Constructionism through Mobile Interactive Knowledge Elicitation (MIKE) in Human-Computer Interaction

Dean Mohamedally

Submitted for Examination of Doctor of Philosophy

Centre for Human-Computer Interaction Design
City University London
United Kingdom

March 2006

Table of Contents

List of Figures

List of Tables

Appendices

Acknowledgements

By the grace of God, the Merciful and the Kind.

This thesis is firstly dedicated to my parents, Dr. Sheik Mabob Mohamedally and Mrs. Omma Devi Mohamedally. Your love, dedication, patience and courage instilled in me are without hindrance and are eternal. This thesis is also dedicated to my supervisors, Dr. Panayiotis Zaphiris and Prof. Helen Petrie for leading me and teaching me the level of character and wisdom necessary to fulfil the aptitude required of this journey. Thanks to my parents and supervisors, I hope I may represent your esteems and legacies well in all of my future endeavours. I know no end of gratitude for those things which you have given me especially in allowing me to further a field that you all know I am so thoroughly keen to explore ☺

A few notable mentions of thanks: Prof. Neil Maiden for allowing me to walk this path and always being inspiring. The participants from my supervisors' classes, I thank you. Dr. Stephanie Wilson for support and also allowing me to utilise her classes in my case studies. Dr. Cornelius Ncube for cheerful insight and advice. The Centre for HCI Design and all of the PhD students as a whole, for all of your most respectful motivation and helpful assistance in enabling me to bring Mobile Computing to HCI with User Centred Design. EPSRC for the scholarship award, without which I would not have been able to afford the PDAs, tabletPCs and other numerous mobile gadgets to experiment and explore this research with. The School of Informatics, City University London, for giving me facilities needed to undertake this research, publish and attend conferences. From King's College London, Mr. Malcolm Bird, Prof. Russel Winder and Dr. Odinaldo Rodrigues thank you for setting me on this journey. Prof. Stefan Edlich from University of Berlin for the enthusiasm towards this field. Microsoft, Sun Microsystems, IBM, Nokia and SonyEricsson for giving me the access needed to the state of the art in developer tools for mobile computing technologies, making the software contributions of this thesis a reality.

Where would we stand on a journey without our friends and family? Thank you Grandpa and all my relatives in the UK, New York USA, Trinidad and Mauritius. Back here in London, Ms Saira Chowdhury, Mr Tahir Khan, Ms Aaysha Awais, Ms Mahgul Nazim, Ms Nilufar Anwar & Ms Afra Khan; a special mention as yours has been a steadfast trust that has given direction to the sails of this voyage from the very beginning. Numerous others have contributed to aiding, debugging and when absolutely necessary, rebooting my state of mind at various stages on this journey; to all of you with sincere kindness, I thank you.

My father's motto since I was a child is *Always Value Your Time*. This PhD taught me the meaning of this statement on a level of deepness and integrity which I am certain he felt when he completed his.

My own motto, as I have acquired having seen from the ways that my parents, supervisors and their colleagues have achieved in their careers, is *Angels Favour the Bold*. With a will to explore rigorously and meticulously, there is little to stop a person from making it a significant endeavour if they are up for the challenge.

Declaration

I grant powers of discretion to the University Librarian to allow this thesis to be copied in whole or in part without further reference to me. This permission only covers single copies made for study purposes, subject to normal conditions of acknowledgement.

Abstract

Mobile computing holds significant as-yet unknown applications of interest in the field of Cyberscience (e-Science) methods. This thesis provides a diverse exploration into the advancement of HCI theory through the development and testing of mobile cyberscience tools. This is done by synthesising new metrics from learning epistemologies, with the benefits that can be provided by mobile computing solutions.

This thesis aims to explore how mobile cyberscience can improve HCI knowledge elicitation (KE) methods. A review of the current state of the art in mobile computing and mobile HCI demonstrates that there is very little reported research in the direction of applying mobile computing to HCI theory (rather than the reverse which is demonstrated to be significantly considered in academia). This motivates a review of the current methods and cyberscience-based tools in the domain of KE in HCI, with several prototype mobile tool designs discussed. A review of candidate grounding theories in pedagogical epistemologies is then covered to build a theoretical foundation for this work. This facilitates the acquisition of a mobile-applicable investigation candidate, namely Constructionism theory, for software modelling in mobile computing methods in HCI KE. A framework for investigating constructionism is designed and presented, describing three key models that extend the domain of HCI KE theory. Through the design, implementation and testing (both expert and user testing) of several mobile computing tools for HCI KE, termed MIKE (Mobile Interactive Knowledge Elicitation) tools, these three key models of constructionism are explored through empirical research and are reported in this thesis as separate case studies.

Case study 1 investigates the use of inert constructionism through the use of card sorting. Case Study 2 investigates the use of semi-dynamic constructionism through the use of affinity diagramming. Case Study 3 investigates the use of dynamic constructionism, through the use of low fidelity paper prototyping. The findings from these case studies indicate that mobile cyberscience has a significant scope for application in the practice of current-day HCI methods, and that new qualitative measures in HCI can be acquired through mobile cyberscience tools.

There are three main contributions of this thesis that provide practitioners, educators and researchers in HCI with new knowledge. Firstly, the fields of mobile computing and mobile HCI are expanded with the empirically tested simulation of the techniques of card sorting, affinity diagramming and low-fidelity paper prototyping in HCI theory through mobile software. Secondly, a developed framework of constructionism theory successfully enhances the field of HCI KE, contributing to the growth of grounding theories in the field of HCI through the findings of three separately reported case studies. Lastly, cyberscience research for HCI has been given an expansion of research in the area of augmenting HCI with mobile computing. This is achieved through the user centred design, development and user testing of several mobile tools incorporating facilities unique to HCI practitioners, educators and researchers, leading to several related peer-reviewed publications.

Chapter 1: Introduction

"We cannot teach people anything; we can only help them discover it within themselves."

– Galileo Galilei

1.1 Overview of Thesis

This thesis contributes to the science of Human-Computer Interaction (HCI) by incorporating the role of mobility in HCI cyberscience, and further improving the state of art in HCI theory by exploring this mobility through cognitive theories. This mobility is investigated in a pedagogical context of use. This thesis investigates three key subject areas to achieve this contribution. Firstly, it looks at methods and techniques used in Human Computer Interaction (HCI) that elicit human knowledge of value to the design and evaluation of computing systems (Chapter 3). Secondly, it investigates the relationships of those methods and techniques in the direction of pedagogical epistemology leading into an investigation of the role of Constructionism in HCI (Chapter 4). Finally it investigates the potential of improving HCI methods using Constructionism Theory, through state-of-the-art mobile technologies (Chapters 5-8) in several case studies of a pedagogical nature.

The research direction was created by firstly exploring the roles of the current state of the art in Mobile HCI research, with a taxonomical analysis of the current literature (Chapter 2). This led to identifying a research deficiency in peer-reviewed Mobile HCI. The literature reviewed did not demonstrate a significant contribution or exploration of HCI using mobile systems, only HCI for mobile systems.

In order to investigate this research deficiency further, an array of mobility solutions were designed as case studies, as the various methods of HCI Knowledge Elicitation (KE) were being reviewed. In order to contribute to the HCI domain, and improve the current state of the art in HCI KE theory, a review on human cognitive learning theories and pedagogical epistemologies was conducted to further understand the nature of the user knowledge that current HCI methods attempt to elicit.

KE techniques in HCI exist to better understand the nature of HCI knowledge that is learnt, experienced, acquired, understood and retained by potential computing system users, for the benefit of HCI practitioners and researchers. Our main hypothesis incorporates KE with the variables of mobility, asynchronicity, digital data collection and geographical dispersion in line with the field of Cyberscience practices. More significantly we expand on the field of KE itself to incorporate the epistemological views of Constructionism Theory in a HCI context and in so doing, devise and introduce HCI to original techniques for measuring Constructionism in HCI KE.

1.2 Introduction

In just the past ten years, we have seen a dramatic rise in the production of a wide variety of computer-based mobile systems (henceforth termed just mobile systems) and components to create multi-billion pound industries across the world. The availability of faster, smaller and more energy efficient central processing units (CPUs), better display screen technologies, alternative input devices and micro sized storage media formats are all ensuring strong growth in mobility applications in both hardware and software engineering.

