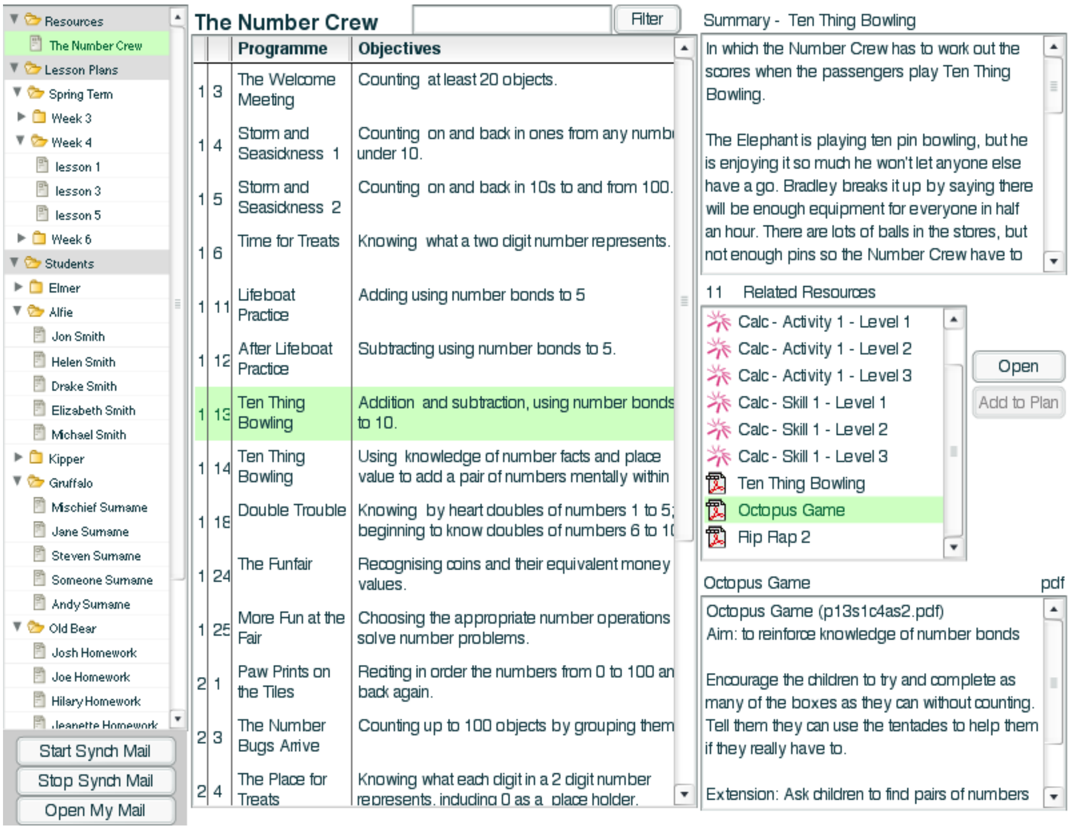


Figure 2. Teacher Interface: browser.

This semi-functional prototype allows the teacher to browse a subset of all the available resources (videos, interactive games, worksheets and lesson plans) from the Number Crew library (see Figure 2). She can identify numeracy objectives, read short summaries and access any of these resources through the browser. For this library the resources are arranged around programmes, as this is how the producer has designed them and intended them to be used. However, the system supports alternative visualizations of different resource libraries through plug-in user interface components. The XML metadata describing the individual number crew resources in the library is processed using XSLT in order to produce the programme centric XML representation of resources used by the teacher interface browser component.