In particular, laptops, Personal Digital Assistants (PDAs) and mobile phones have been driving influences in the portable computing markets. The HCI issues in such devices (henceforth termed "mobile HCI"), show us that although usability play important roles in large and desktop systems, mobile systems have added issues of the constraints of miniaturisation and processor efficiency. This is in part facilitated by the massive consumer demands insisting that in general, smaller and discreet computing is a better computing experience (Miner, 2001). Since the late nineties, the construction of various global digital wireless networks and protocols has broadened our view of mobile computing and given us the supporting infrastructure to envisage mobile computing almost physically anywhere (Ghosh, 2000).

HCI research that applies to the evolution of mobile systems is still an emerging area of research. An even less reported area of research is the inverse of this statement that is, ***researching mobile systems that can be used in the practice of HCI***.

The following section describes the aims and objectives of this thesis, followed by a view of research contributions that this work will make. Finally, an outline plan for the rest of this thesis completes this chapter.

1.3 Aims and Objectives

The main objective of this thesis is to advance the state of the art of knowledge elicitation (KE) in HCI, theoretically and practically, by incorporating the use of mobile technologies.

This is to be achieved by investigating KE currently used in HCI (chapter 3) and the related areas of psychology associated with human learning models (chapter 4). This leads to the development of a constructionism-based KE framework to apply to HCI theory (chapter 5). Exploration of this framework is facilitated by the development of several software tools (chapters 6, 7 and 8) to assist HCI practitioners and researchers in conducting HCI cyberscience. Chapter 9 discusses these findings in a general overview of its contributions to the HCI field and outlines the key assets of this work.

The main research questions of this thesis are defined as follows:

Main Research Question (R-Main): Does mobile cyberscience improve HCI knowledge elicitation methods?

There are several key sub-questions that describe this main research question in stages to explore, which are:

R1) What Knowledge Elicitation (KE) techniques are currently used in HCI practice?

R2) How do existing cyberscience tools assist practitioners with conducting HCI KE techniques?

R3) What can Mobile Computing provide to existing HCI KE techniques in terms of

a) Extending the domain theoretically?

b) Enabling additional functionality in practice?

R4) Can Mobile KE be simulated empirically as an alternative to the standards of existing HCI KE practices?

R5) Can existing HCI KE methodologies be enhanced with knowledge from other non-mobility domains and contribute to the science of HCI, such that it will allow for new expansion of future related research directions for HCI KE?

This thesis explores all of the above questions in detail.

1.4 Research Contributions

The key practical contribution of this thesis will be the development of several cyberscience tools for HCI practitioners and researchers. These tools will enable them to conduct empirically-sound digital data collection in HCI KE that have not been explored before. In addition to this, the contributions that this research leads to are as follows:

- Empirically demonstrated capabilities of HCI knowledge elicitation techniques with facilitating digital data collection from stakeholders on-site.
- Simulate electronically the existing HCI KE practices to be as close as possible to the existing paper practices.
- Enhance the existing practices with new capabilities other than just mobility, based on cognitive modelling theories that may be suitable to mobile environments and as such have not been able to be explored before.
- Improve on existing practices by reducing practitioner workload with digital recording and processing of HCI KE data.
- Present HCI researchers with an opportunity to further a domain of research, namely researching the use of mobile cyberscience tools as aids to HCI development.

1.5 Thesis Outline

This thesis consists of 9 chapters. The next chapter investigates the current state of the art in mobile HCI research, and identifies through a taxonomical analysis a deficiency in the research landscape that forms the basis for this thesis' exploration.

Chapter three investigates the theory of knowledge elicitation in HCI. Weaknesses are identified and initial case studies are explored.

Chapter four investigates some of the important principles that pedagogical epistemology has constructed to understanding the real world interpretations of learning and acquiring knowledge; these have set the stage for knowledge elicitation methods in HCI. In particular the theory of Constructionism is discussed.

Chapter five describes the creation of a new framework for knowledge elicitation in HCI utilising artefact-driven Constructionism and pedagogical epistemology.

Chapter six discusses the development and analysis of a mobile Card Sorting technique that uses a fixed model of inert constructionism.

Chapter seven discusses the development and analysis of a mobile Affinity Diagramming technique that uses a semi-dynamic model of constructionism.

Chapter eight discusses the development and analysis of a mobile Prototyping technique that uses a richly dynamic model of constructionism.

Chapter nine discusses an overall review of these studies, and presents closing conclusions and key contributions.

Chapter 2: The State of the Art in Mobile HCI

2.1 Introduction

This chapter delivers a literature review of the current state of the art research in Mobile HCI (Human Computer Interaction). This is done to benefit the reader by illustrating the motivation and diversity of the current field. Subsequently it also illustrates to the reader a research deficiency in the field for further exploration in this thesis. Starting from the mobile HCI papers from the period of ACM Mobile HCI Conference proceedings 1998-2003, 104 papers were studied that address issues relating to HCI and mobile computing.

2.2 Taxonomical Analysis of the Field

An initial taxonomy of the 104 papers reviewed was created, consisting of twenty high level categories shown in figure 2.1. This process first started with the author of this thesis going through the 104 papers, summarizing and categorizing them through the use of a taxonomy template (appendix A.1).

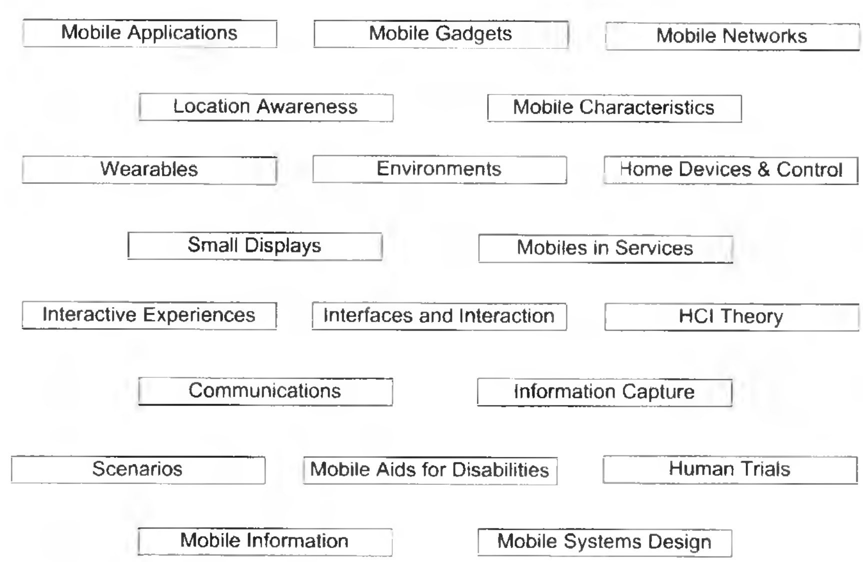


Figure 2.1 first review headings given to the ACM Mobile HCI proceedings papers

Under a controlled experiment, as reported in section 6.8, a software-based Card Sorting tool was developed to aid HCI practitioners with card sorting. Trialling this tool, the experiment involved 4 members of staff from the Centre for HCI Design, City University London, each of which was asked to Card Sort a group of approximately 26 of the same Mobile HCI abstract summaries of the 104 papers.

All four members of staff are lecturers or assistant tutors of HCI and Computer Science undergraduate and postgraduate courses at City University. The result of the cluster analysis of the papers as recommended by the card sort participants is denoted by research direction popularity (Figure 2.2). The result of this card sorting refined these 20 categories into 13 high level categories by experts in the field of academic HCI. This chapter subsequently explores some of the noted findings revealed within this literature review, under the categories defined from these Card Sorting classifications.

2.3 Information Visualisation

2.3.1 Scalable Interfaces

One of the fundamental objectives of miniaturisation of computer technologies is to present a platform from which users can maintain usable levels of interaction with their data from wherever they are. Information visualisation has come a long way since the days of two-colour text-only format screens. Yet constraints determined by factors of physical engineering feasibility, such as screen quality, battery longevity and network capabilities, give us a particularly popular arena for exploration in mobile HCI research.

Such information visualisation (IV) constraints are being addressed in a number of novel interfaces. A recent series of studies presented the Rapid Serial Visual Presentation (RSVP) concept (Bruijin et al, 2001; Goldstein et al, 2001; and Öquist et al, 2002). This has presented several investigations into the type of presentation of information e.g. searching on a small screen (Jones et al, 2002) and sequential access of human prioritised knowledge.