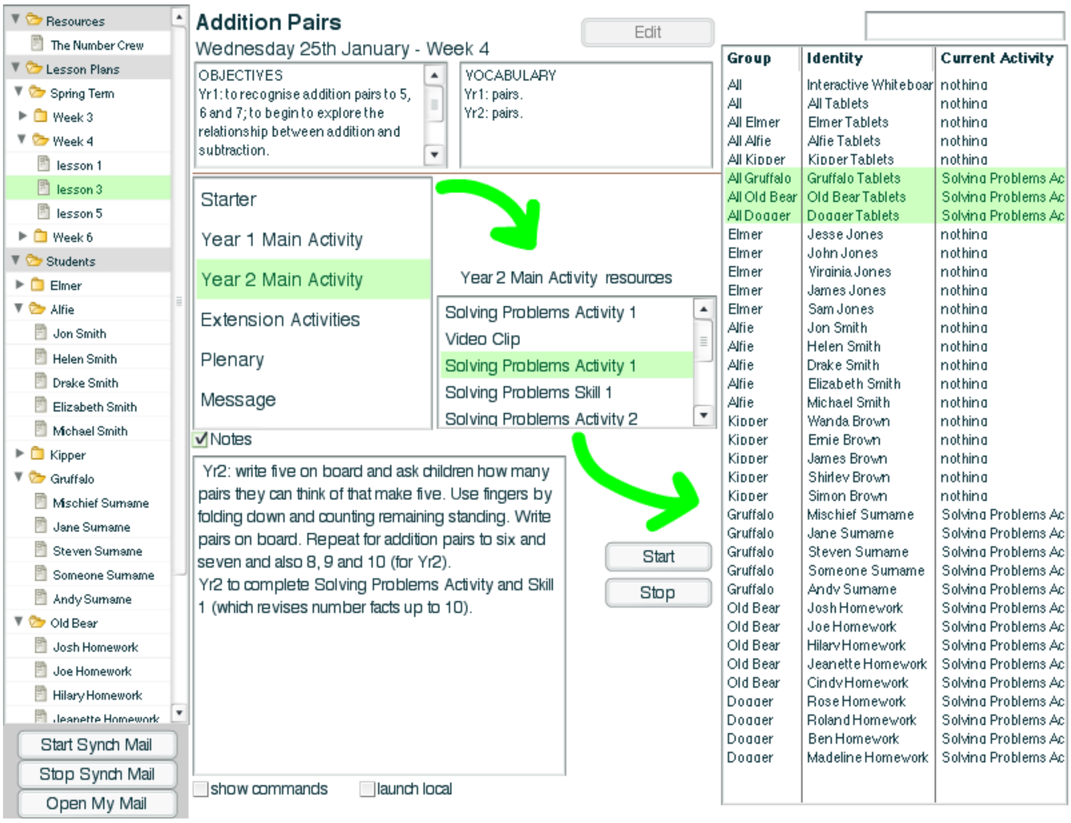


Figure 3. Teacher Interface lesson plan/control.

We used the browser with the teacher to identify the resources she wished to use to support delivery of numeracy topics dictated by the year 1 and 2 curriculum for the period of the study. The teacher produced her plans incorporating these resources. We then produced an XML representation of her plans that we presented back to her through the teacher lesson plan/control interface (Figure 3). We also checked that our schema would support encoding of sample numeracy plans provided on the UK National Curriculum website and the lesson plans supplied with the Number Crew content. We did not start from any existing learning design representation, such as IMS-LD (van Es & Koper, 2006), because at this stage our primary interest was in representing back to our user her own plans as efficiently as possible and integrating links to the resources and available devices so as to allow her to check resource contents and control the flow of the lesson from the plan. Plans are represented visually to the teacher as discrete sections (e.g. starter, main activity, extension activities, plenary) with each section having associated resources, if required. Further, she can plan to launch a specific resource on any single device or group of devices. Our current XML representation maintains this structure with a lesson consisting of an arbitrary number of section nodes each of which may have zero or more resource nodes. Resource nodes may in turn have any number of device nodes. Future work, arising from our planning and classroom numeracy session evaluations in Phase 6, will identify the limitations in our current representation and explore the options for using a standardized existing learning design representation. We will also explore the potential for the system to guide the teacher at the planning stage in identifying appropriate resources for individual learners using content metadata and learner model characteristics.