As Jones et al (2002) pointed out, search engines are the most commonly used Web services. Services such as Google™ (and other search engine providers) have started to make available their content on PDAs by reduced visualisation page formatting and causes of failures to browse effectively were recorded.

Chittaro and Camaggio (2002) presented a method for numerical visualisation of bar charts on WAP screens and two proposed solutions to the constraints for WAP numerical visualisation based on the results of a controlled study of non-expert users.

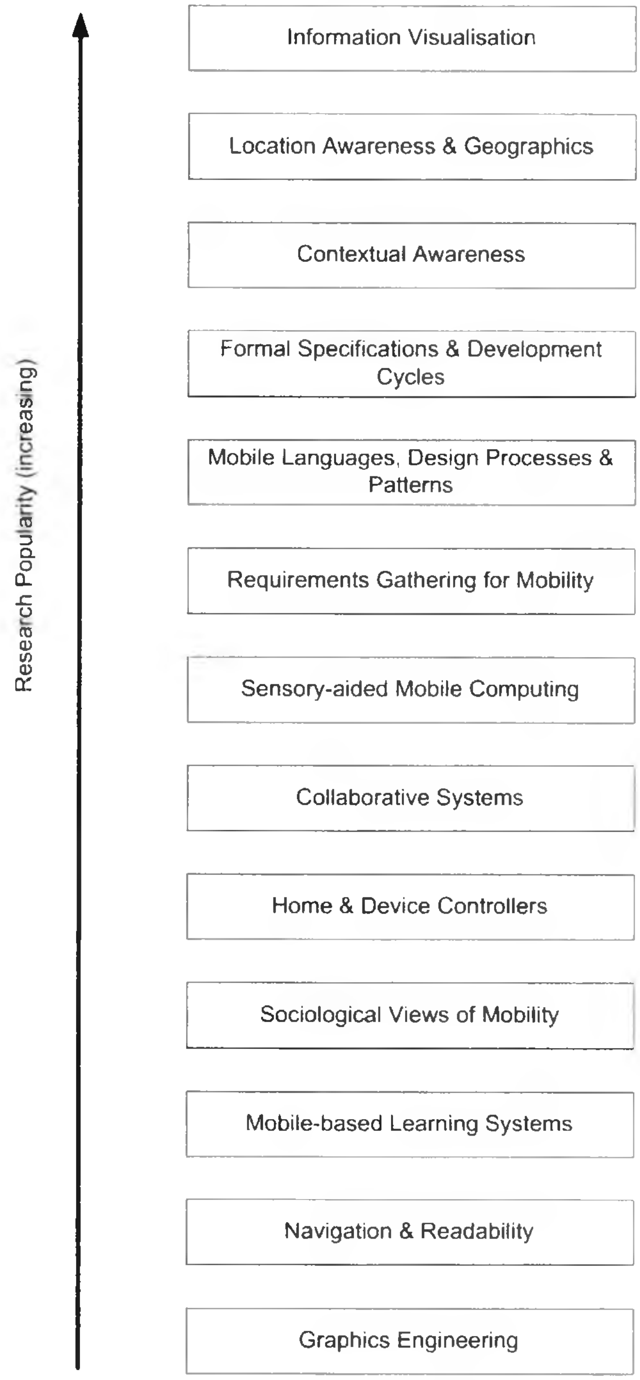


Figure 2.2 Expert Ranking of Mobile HCI Taxonomies

2.3.2 Sensory Interfaces

Novel auditory interaction complements mobile HCI interaction with the developments of mobile auditory spatial reasoning and analysis (Walker & Brewster, 1999) and auditory notification recognition, as seen in the ongoing development of the Earcons concept (Brewster et al, 1998). As noted in their paper, small, hand-held mobile devices lack screen space, and this can be a serious handicap in their efficient use. Brewster (1998) acknowledged a wide range of auditory recognition techniques requiring HCI development and is as such widely credited for promoting the expansion in this particular area of the field.

As the earcons concept defines,

> "earcons are abstract, musical sounds that can be used in structured combinations to create sound messages to represent parts of a human-computer interface."
>
> (Walker & Brewster, 1999)

This of course reaches a wide domain of users whose requirements in HCI usability have required special attention, such as blind users and children. Walker and Brewster (1999) showed that auditory display spaces can be expanded using 3D surround sound algorithms to provide a much wider field of audible information visualisation. An audio menu system is presented by Lorho et al (2002) whereby menus can be traversed by spatial presentation of hierarchical structures in using a set of sound positions obtained by stereo panning with 3-D audio processing techniques.

Another sensory-enhanced technique in visualisation of information is discussed by Deshe and Van Laar (1999). They describe a method for adding enhanced usability using a psychologically effective yet elegant technique employing principles of human factors, cartography, colour science and colour perception to generate displays that use colour coding to emphasise task relevant interface components. This is achieved by producing the illusion of perceptually different layers, upon which supports the structure of the user's task.

2.3.3 Information Reduction

The magic lounge project by Rist (1999) brings mobile information visualisation to the fields of Computer Supported Collaborative Work (CSCW) and geographically dispersed collaborative communities. A method for dynamic reduction of information is described. What is interesting here is that a gateway is introduced that can scale the level of visualisation according to the physical attributes of the systems that it connects with. Naturally, a small mobile phone doesn't cover the level of graphical representation that a medium sized PDA does, nor does a PDA cover the level of graphical representation of desk based PC. It is a matter of opinion that scalable architectures will play a subsequently vital role in the development of future mobile devices, as the capabilities of devices become more varied and the lines of segmented groups of systems such as phones, PDAs, laptops, become distinctly blurred into hybrid systems.

Sticking with ideas of information reduction, web clipping has become a practical form of information visualisation transformation by isolating regions of useful information and retaining partial document integrity and flow to fit a mobile device (mostly PDAs) screen. Gomes et al (2001) presented us with a heuristic analysis of how best to clip the information and how subsequently a system should decide what levels of information can be dropped - and the practical shortcomings of this technique. As such, its usefulness at improving minimalist web sites whilst maximising information detail coherently agrees with the ideology behind the WAP protocol method for displaying pages. Thereby, it is found that web clipping facilities have been proposed as a standards protocol in the form of web clipping markup language (WCML) as described by Yang et al (2002) to rival the wireless markup language (WML).

2.3.4 Multidimensional Visualisation

In Izadi et al (2001) an augmented reality project is described that synthesises mobile devices with the capability for visualising information virtual 3D environments. It describes two prototype demonstrators. In the first, an information visualisation application was developed in which a search party can explore an archaeological site, enacting scenes within the virtual world that are of a historical relevance to their particular physical location. The second describes a museum experience where participants explore an outdoors location, hunting for buried virtual artefacts that they then bring back to a museum for a more detailed study.

Vanderdonckt et al (2001) proposed minimalist guideline techniques that would allow designers to build UIs across multiple mobile platforms, while respecting the unique hardware constraints and capabilities posed by each platform.

2.4 Location Awareness and Geographics

Much of the research in geographic and location aware mobile systems correlate with innovative ideas in information visualisation. For example, audio user interfaces for Global Positioning Satellites (GPS) have been designed to meet the needs of visually handicapped users (Holland & Morse, 2001). Another idea presented by Yee (2003), is in the utilisation of a PDA's screen as a spatial hole with which by moving its location physically, a larger view of information can be seen.

A usability evaluation of a location aware PDA-Phone based system that receives location specific personalised information was conducted by Chincholle et al (2002). It showed that the circuit-switched GSM connection provides far too slow data throughput for their personal navigation tool service. This indicates that real-time mobile location-based services have a time-critical component even as the bandwidth increases with future mobile systems, and network signal dropping is a particular concern when on the move. The service must be designed for few input steps and short response times since easy and fast access to the service and the information available is of high importance.

The proliferation of GPS based location services has seen an impressive array of uses for location awareness in mobile deployment activities. Such capabilities are now being built into the upcoming generations of mobile phones and smart personal devices for a wide range of functions in mass consumer products. Examples include experimental tourist guides (Davies et al, 1998; Cheverst et al, 2001), systems for disabled and elderly people (Petrie et al, 1998; Holland & Morse, 2001) and collaborative systems (Rist, 1999).

Salber et al (2001) implemented a number of location-aware applications to support the activities of mobile students' workgroups on campus. Two main shortcomings were recorded in this; firstly location is sensed through an 802.11b wireless network that covers the whole campus with each network access point tracking mobile devices in its coverage zone. However a base station will cover an area of a few hundred square feet and as such, the granularity is insufficient to determine precision geospatial context information on the device's whereabouts. Secondly a mobile device can only be tracked when they are on.

The PLACE project designed by Lin et al (2002), presents an idea for services that are specific to user location, using a location representation consisting of semantic names and relations. In this project, collaboration is facilitated between location sources with different, yet related perspectives of the world.

On a similar vein, a prototype of a mobile tourist guide application for UMTS digital telephone networks is presented in Pospischil et al (2002) called LoL@ (Local

Location Assistant) and implements a tourist guide for users in Vienna. A first stage development and user study of a user-centred design for a mobile, location-based fair guide is presented by Hermann and Heidmann (2002) which aided in deriving the principles for visual layout and interaction design of maps on small screens.

2.5 Contextual Awareness

An issue in HCI research that remains relatively unexplored is investigating comprehensive models and scenarios whereby the importance of maintaining consistency between the user's view of their environment, the view of the environment reported by the system and the actual state of the environment are evaluated. Context aware systems have to react not only to the user's input but also input (i.e. context) from the user's environment (Schilit et al, 1994; Brown et al, 1997).

User-centered design offers opportunities for helping people accomplishing their goals more effectively. In a paper by De Groot and Van Welie (2002), we find a proposed structured approach and analysis of factors that aid in improving the design of contextual systems from the user centred viewpoint. Adaptive user modelling is investigated in Marucci and Paternò (2002), which considers awareness based on updating information about user preferences and knowledge at run-time. Such information is used to adapt the navigation, presentation and content of each user interface also taking into account users' accesses through different interaction platforms.

An interesting concept in this domain involves a specifically mobile systems orientated question – do we push the contextual information into the mobile system as they move within monitored zones, or pull it on demand at their request? This is looked at by Davies et al (1998). Costa-Montenegro et al (2002) also looked at pushing contextual information onto PDAs and analyzed the problem of pushing web contents with minimum client participation. It was determined that typical web-based HTTP or Javascript implementations require periodic client reloads, which impose an inefficient network utilisation. Their resolution was to utilise a Java based listening client, with a central server that can effectively push new information to the PDAs listening client sockets as the server administrator requires.

From O'Hare & O'Grady (2002), we find that mobile agents can be utilised as a means of supplementing the user experience through interfacing with the physical environment and anticipating user requirements giving a sense of predictive or foresight behaviour. In fact, one of the achievements that have been recently made in handheld technologies is with the development of Multi-Agent Systems (MAS) on mobile devices that are automated at seeking and retrieving information or running processes, such as Agent Factory Lite by O'Hare et al. (2002).

Context detection for mobile users constructs novel theories of human-centric interfaces with wireless boundaries and allows it to take place without requiring any central point of control, supporting both push as well as pull modes. One of the challenges in context awareness is discovering computing services and resources available in the user's current environment, utilising discovery protocols such as Jini (2001), IETF SLP by Perkins (1997) and SDP by Czerwinski et al (1999).

In Michahelles and Samulowitz (2001) an approach is demonstrated using these kinds of discovery protocols, whereby a mobile user is given access to services available in his surrounding environment with the aim being to gain the user's context from sensors capturing feature data in self-organised sensor networks without the need of central points of control. It envisions an environment with disseminated computing empowered sensors (termed Smart-Its, 2002) which can be attached to day-to-day devices such as cups, tables, chairs etc. These can be equipped with various sensors for perceiving temperature, light, audio, co-location, movement and so on. These devices are supplied with a wireless communication such as RF or Bluetooth (1998) to achieve their network capabilities.

Contextual interactions designed for route navigation were investigated by Bradley and Dunlop (2002). In this study, participants were interviewed to determine how they interact with or use objects in their environment with which they could use to navigate with.

Schmidt et al (2001) reported on a study which explored how context aware information can be added to mobile phone phonebooks using the advantages of a network-based application to show what state of operation a phone user is in. This gives us with strong evidence that situations of usage do matter to people when using their phones, and as such contextual awareness can strongly influence a user's actions and perceptions of use with mobile devices. Another project is presented in Hibino and Mockus (2002) that demonstrates a prototype system named HandiMessenger, which provides mobile access to awareness-enhanced communication from a wireless PDA. Here users are not constrained to the mode of communication in which they are accessing a message, but can easily follow tap-to-contact links to initiate alternative modes of communication.

So-called fuzzy contexts are examined by Mantyjarvi and Seppanen (2002) which presents an approach for controlling context aware applications in the case of multiple fuzzy contexts. Fuzzy logic controllers, which use predetermined sets of multiple fuzzy contexts, are designed for adapting specific features of user interface applications. It demonstrates the design of controllers and experiments with real user data and its results show that the applying fuzzy logic processes can enhance the capability of adapting the contextual information represented in a mobile terminal.

2.6 Formal Specifications and Development Cycles

Formal specifications that have been ratified by peer driven committees provide varying degrees of the infrastructural foundations in the development of mobile systems hardware and software specification compliance. It is in the generally agreed that standards, protocols and their architectural premises should be available under license across the world, from pure data transfer, to mobile video, imagery and audio specifications.

With many alternatives available in each area, factors of mobile HCI are often driven not just by the user-end definitions of mobile systems, but by the infrastructures supported or limited by the mobile systems. The original GSM (1993) protocol for example has long been a widely adopted standard for mobile manufacturers to implement wireless networking, yet it contained a severe drawback by design with global data communications running at a standard 9.6kbps actual data rate. Since then, rival protocols such as General Packet Radio Service (GPRS, 1998) and Wideband Code Division Multiple Access (WCDMA, 2000) with always-on wireless connectivity and actual data rates between 128kbps-384kbps have since been ratified by committees and deployed by mobile manufacturers, and the rollout of even higher speed 3rd generation (3G, 2002) networks that support larger bandwidth video interaction is currently being deployed in small regions of the world.

However, as higher speed networks are deployed to businesses and consumers, it is only a matter of time before throughput of data requirements becomes a non-issue.

Undoubtedly it is presumed that higher bandwidths are being devised. Mobile IP phones are investigated by Kohno and Rekimoto (2002), with the potential to utilise upto 54MBps connections (approximately 10-20Mbps actual data rate) with IEEE's 802.11a/g specification, wireless Ethernet compatible.

This idea sees convergence in the mobile markets if and when it is available for a spectrum that is available for a much wider audience of networking in industry and business e.g. pc's, laptops, printers, routers etc. Even DVD Video quality data signals can be transmitted at this rate so there are many exciting possibilities for HCI to utilise the extra bandwidth and model new paradigms of interactions in a different style of roaming network translucency as described by Ebling and Satyanarayanan (1998).

This literature review has identified many theoretical and evaluation papers in mobile HCI research that are not only academic but also come from major companies. Due to corporate systems development cycles they tend to have a high level of implementation thanks to the resources available and are contributing substantially with academia in the development of network infrastructures, standards, context aware systems and usability guidelines research. Of many such industry players and example papers include Hewlett Packard (Brown et al, 1999), IBM (Salber et al, 2001), Microsoft (Lamberts, 2002; Marshall et al 2001), Nokia (Hjelmeroos et al, 1999; Koppinen, 1999; Kaikkonen & Roto, 2002; Lorhol et al, 2002), OpenWave (Passani, 2002), Philips Research (De Vet & Buil, 1999), Siemens (Michahelles & Samulowitz, 2001), SonyEricsson (Goldstein, 1998, 1999, 2001), Sun Microsystems (Waldo, 2001), Symbian (Jordan et al, 2001; Karlsson & Djarbi, 2001; Melchior, 2001) and Xerox (Eldridge et al, 1999).

Together with this level of industrial effort, community developers and standards organisations such as ETSI (Von Niman et al, 2002), the founding framework specifications for protocols, libraries and languages for mobile HCI are becoming more complete and robust. As Melchior (2001) describes mobility in support for the IPv6 protocol, which is the next generation protocol of internet address allocation, the future of protocols must be carefully thought out and planned for contingent growth.