## HOMEWORK GOES HOME

Whilst most projects of this kind working with children have focused exclusively on the school context (see Scaife, Rogers, Aldrich and Davies, 1997 for example), the HOMEWORK model is designed with both the school and less formal home contexts in mind. For the learner model a number of pedagogical categories were felt to vary between formal and informal environments, especially for very young learners who have far less control of their environments. For example, the confidence of a child with a non-English home language may well be considerably lower within the school context compared to a child from a home where work can be discussed with a native speaker. Conversely, the collaboration potential within the home would be far lower for a child with no siblings compared to the classroom setting. Such variations require consideration when designing a single user model profile for each child. The question: "How can the profiles for these two contexts be combined into a single learner profile?" is one which is currently under consideration. Insights into the design of the learner model were largely derived from the work under Phase 1 of Table 1 described earlier. In this section of the paper we consider Phase 2 of the design process as described in Table 1 and provide more detail about the manner in which our studies with users in the home context have impacted upon the HOMEWORK system development.

### Learning about the Home as a Learning Context

Two primary schools in Sussex volunteered to allow us into their classrooms and to work with the children's families. School A is a large suburban primary school and the catchment area covers a wide range of families in terms of socio-economic status. School B is a small village school that serves local villages, remote farms and a small town. The class we worked with in School B was a double year group. The aim of the home-based study was to assess family availability and enthusiasm for Homework tablet activities.

#### *Home Context: Diary Study*

A range of family members volunteered to record, every half hour and in real time, what they were doing at that moment in time during one term-time evening and one day of a term-time weekend. We received a total of 76 completed diaries covering weekdays and weekends.

Analysis of the data revealed that all carers had high availability and energy for helping their children in the hour immediately after children return from school, with a fall-off after 7pm. At weekends the most likely time for them to be willing and able to help is when children are watching TV (regarded as a low priority activity). There were clear differences between the families at the two different schools. Parents at School B reported higher levels of energy to do an activity with their child when they first returned home from school and were also more likely to ask their children to do an activity at the weekend. This may reflect a more affluent school location; it may also indicate the importance of the approach adopted by the school. For example, whilst both sets of families were keen on the idea of tablet homework activity, it was likely to be less effort for School B families as they already received more homework, some of which was already designed to involve parent and child working together.

The implications of these findings for system design are that the system:

- Must be flexible enough to meet the needs of a diversity of home school link arrangements, such as those reflected in these two school groups, and
- Should provide collaborative activities for when parental availability is high and support is available and activities suitable for the child's individual use at other times.

***Home Context: Parental interviews***

Twelve sets of parents from families at both participating schools were interviewed for 45 minutes using a semi-structured scripted approach supported by a PowerPoint storyboard illustrating the proposed system vision. Findings from this data illustrated more consistency between the two schools than that collected using the diary methodology. Variation between the two schools was limited to the area of home-school links. The majority of parents thought their children received an *'OK'* amount of homework (50%), although 36% of parents thought they got too much: *"Its horrendous. I'm surprised at how much they get. At his age I don't think they should get any homework. If it can be made fun then so much the better…"* and 14% thought not enough: *"it's diabolical as far as I'm concerned. Much less than her previous private school".* There was a large variation in the amount of time spent on homework, ranging from 30 minutes to 5 hours. Most parents wanted to help their children: Types of help varied from helping the child understand the task, encouragement, doing the task for them and leaving them alone. Previous work completed at Sussex has demonstrated that parents responded well to software scaffolding to support them in helping their child complete arithmetic activities on a tablet PC.

A variety of existing home/school link types were identified: parents going in to help, being school governors, filling in reading record books, children taking home exercise books with merit stamps in them, for example. However, despite this, all parents wanted to know in more detail what their children did on a daily basis. Their children couldn't remember, and just seeing the homework that had been set was not enough. There was a strong sense that parents thought that teachers were too busy and therefore were only to be visited when there was a problem. Parents were keen on the idea of the tablet PC being used for homework; the 'History' function which they were told would allow parents/carers to see what activities their child had been doing was particularly favoured. One parent summed this up by saying that "this [tablet] is wonderful from that point of view because it means that we know what he's actually doing".

The implications of these findings for the system design were that the system should:

- Provide users (parents and children) with detailed information about, and access to, what has been done at school both recently and in the more distant past.
- Help parents to identify whether a child needs support with particular topics.
- Clearly identify some activities as 'homework'. Parents will prioritize these activities and often be willing to assist with them.

Provide short (<30 min) (collaborative) activities as well as providing options for much longer (individual) use.

The key insight of the work under Phase 2 of Table 1 was the strength of the parents' feelings about wishing to have more involvement and knowledge of what their children have done in school. While we had expected this to be the case in general, we were surprised by how grateful parents were to be able, not only to see what the children had done but also to work with their children on those same activities. This however brought another surprise: the children themselves sometimes took such a strong sense of ownership of the tablet PC and of the classroom work they do on it that they want to do the work again at home *without* help from their parents

Through Phases 4, 5 and 6 we have gradually evolved and evaluated a home user interface intended to support these requirements. Evaluation data has supported our expectations arising from Phase 2 and to some extent illustrates that we have enabled parents to learn more about and become more involved in children's schoolwork. For example one parent commented that: *"it means that if [child] starts to talk to me about something she's done at school, you know what she's talking about".* Another parent was pleased with being able to link informal learning at home with what was happening in the classroom: *"I've got a lot better understanding of what level they were operating at, and the theme of what they're looking at…….if you're giving them their pocket money or things like* *that… instead of giving them a fifty pence, or something, then you can give them five tens and you can back up and reinforce that message".* Analysis of data obtained in Phases 5 and 6 is ongoing.

In the next section we briefly describe the adjusted vision of the system as it has emerged from the user-centred design process described in the previous few sections. The overall vision of the system has not changed, rather there have been changes in emphasis on some aspects of the system over others: in particular, making sure that parts of the system that link home and school are given more detailed thought.

## THE REVISED HOMEWORK SYSTEM VISION

All of the work described in this paper has lead to our current vision for the HOMEWORK system.

*Mary is 6 years old and her school is tuned into the 'Number Crew' from Channel 4. The programme and associated interactive materials are available from the school server. The children watch Bradley and the crew solve number problems on the good ship Mathematical. Whilst the digital video on the interactive whiteboard engages the class, each child's tablet PC starts-up and launches the interface today's lesson. Interactive exercises, activity sheets and any other required content was preloaded on the tablets over the school network when Ms Long planned this session. These exercises are differentiated and personalised to each child through Miss Longs' planning in which she is assisted by the Broadband Learner Model maintained by the system for each child. When Bradley and the crew say goodbye each child's slate is ready and the children can work as individuals (or in pairs or small groups) with the interactive materials distributed to their tablet PCs. Jo, Mary's classmate, is of sick today but she has access to all the work planned for today's session at home on her tablet which has automatically updated to provide her with access to today's lesson content. That night at home, Mary switches on her tablet PC and sees the home interface which provides her with structured access to her homework, activities done in school today and a history of her numeracy activity. Mary's teacher had suggested that some consolidation on addition would be good and has made sure that this information was communicated to Mary's tablet PC. When Mary's mum finds a moment, she comes over to find out what Mary has been doing today at school and to offer some help, she feels Mary is having difficulty with addition. Later, after Mary has gone to bed, Mary's mum has a look at today's tips for parents who want to help and finds a suggestion for practicing counting while cooking together, she also writes a quick note to Ms Long about Mary's trouble with the homework.*

This is partially developed in the HOMEWORK prototype system used in Phase 6 of the design process in Table 1. This version of the Homework system is yet to be linked to the learner modeling component, but it has proved sufficiently robust for use in school and at home over the course of two evaluations, one lasting 4 weeks and the other 2 weeks. Over the course of these two evaluations we successfully delivered sufficient and appropriate content to two classes of approximately 30 children and their carers and teachers. The current version of the system is preloaded with all the resources that the teacher requests from those made available to her during lesson planning. The teacher is able to select from amongst these, those that are for use in class on the interactive whiteboard or on individuals' tablet PCs, and those that are for use at home. Lesson planning was thus effectively undertaken offline by the teacher in anticipating which resources she was going to use for a particular lesson. In the classroom, activities can either be launched from the teacher's tablet, on a child's tablet PC or any group of tablet PCs; or the children are presented with an interface providing links to the planned activities. At home, the home interface on the tablet PC provides child and carer with structured access to objectives and content used at school today, used in the past and activities assigned for homework. At this stage in development no individualization of interaction is undertaken by the system itself, though there is scope for the teacher to plan for individual children or groups of children to use specific resources. In practice, this has resulted in year 1 children receiving different content to year 2 children in the double year class.