The Émigré project by Dourish and Van Der Hoek (2002) assumes that at design phase, there is more of a need to accommodate rather than eliminate the boundaries of seamless access to information and computation wherever a user goes.

The use of UML (Booch et al., 1998) has long been a methodology promoted heavily in requirements engineering, to speed up development time by modelling object orientated systems in a structured design approach. As such it contributes to rigidly accurate objective modelling in various phases of the development cycle. Mayora-Ibarra et al (2002) show us how the UML language is being used to model and describe an approach for generating graphical (GUI) and speech-based user interfaces (SUI) from a single source in a home environment application. The method described introduces a generic dedicated widget (GUI components) vocabulary that aids in defining mobile user interface descriptions.

Nokia performed a usability evaluation in a paper by Kaikkonen (2002), with XHTML in Mobile Application Development, which derived whether Mobile Profile components were of a high enough quality to be usable in wide mobile deployment. They compared different user interface solutions and their findings were rated on user performance, perception, and preference. The results of this usability evaluation contributed to the making of XHTML Mobile Application Development Guidelines, of benefit to mobile software development community.

2.7 Mobile Languages, Design Processes and Patterns

The advent of object orientated practices in systems development caused a dramatic upheaval and acceleration of development times for software in industry. Code reuse is now a standard practice; there is no logical need for reinventing the wheel.

2.7.1 Key Language Developments

In particular, developing languages around formally approved specifications has seen to the widespread deployment of architecturally neutral languages such as Java (Sun Micrososystems, 1996) and C++ (Stroustrup, 1997). Virtual machine processors and cross compiler techniques and standardised code libraries employed allow developers to write software on one hardware platform and port them to others with relative ease. Even scripting languages such as Python (1990) are improving the quality of software usability with accessibility feature-sets common across platforms.

MIDP (Sun Microsystems, 2000), the Java 2 Micro Edition derivative of the Java specification for mobile phones and PDAs, has seen an intense explosion of both interest and deployment in mobile markets, on a multitude of device categories (phones, pdas, pagers, smart cards etc.) and services. The cross-platform execution nature of Java code on virtual machines is naturally one of the powerful drawing points for developers and researchers as it reduces overheads of platform execution incompatibilities for software developers.

Over-the-air (OTA) transmitting of executable applications and games, called midlets after their web forbearers Java applets, has given mobile software developers a long-requested opportunity to operate and deploy to moderately tech-savvy phone and PDA users on a global audience, and bears exciting prospects for modelling relatively new paradigms in mobile HCI. There are already many development suites available, and in Carboni et al (2002) they describe a code generation tool for supporting midlet development, using an XML backend to generate midlets based on visual choices in an IDE called PLANES.

Design processes now integrate patterns for software modelling reuse within software development. Design patterns for software are commonly associated with paradigms in life, such that it determines there are patterns in existence, ways and methods to best describe good practices and designs that capture the experience of others, in a form that allows others to reuse that experience (Gamma et al, 1994; Stelting et al, 2001). To oppose this argument, anti-patterns exist to determine that not all design patterns are fully applicable to each apparently coherent situation and that implications of using patterns can lead to problems later, endangering system uniqueness and possible versatility, and as such refactoring processes need to be considered (Brown et al, 1998).

In Roth (2001) we find mobility patterns being proposed to address HCI issues including mobile security, network access consistency, user interface requirements of minimal interfaces and service synchronisation usability. WAP problems and design issues of successful WAP implementations are discussed by Passani (2002) which concludes that it is necessary to design several versions of the same WAP application to optimize the user experience on each class of devices.

2.7.2 Direct Combination and Ambient Combination

The user interaction pattern theory of Direct Combination (DC) is demonstrated within a mobility context (Holland et al., 2002). DC is a recently introduced user interaction principle which strongly relates to the HCI principle of Direct Manipulation (DM) as described by Shneiderman (1998). Direct Combination allows the user to exploit objects in the environment to narrow down the range of interactions that need be considered, by system and user. As a design process, DC appears to offers a new way of applying context-aware information.

The principle of DC, which previously applied to desktop computing, can greatly reduce the degree of search, time, and attention required to operate user interfaces. The reduction in search afforded to users can be applied to address several issues in mobile and ubiquitous user interaction including: limited feedback bandwidth; minimal attention situations; and the need for ad-hoc spontaneous interoperation and dynamic reconfiguration of multiple devices.

When Direct Combination is extended and adapted to fit the demands of mobile and ubiquitous HCI, Holland et al (2002) define it as Ambient Combination (AC). Ambient Combination (AC) is the adaptation, extension and application of Direct Combination (DC) to Mobile, Ubiquitous, Tangible and Mixed Reality Computing.

2.7.3 Augmented Design

Dubois et al (2002) present a language named ASUR++ for describing mobile systems that combine physical and digital entities dedicated to the handling of mobility of users and enabling a designer to express physical relationships among entities involved in the system. The language notation is distinctly associated with design processes as defined by the same lead author in Dubois et al (1999), a Mixed System is an interactive system combining and allowing visualisation of physical and digital entities.

Two classes of mixed systems are discussed in Dubois et al (1999) – firstly systems that enhance interaction between the user and their real environment by providing additional capabilities and/or information, are defined as Augmented Reality systems. Secondly systems that make use of objects in reality to enhance the interaction between a user and a computer are defined as Augmented Virtuality systems. Ishii and Ullmer (1997) presented seminal work on the field of tangible bits that are entities that augment interaction between users and digital interfaces.

2.7.4 Semiotics in Mobile Computing

In Van Welie and De Groot (2002), a method is demonstrated to categorically group devices by characteristics of their design rather than features. Another design process is described through the use of semiotics in Kjeldskov (2002) with the view that context sensitivity in designing mobile device interfaces can be less complex and easier to interact with semiotics. The field of semiotics concerns the meaning and use of signs and symbols, and cognitive mental mappings of representations of signs and symbols.

As Kjeldskov (2002) illustrates, based on a semiotic approach to information representation, the design of mobile device interfaces can benefit from increased spatial and temporal indexicality, focusing on information and functionality relevant where and when it is demanded. This can allow information to be left out from the interface when present in the appropriate context. Furthermore, simplifying the user interface on the basis of context reduces demands for user interaction and contributes to less required attention.

2.8 Requirements Gathering for Mobility

Requirements gathering have long been a process of utmost importance to HCI research. Every domain of HCI is influenced by a variety of input, process and output domains and therefore the requirements gathered for a technology are always going to be critical to its success and appropriateness. An experiment is demonstrated in Iacucci (2001) which aimed to find new approaches to inspire the design and collection of requirements by engaging people in activities, correlating observation methods with design choices.

The hardware capabilities of PDAs and indeed principles of ergonomics as shown by Salvendy (1997) ensure that novel paradigms in mobile scenarios get constant attention and improvement from HCI researchers. One of the most notable paradigms in using mobile systems such as PDAs and TabletPCs is the use of a stylus pen, which through the use of pressure sensitive screen displays can interact in a point and click mouse-like fashion without a tethered connection.

Mizobuchil et al. (2002) undertook an empirical study to identify the requirements for the optimal size and number of targets for stylus interaction. Such information is valuable to subsequent iterations of stylus design and capability as high precision in screen sensitivity quality bears strong influence to the responsiveness and level of action that mobile users may take (Sears et al., 1992). Another empirical study undertaken by MacKenzie (2001) identified requirements for text entry methods based on measurements of keystrokes per character (KSPC).

2.9 Sensory-aided mobile computing

Mobile HCI has also changed the nature of computing for the demographics of users that have sensory disabilities, or alternatively require sensory enhancement. A low fidelity prototype with supplemented tactile cues is presented in Sokoler et al, (2002) with the TactGuide prototype. This is operated by subtle tactile inspection and designed to complement the use of our visual, auditory and kinesthetic senses in the process of way finding. It was found to successfully supplement existing way finding abilities.

An innovative mobile system that lets a blind person use a common pointer as a replacement of the cane is demonstrated in Fontana et al, (2002). It presents an electronic travel aid device that enables blind individuals to "see the world with their ears." A wearable prototype was constructed using low-cost hardware that is able to detect the light spot produced by a laser pointer, compute its angular position and depth, and generate a correspondent sound providing the auditory cues for the perception of the position and distance of the pointed surface. Another wearable system for blind users to aid in navigation is presented by Petrie et al, (1998) which projects a simple visual image in tactile form on the back or stomach.