When children take the tablets home it is easy for them or their parents to access the resources that have been used by the class that week and indeed if they miss a class the tablet automatically updates the home interface to allow access to the content planned for use in class on that day. However, there is no specific automatic individualization of resources on a per-child basis.

Extensive logs are kept by the system on a per-child basis but these are not currently linked back into either the home interface or the teacher interface in order to provide feedback on a child's activity and performance, either live or retrospectively. We have developed a range of data representations and used an array of analysis methods as indicated in the data column of Table 1. These have been tested and have evolved through all phases of the design process. An example, arising from our analysis of data captured during home use, is shown in Figure 1. This illustrates interface screen shots with superimposed log file data. The log data from the phase 3 system evaluations shows 28 children's sessions and illustrates that 100 percent of the user group visited 'this week at school' and launched 1 or more pieces of linked content. 93 percent visited 'this week at home' with 100 percent of these launching 1 or more pieces of content. 75 percent visited 'My history', though few of these actually launched activities. Designing and implementing the components to represent this data back to teachers, children and carers, is one of our current endeavours and is supported by the ongoing work in analyzing and representing the data captured in Phases 5 and 6.

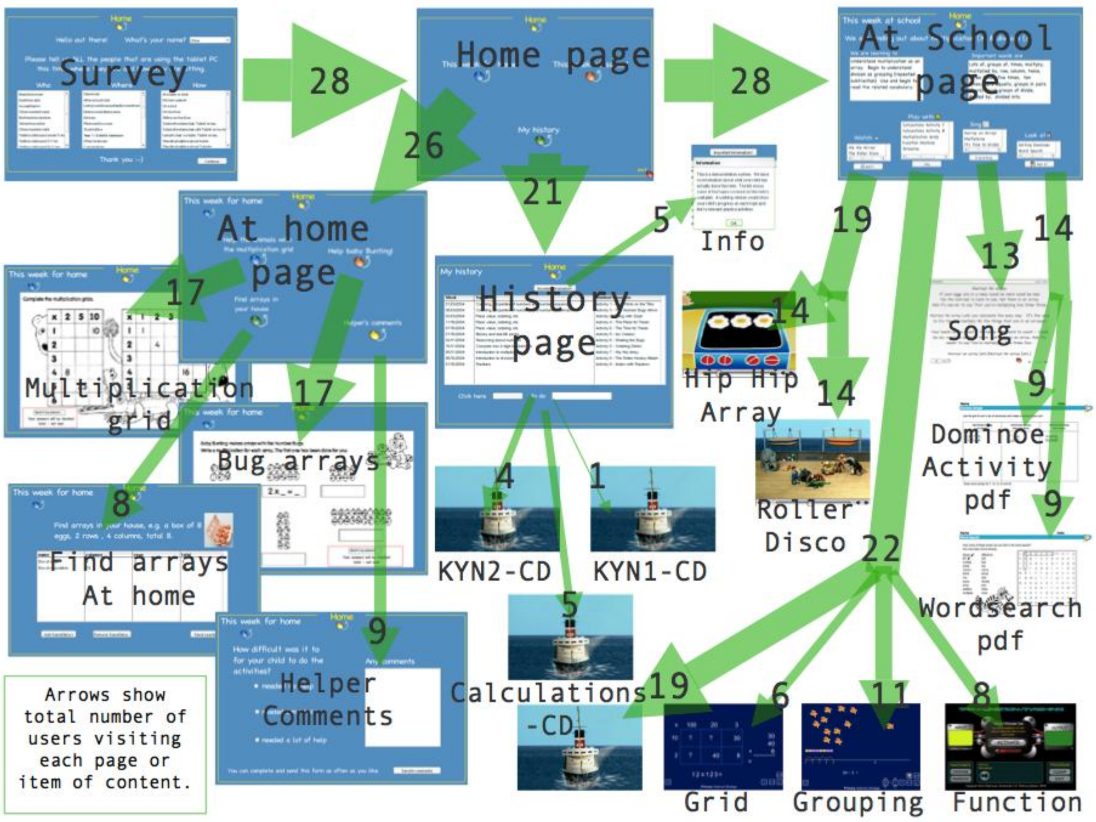


Figure 4. Use of the HOMEWORK 'home' interface and content

While this version of the system lacks several of the crucial components of the original vision it provides us with a very useful test-bed to try out the practicalities of the use of the tablets in the classroom, the transport of the tablets backwards and forwards between classroom and home, as well as the use of the tablets in the home context. In addition, this kind of real context semi-functional formative evaluation allows us to identify clear roles and requirements for the knowledge and adaptive components we planned to develop.

## CONCLUSIONS

At the outset of this paper we described the process of Human Centred Design as a cyclic process of evolution in which an initial system design vision is communicated to a range of stakeholders and revised to produce a modified vision that is increasingly grounded in a genuine understanding of user needs and context. The latter stages of this process employ contextually evaluated prototypes, associated documentation and an iteratively refined framework for data capture and analysis. We have used the HOMEWORK system development as a case study to demonstrate the use of this HCD approach and to illustrate the benefits that user involvement in the design process can bring to bear upon the development of an Interactive Learning Environment, the type of methodology that can help designers to reap these benefits and the resource implications arising from this type of work.

The HOMEWORK system described in Section 6 above is the latest system vision. It has many of the same features that were present in the original vision. This original vision was grounded in a pedagogical framework that represents an interpretation of Vygotsky's Zone of Proximal Development and a constructivist philosophy. It was informed by the evaluation of previous software systems that had been developed from an earlier version of the pedagogical framework. Our engagements with users have driven our evaluation of the system vision current at each phase in the design process. This evaluation and revision draws upon multiple data sources from user studies and also upon the pragmatic considerations that arise from resource limitations and tight time frames for development. The key output from the design process at each phase is more than the latest version of the system prototype and a modified system vision; it is also the *analytical methodology* that has been iteratively developed in parallel to the system software. This informs and helps us to refine the nature of the data we collect and the analysis we conduct. It also helps us to address the five challenges we identified in Section 3. We can identify and adapt the representations and activities that have helped us to share our system vision with users. The gaps in the system vision can be identified and the cost and effort that would be involved in addressing them can be evaluated to define the number of iterative cycles that need to be conducted. The data capture and analysis methods are evaluated at each stage so that a meta level plan that describes how different elements in the data analysis process fit together can be formulated. The explication of this meta level analysis plan is the subject of ongoing work that is linked to our endeavours towards understanding and mapping educational contexts (see Luckin, du Boulay, Smith, Underwood, Fitzpatrick, Holmberg, Kerawalla, Tunley, Brewster, and Pearce, 2005 for example). The resources that have been needed in the different phases of design are recorded and tracked so that their impact can be evaluated. Finally the prototypes are introduced to a variety of users in groupings that vary in size in order to minimize the risk that we design for idiosyncrasy.

The empirical studies that form part of the HCD process have enabled us to demonstrate that when designed and used appropriately educational technology can improve links between home and school learning and close the gap between parents, teachers and learners. Such technology can provide continuity across locations when the activities offered to learners are contextualized across school and home environments. Children very much enjoyed having their own personal device both in the classroom and the home and results from pre-and post study maths tests reveal a possible relation between the amount and kind of home use of the tablet and learning gains.

From an AIED standpoint the HCD design methodology has led to a distinct change of focus around the role of AI in HOMEWORK (even allowing for the fact that the system is not yet fully implemented). At first we anticipated that the major role for the student modelling, pedagogic modelling and resource modelling (domain modelling) would be to provide help for the teacher in the lesson planning phase of her work e.g. to help her construct an appropriate sequence of activities for classroom and home individualized for each child or group of children. Our observations of various versions of the prototype in the classroom emphasized the importance of the teacher's role in real-time dynamic monitoring of how well each child was doing, who had finished far ahead of expected time, who was stuck and needed help, who was bored or sleepy and so on. So the design emphasis has shifted somewhat, and further needs to shift, from help with planning toward help with monitoring: in both cases respecting the teacher's absolute need for overall control and professional responsibility of what happens. Of course, many of the same underpinning system components can be re-applied from lesson planning to lesson monitoring, but this we believe is a change of design direction that derived from the HCD process.