A mobile device for aiding the control of smart wheelchairs for severely motor impaired people has been designed and investigated by Abascal (2002). The structure of an adaptive mobile interface for smart wheelchairs that is driven by the context is presented.

2.10 Collaborative Systems

Doherty et al. (2001) considers the level of detail and abstraction determined by the physical form factor, the integration of information from other external and communicated information sources (and representations), and the use of represented information in collaborative acts and communications. One successfully enhanced scenario is presented with Air Traffic Controllers (Buisson & Jestin, 2001). This gave an effective solution for a distributed interaction prototype that would assist desk-based systems with the collaboration of a mobile operations manager.

In Siirtola and Heimonen (2001) a scalable architecture for CSCW is described in the form of a portal system that supports multiple levels of mobility and scalability in

WAP phones and terminals, PDA devices, and desktop and portable computers. Scalability is a vital process in designing mobile systems to ensure usability performance across a wide variety of specifications for mobile systems. Collaboration is also examined by Huang et al (2002), who presented a decentralized system designed to mimic and enhance the word-of-mouth communications model.

By using an augmented word-of-mouth model of communication, their system gives users accurate information while simulating the personal relevance of face-to-face communication. To do so, the system takes advantage of the fact that one can gather data through proximity using handheld devices and improves the relevance of information presented to users by wireless data gathering.

Collaboration is also an extensive area in augmented reality systems like that found in Nigay et al. (2002). Here it addresses the combination of the physical and digital worlds seamlessly in the context of a mobile collaborative activity in the domain scenarios of archaeological prospecting. Entities can be seen as functionally limited but contextually relevant (Norman, 1998).

2.11 Home and Device Controllers

Much of the research in the area of mobile human-computer interaction has focused on the user interfaces of mobile devices themselves such as their input methods and displays. As electronics are becoming more computerized and are able to communicate with each other, mobile devices can serve as a personal, portable focal point for interactions with the world. An important idea in mobile HCI is to have mobile devices which improve the user interface of other systems, as well as being its own interface requiring user mastery.

Home and device controllers are a relatively new and underdeveloped area for consumer interests beyond the usual remote controls. However, over time they have been the subject to some novel theories and simulations of use and as theories that apply, they are quite often affiliated with the ideas of the many futurist visionaries such as Mark Weiser (Weiser, 1991).

We find now that protocols are being developed by companies and peer driven international committees, such as those that will enable the future wave of mobile and non-mobile devices to cooperate together on much more ubiquitous levels and facilitate growth in this area. Examples of these include Bluetooth (1998) short range wireless networking, Jini (2001) embedded devices networking in everyday home consumer equipment like light switches and kettles, and HAVi (2000) home media connectivity networking for audio visual equipment to name a few.

An example of modelling future simulations of device controllers is found in Huttenrauch and Norman (2001) where a device is simulating the control of household robots. Already robotic pets are being mass manufactured for consumers such as the Sony Aibo robotic dog (2001), and it is only a matter of time before useful robotic/automatonic devices aid us in our lifestyles. Being able to control them with interactive feedback such as their visual and sensor relays (as found in the Aibo's Navigator software) has a lot of scope for future Mobile HCI development.

In Myers (2002) we are introduced to the notion of personal universal controllers (PUCs) whereby a mobile device exists in a continuous state of communication for controlling and augmenting the facilities in its environment, as seen in its Slideshow Commander prototype application. Tarrini et al. (2002) describe the research undertaken to deal with the implementation of functions, based on mobile devices as the remote control of commercial home automation systems.

A popular consumer orientated protocol being corporately developed is the X10 (2000) protocol which can control and relay electrical hardware information to other protocols such as email and internet access. This combined with mobile usage scenarios can give rise to a host of ubiquitous and ambient intelligent hardware in physical locations.

2.12 Sociological Views of Mobility

SMS text messaging is an asynchronous channel of communication that operates upon a principle of 'store and forward' - the sender sends a message, when his or her device has a connection, and then the message is forwarded to the recipient when the recipient's device has a connection. Sociological aspects of mobile HCI are particularly interesting in that mobile systems are changing the way we live our everyday lives and provide new interactions e.g. social communication by SMS text messaging using innovative short hand rather than usual languages and assistive technologies such as Tegic Corp's patented T9 (1997) text prediction algorithm.

An interesting empirical diary study is presented in Colbert (2002) of an initial analysis of rendezvous by using mobile devices, as performed by university students. Some of its findings include rendezvousing were often in locations at which diary keepers had rendezvoused before (61%), and included people with whom they had close relationships (immediate family 15%, close friends 64%, extended family 18%, acquaintances 17% and strangers 7%). On 44% of occasions, these rendezvous occurred as initially planned. The paper suggests that there is a need for greater connectivity and service availability, rather than greater bandwidth in terms of network infrastructure to support the widest audience of mobile users.

In Soronen and Tuomisto (2002) we find presented some future outlines of the use of mobile camera phones in the Finnish mobile culture and it is interesting to see the usage patterns of one of the worlds' most popular mobile phone using countries (Aneki, 2003).

2.13 Mobile-based Learning Systems

A straightforward definition of mobile based learning is given by Clarke and Philips (2001);

> "M-Learning represents the marriage of mobile devices and electronic learning".
>
> Clarke and Philips (2001)

Glaser (1960) stated that the origins of modern automated learning stems from the work of Pressey (1924, 1925) who explained automated teaching machines in general as

> "...unique among instructional aids, in that the student not merely passively listens, watches or reads but actively responds. As he does so he finds out whether his response is correct or not, and a mechanical record may be kept which aids in improving the materials."

Learning systems that utilise mobile technologies and models of ubiquity are an area for growth in mobile HCI, though popular in their own right. Roschelle's (2002) keynote speech at IEEE WMTE 2002 captured the current state of the art in learning with mobile systems:

> "The field of computer supported collaborative learning has already successfully tackled two key issues, control and representation (Koschman, 1996). This current research base, however, is insufficient to unlock the value of wireless internet learning devices (WILDs). A third issue, hinted at but not fully explored in prior work (Morrison & Goldberg, 1996), now must become our central focus of attention. The issue is the nature of the coupling between social and informatic worlds, and within the social and informatic worlds."

His last point prepositions a thought that we shall hold onto, that more needs to be done to bind learning to the transfer of knowledge from people to machines. The advances of desktop computer technology have been demonstrated to enhance the quality of learning (Navarro & Shoemaker, 1999; Cuban, 1986).

Primarily considered to be a classical model of knowledge presentation in classroom scenarios, the blackboard model has had numerous developments to enhance the capabilities of electronic learning, such as Chang and Sheu's (2002) Ad Hoc classroom system. Knowledge information domains are most likely to be one of the main forms of teleworking this century (Drucker, 1999).

Tummolini et al (2002), describe a tutoring system for electrical engineers that addresses the needs originating in contemporary industrial workspaces for distribution of electronic information within learning, knowledge transfer and information management processes. In order to achieve the goal of a flexible and adaptable information delivery system in the working environment, iTutor integrates a mobile wearable device with a voice and gaze controlled, web-based graphical user interface based on XML (1998) standards. It wirelessly integrates with an enterprise information system where the technical knowledge information is stored reducing storage overheads for the client mobile devices.

As Paredes et al. (2002) describes, mobile tools can be useful in aiding foreign language learning, in their case English, by utilising collaborative and ubiquitous computing paradigms together to integrate both fields into the educational environment. The KnowledgeSea prototype by Brusilovsky and Rizzo (2002) is another mobile education tool that utilises an approach based on self-organised hypertext map paradigms on a mobile system, to access libraries of information.

Learner-Centred Design (LCD) is an approach to building software that supports students as they engage in unfamiliar activities and learn about a new area. LCD has been successfully used to support students using desktop computers for a variety of learning activities, and in Luchini et al (2002) LCD is extended to the design of educational software for handheld computers. It presents a case study of ArtemisExpress, a tool that supports learners using handheld computers for online research. While User-Centered Design methods typically focus on making more usable software to support the work of expert computer users, LCD techniques focus on developing software that provides learners with the supports they need to learn about the content, tasks, and activities of the new domain they are exploring.