There are also some pragmatic and methodological issues that need to be highlighted. A system for simultaneous use by 32 5/7 year olds needs to be extremely robust and responsive, as does the hardware. Pre-loading of content on tablets needs to be automated and scheduled to take place at a time when all tablets are available on the network and not in use. This has organisational and infrastructure implications. Most common problems experienced by users related to the usability of the tablet PCs, for example bad pen tracking, slow start-up, unresponsiveness, poor camera usability. The technical difficulties and setup time can seem daunting to teachers especially the thought that they might need to solve problems 'on the fly' as they occur, single-handedly without researcher or other IT support. Working with users and beneficiaries has a big and positive impact on system design, but it is resource intensive, requires incremental and targeted engagement and careful management of user expectations.

There is plenty of scope for further development of the adaptive aspects of the system. Within the project we moved towards a shared responsibility model for the teacher and system and aimed to support the teacher in maintaining an accurate and dynamic knowledge about what each child knows and assist them in acting on this through individualised planning. The system is designed to support this and potentially the system can make suggestions to the teacher on which activities to choose in order to best plan for a particular learner, utilising the available knowledge about that learner. However, as a result of the change in priorities in this area implementation was only partial. This is an area that could be progressed in future work; both from a scientific and exploitation standpoint. Likewise there is a need to explore how the links between home, school and other learning contexts can be improved. The tablet PC could offer information about a great deal more than numeracy. There are many areas of the curriculum that could be included. In addition to the provision of support for parents to help their child learn, there could also be support for parents to increase their own skills and knowledge about particular subject areas including numeracy and literacy. Beyond, the curriculum, the tablet could act as a gateway for communicating information about housing, benefits, social services and other local and national government services and initiatives.

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# REFERENCES


Aleven, V., McLaren, B., Roll, I., & Koedinger, K. (2004). Toward Tutoring Help Seeking: Applying Cognitive Modeling to Meta-cognitive Skills. In J. C. Lester, R. M. Vicario & F. Paraguaçu (Eds.) *Proceedings of the 7th International Conference on Intelligent Tutoring Systems, ITS 2004* (pp 227-239). Berlin: Springer Verlag.

du Boulay B. & Luckin, R. (2001). The plausibility problem: An initial analysis. In M. Beynon, C. L. Nehaniv & K. Dautenhahn (Eds) *Proceedings of the 4th International Conference on Cognitive Technology: Instruments of Mind.* Lecture Notes In Computer Science; Vol. 2117, (pp 289-300). London: Springer Verlag.

Druin, A. (1999). *The Design of Children's Technology*. San Francisco, CA, Morgan Kauffmann.

Gallimore, R. & Tharp, R. (1990). Teaching mind in society: Teaching, schooling, and literature discourse. In L.C. Moll (Ed) *Vygotsky and education: instructional implications and applications of sociohistorical psychology (pp175-205)*. Cambridge, Cambridge University Press.

Hartley, J. R. (1973). The Design and Evaluation of an Adaptive Teaching System. *International Journal of Man-Machine Studies*, 5, 421-436.

Holzman, L. (1996). Vygotsky in practice: Development projects of the international center for human development (New York) (conference presentation). Abstract in the abstracts of the *2nd Conference for Socio-Cultural research: Vygotsky-Piaget*, Geneva, September 11-15 1996.

Laurillard, D. (1993). *Rethinking university teaching: A framework for the use of educational technology*. London, Routledge.

Luckin, R. & du Boulay, B. (1999). Ecolab: the Development and Evaluation of a Vygotskian Design Framework. *International Journal of Artificial Intelligence and Education* 10(2): 198-220.

Luckin, R. & du Boulay B (2001). Embedding AIED in ie-TV through Broadband User Modelling (BbUM). In J. Moore, W. L. Johnson and C. L. Redfield (Eds) *Proceedings of 10th International Conference on Artificial Intelligence in Education: AI-ED in the Wired and Wireless Future*. (pp. 322-333). Amsterdam, IOS Press.

Luckin, R. & Hammerton L. (2002). Getting to know me: helping learners understand their own learning needs through metacognitive scaffolding. In S. A. Cerri, G. Gouarderes & F. Paraguaçu (Eds.) *Proceedings of the 6th International Conference on Intelligent Tutoring Systems, ITS 2002.* (pp. 759-771). Berlin, Springer-Verlag.

Luckin, R., Plowman, L., Laurillard, D., Stratfold, M., Taylor, J., & Corben, S. (2001). Narrative evolution: learning from students' talk about species variation. *International Journal of Artificial Intelligence in Education,* 12: 100-123.

Luckin, R., Underwood, J., du Boulay B., Holmberg, J. & Tunley, H. (2004). Coherence Compilation: applying AIED techniques to the reuse of educational TV resources. In J. C. Lester, R. M. Vicario & F. Paraguaçu (Eds.) *Proceedings of the 7th International Conference on Intelligent Tutoring Systems, ITS 2004* (pp 98-107), Lecture Notes In Computer Science; Vol 3220. Berlin: Springer Verlag.

Luckin, R., du Boulay, B., Smith, H., Underwood, J., Fitzpatrick, G., Holmberg, J., Kerawalla, L., Tunley, H., Brewster, D. & Pearce, D. (2005). Using Mobile Technology to Create Flexible Learning Contexts, *Journal of Interactive Media in Education,* 22. Special Issue on Portable Learning – Experiences with Mobile Devices. <www-jime.open.ac.uk>.

O'Connor, J., Kerawalla, L. and Luckin, R. (2005) *Using Discussion Prompts to Scaffold Parent-Child Collaboration Around a Computer-Based Activity*, Artificial Intelligence in Education, Supporting Learning through Intelligent and Socially Informed Technology, IOS Press, Edited by Looi, C.,K., et al, Netherlands, 176-183..

Preece, J., Rogers, Y. & Sharp H. (2002). *Interaction Design*. New York, NY, USA.

Read, J. C., Gregory, P., MacFarlane, S. J., McManus, B., Gray, P., & Patel, R. (2002) An Investigation of Participatory Design with Children - Informant, Balanced and Facilitated Design. In *Proceedings of Interaction Design and Children 2002*, (pp 51-58) New York, NY: ACM Press.

Scaife, M., Rogers, Y., Aldrich, F. & Davies, M. (1997) Designing for or Designing With? Informant Design for Interactive Learning Environments. In *CHI'97: Proceedings of Human Factors in Computing Systems*, (pp 343-350) New York, NY: ACM Press.

Tikhomirov, O. K. (1979). The psychological consequences of computerization. In J. Wertsch (Ed) *The Concept of activity in Soviet Psychology*. Armonk, New York: M. E. Sharpe.

Tunley, H., du Boulay, B.,Luckin, R., Holmberg J. & Underwood J. (2005). Up and down the number line: modelling collaboration in contrasting school and home environments. In L. Ardissimo, P. Brna & A. Mitrovic (Eds) *Proceedings of User Modelling 2005*, Lecture Notes In Computer Science; Vol.3538. (pp 424-429). Berlin: Springer-Verlag.

van Es, R., & Koper, R. (2006). Testing the pedagogical expressiveness of IMS LD. *Educational Technology & Society*, 9 (1), 229-249

Vygotsky, L. S. (1978). *Mind in society: the development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (1979). The genesis of higher mental functions. In J. Wertsch (Ed) *The Concept of activity in Soviet Psychology*. Armonk, New York: M. E. Sharpe.

Vygotsky, L. S. (1986). *Thought and Language*. Cambridge, MA: The MIT Press.

Wood, D. & Wood, H. (1996). Vygotsky, tutoring and learning. *Oxford Review of Education,* 22(1): 5-16.

Wood, D., Wood, H., Ainsworth, S. & O'Malley, C. (1995). On becoming a tutor: Towards an ontogenetic model. *Cognition and Instruction*, 13(4): 565-581.

Wood, D. J., Bruner, J.S. & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry* 17(2): 89-100.