2.14 Navigation and Readability

Voice recognition and synthesis has evolved in Computer Science to varying degrees of success. Motorola's Mya Voice Browser as described by Chesta (2002), uses Automatic Speech Recognition (ASR) to understand and process human speech, capture requested information from voice-enabled web sites, and then deliver the information via pre-recorded speech or Text-To-Speech (TTS) synthesis software that "reads" the relevant data to the user. Researchers have to remain critical of the choices of design, as found in Chesta (2002).

As Chittaro and Cin (2001) demonstrate, the WAP/WML protocol navigation capabilities can be optimised for performance, in particular for navigating links, list of links, action screens and selection screens.

From a HCI perspective, the success and failure of SMS and WAP respectively, can be explained by looking at the balance between the value to the user these services offer versus the 'basic' usability and navigational facilities. SMS is a relatively simplistic interaction model with straightforward readability in message reception and transmission in comparison with WAP information exchange.

As found by Melchior (2001) some smart techniques can be employed to enhance readability on constraint screens. The process presented here is innovative in that it allows a user to successfully read through passages of text comfortably by subtle graphical changes in fading new text onto the screen to replace old text. The aforementioned RSVP techniques (Bruijin et al, 2001; Goldstein et al, 2001; Öquist & Goldstein, 2002) in information visualisation are also assistive techniques in enhancing constraint readability. Gonzalez-Castano et al. (2002) present a technique termed Hierarchical Atomic Navigation, to postulate a micro navigation page with iconified symbols representing zones of information to be navigated.

An alternative strategy to navigating with minimalist graphical interfaces or symbols on constraint screens is navigating by questions and answers. This concept as presented by Schofield, and Kubin (2002) is interesting as a navigation method for retrieving online information. The questions are asked either by typing, stylus of speech recognition software although using speech was found to be potentially disruptive in public as well as lacking in obvious confidentiality.

In Sazawal et al. (2002) we find a technique for navigation by resorting to tilt-based interfaces as a possible alternative for the stylus and keyboard. Their system, named Unigesture, is a tilt-to-write system that enables onehanded text entry. With Unigesture, the user can jot a note with one hand while leaving the other hand free to hold a phone or perform other tasks.

Another tilt-based navigation system is presented by Fallman (2002) whereby screen elements are given weights and can be manipulated by tilting the PDA. The theoretical support for the use of gravity in this context draws primarily on the work of Lakoff and Johnson (1980). Another novel mechanism is presented by Öquist (2002) who proposed RSVP as a means to aid navigation and readability by being augmented with gaze detection technology. This allows end user eye motion to be analysed as an interface navigator.

2.15 Graphics Engineering

Computer graphics engineering has been a sought after Holy Grail in HCI in general, for researchers trying to find the most perceptually accurate and aesthetically pleasing representations for allowing humans to access and visualise computational information as responsively as possible. From the days of text-only character monitors to rasterised displays and now hardware accelerated 3- dimensional multi-screen environments, the times are changing in standard computing almost as fast as screen refresh rates.

This demonstrates to us that we have to deal with developing new HCI methods and models for the limited amount of screen space available, as well maximising utilisation of the limited processing and power usage capabilities available to generate computer graphics. As technologies and industry standards develop however, some of these constraints will be removed altogether. An impressive 3D visualisation system on mobile devices is presented in Vainio et al, (2002), with a tool for displaying 3D city information with real-time GPS navigation as an aid for mobile users and as a demonstration of the technology for future mobile services. Their results show that three-dimensional models in their system illustrate motion and change of location more clearly than two-dimensional map alone.

In Rist and Brandmeier (2001) we find several transformational approaches for converging graphics from the web to mobile systems. Such processes as noted include uninformed transformations whereby bitmap graphics have little information about the source graphics taken into account when selecting and adjusting the transformation. However it is shown that it is very difficult to find a general-purpose transformation that reliably produces consistently accurate results for the large variety of graphics found on the WWW. Informed transformations on the other hand take into account added information and subsequently generate much higher quality imagery and it is believed that machine learning algorithms in the future will improve the quality of the transformations.

Constraint visual computing experiences are pushing requirements into constructing new and more powerful miniature hardware and software for the support of video and real time 2D/3D acceleration. This can be seen in communication products from Nokia and SonyEricsson in the form of J2ME 3D enhancement to mobile phones. Work by the Khronos group (2002), ATi Corp and NVidia Corp's mobile embedded graphics processors and real time 3D software engines, attempt to bring a platform for embedded realtime computer graphics to mobile devices. As an open specification, these bear construction and development similarities to its desktop precursor, the OpenGL (1994) standard by the OpenGL consortium.

2.16 Literature Review Findings

Novel interfaces and information visualisation were found to be the most popular research directions in the field of Mobile HCI, whereas sociological effects, home control systems and M-Learning systems were amongst the least popular reported amongst the literature studied.

A focus group discussion with the HCI researchers led to the identification that there is a weakness in Mobile HCI pertaining to the relationship with HCI methods itself. Many of the papers reviewed explored user centred design through the use of existing HCI techniques for implementing user centred design through HCI knowledge elicitation. The inverse of this, which is to use mobile technologies to improve HCI has been less than adequately explored.

2.17 Chapter Summary

This chapter has presented a literature review of the current state of the art issues of mobile computing. It presents us with a unified taxonomical overview of the most widely investigated research areas dealing with Human-Computer Interaction issues. It laid out expert-based category definitions and some of the most novel applications that are being developed and researched in several key areas of mobile HCI. Through expert taxonomical categorisation, it also highlighted which areas are lacking in current research and which areas have common interests and goals.

This chapter ends with a motivation for scientific exploration in this thesis, with the potential of exploring mobile computing to support HCI practitioners, researchers and educators. This literature review outlined state of the art concepts, limitations and benefits that mobile computing already provides to the HCI of other disciplines of use. Whilst there has not been significant other works reported in the area of mobile computing for supporting HCI to compare against within the peer-driven disciplines, it is noted in this summary that its importance as a contribution to the academic community is as yet unknown and thus is given as reason enough for exploration.

The next chapter explores the methods employed by HCI practitioners and their practices of user based HCI Knowledge Elicitation (KE).

Chapter 3: Knowledge Elicitation in HCI

3.1 Introduction

As mentioned in Chapter 1, this thesis focuses on mobile knowledge elicitation. For that reason, this chapter explores the use of Knowledge Elicitation theory in HCI. Knowledge elicitation (KE) techniques in Human Computer Interaction are viewed by HCI practitioners as a fundamental requirement in understanding the mental models users acquired through time, experience and factual understanding. The success of user centred design (UCD), electronic or otherwise, depends on the end-user's experience. The measure of a good experience can vary from person to person; however the appropriate understanding of a usable design comes from gaining the knowledge that it is functional, efficient and desirable to its intended audience (Kuniavksy, 2003).

As specified in the ISO 13407 (ISO, 1999), user-centred design begins with a thorough understanding of the needs and requirements of the users. Knowledge elicitation methods in HCI are a critical function to the success of requirements gathering and design (Maiden et al., 1995), usability testing and user evaluation stages of software development (Zaphiris & Kurniawan, 2001).

Often users do not have a clear view of the end result of a system (Olphert & Damodaran, 2002) but may have some vague model of what they require. This information extraction is a key element of HCI user knowledge elicitation. Innovation in design also plays a key role in HCI knowledge elicitation, as users and designers direct towards paradigms that they are familiar with. Sometimes there is a need to address complexities dealing with multiple user/stakeholder situations which can either contradict or combine user knowledge artefacts.

Examples of knowledge elicitation methods often start with initial questionnaire feedback, interviews techniques, and focus group sessions which will be discussed in further detail in a subsequent section. It can rapidly scale upwards to more complex psychometric and design and evaluation processes for example various fidelities of prototype construction, direct and indirect observation practices for monitoring user actions and response time comparisons, and methods for eliciting mental categorisation models e.g. in distinguishing expert and non-expert motivations and patterns.

A wide variety of tested and proven experimental user-based techniques exist for practitioners to utilise (Burge, 1998). However, as HCI specialists will know from experience, knowledge acquisition and analysis of data from traditional user-based methods is time consuming and usually requires experts in their respective fields. For HCI practitioners working as part of development teams whereby their results can lead to significant changes in design, it is important to define and incur the highest quality of empirical data capture.

By adopting digital processes, analysis of such data can be enhanced with software tools that incur faster data acquisition and processing times than humanly possible, along with large data storage and retrieval capabilities. Digital tools can therefore raise the quality of user centred knowledge elicitation and analysis. In this chapter we present further our understanding to acquiring further cognitive user metrics within KE in the HCI domain, through the design of several software tools specific to improving the state of the art in user centred knowledge elicitation experiments.

3.2 Knowledge Elicitation Theory

Kelly's Personal Construct Theory (1955) of individuals and groups has been used extensively in knowledge acquisition research to model the cognitive abilities of experts. The works of Gaines and Shaw (1980, 1981, 1987a, 1987b) demonstrate the importance of this theory through the development of early principles, techniques, methodologies and tools for learners who are comfortable with digital technologies. By directly taking the constructivist approach there is a creative model of human knowledge processes that is developed through self exploration which they describe as

> "…the characterization of their human conceptual structures in axiomatic terms that translate directly to computational form".
>
> (Gaines & Shaw, 1980)

Gaines and Shaw termed Knowledge Acquisition (1993) as

> "..not a monolithic process, but like all software engineering it draws on many sources of information in diverse forms such as specifications, experiences, principles, laws, observation and so on, recorded in a variety of media."
>
> (Gaines & Shaw, 1993)

This definition is important as a central concept in learning new forms of knowledge from the constructive experiences of others. What facilitates the access to this diversely acquired knowledge is the use of data collection or elicitation methods, which we refer to henceforth as Knowledge Elicitation (KE). Figure 3.1 from Gaines and Shaw (1993) demonstrates a constructivist understanding of knowledge elicitation in expertise transfer.

There are many different knowledge elicitation techniques (Cooke, 1994) and selecting the "right" technique in a particular situation is not trivial. Choosing an appropriate elicitation technique is significant for specific types of knowledge requirements (Maiden & Rugg, 1996). Implied (semi-tacit) knowledge (Polanyi, 1958) is only accessible through particular techniques, e.g. traditional questionnaires and interview transcripts will fail to access all types of knowledge.

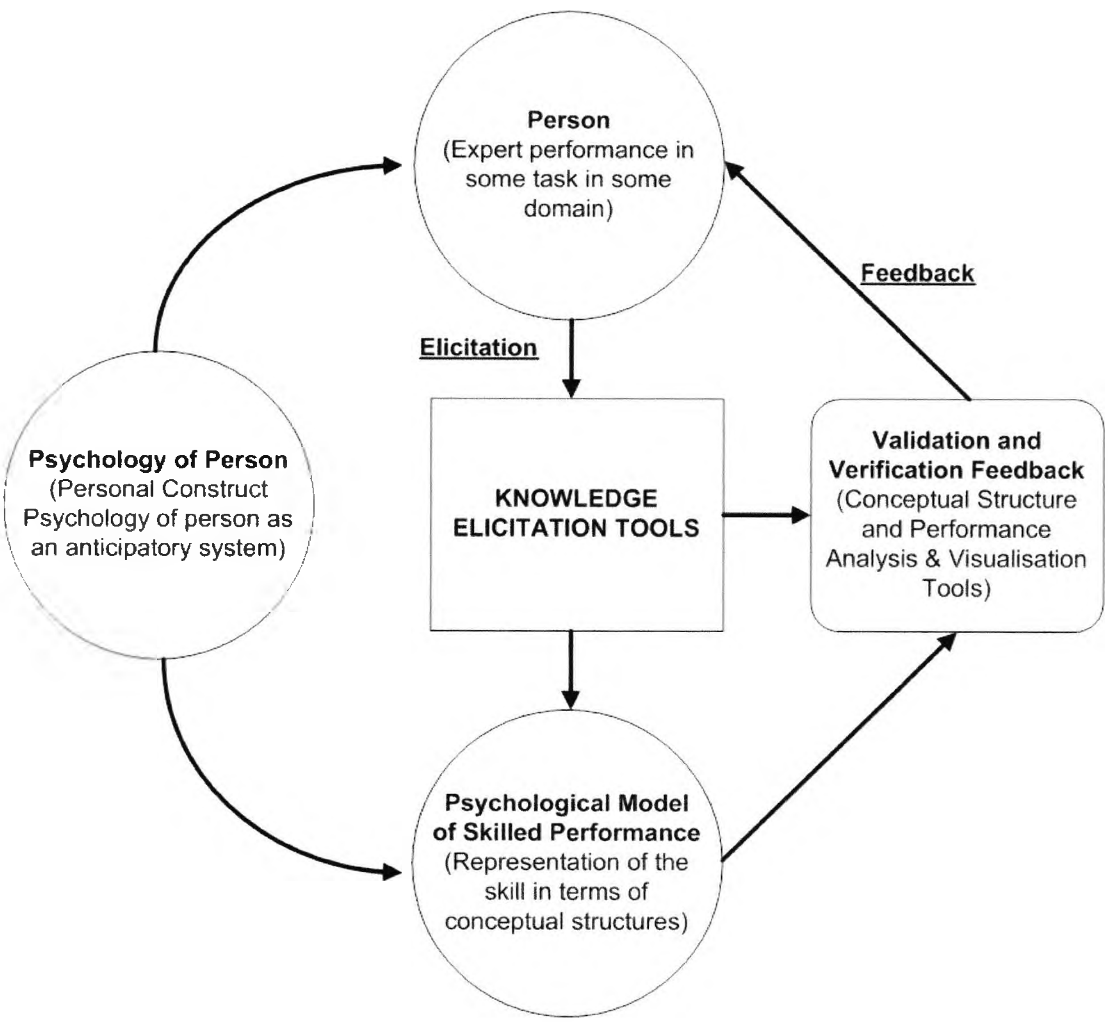


Figure 3.1 Isolation of KE tools relationship; taken within context of Gaines and Shaw's (1993) psychological and computational foundations for theories, methodologies and tools supporting expertise transfer

As Kidd (1987) states, knowledge acquisition of experts involves the following processes:

1. Deploying a technique to elicit data from the expert users.

2. Interpreting verbal data and infer the underlying knowledge and reasoning of the expert users.

3. Utilising this interpretation to construct a model or language that exemplifies the expert's knowledge and performance.

4. Interpreting further data by an iteratively evolving model until the knowledge domains are complete.

5. The principle focus for the knowledge acquisition team should be in constructing models, in domain definition, or problem identification and problem analysis.

Particularly relevant to the acquiring of expert knowledge is the representations constructed from acquired domains. Cognitive mapping is a practical technique stemming from Kelly's Theory of Personal Constructs (1955) and is vital to the model of expertise transfer (figure 3.1). Gierkink & Ruggles (1997) applied the policies of Social Informatics to cognitive mapping in knowledge representation, demonstrating that:

1. It is a useful way to make explicit an organisations' knowledge.

2. Captures and brings sequence to knowledge, both tacit (Polanyi 1958) and explicit which leads to events or processes.

3. Symbolic structures represent knowledge as objective items, and reasoning mechanisms exist to answer questions and to assimilate new information.

4. Knowledge engineering is a set of principles, methods and tools for eliciting and describing specific types of knowledge and expertise and then bringing them to bear more broadly through automated knowledge-based systems (KBS). It too uses knowledge representations in its methodologies.

In knowledge management, knowledge representation is used as a tool to structure the many fragmented pieces of information relevant to a particular process or event that exists in one person or among several people. Representation schemes include maps, books of experts, and electronic 'webs'. These representations are not repositories of information; instead they are used as learning enablers, for knowledge sharing and communication.

Landa (1974) proposed an algo-heuristic theory to understand mental processes, breaking it down into core self-containing knowledge units and mental operarands. Landa's "Landamatics" rules postulate that the performance of a task or step-wise problem solving has a definitive requirement of allocating a set system of elementary knowledge units and operations. Coxon (1999) expanded this further, defining problem solving through sorting elementary units as

> "...putting a number of things into a smaller number of groups and being able to give the rule by which such allocation is made..."

This model of units and operations will be observed further in chapter 5.

3.3 Knowledge Elicitation in HCI

Knowledge elicitation techniques exist for a number of fields in computer science, and the principles on which they are based on remain theoretically similar, i.e the acquisition of knowledge through various models of learning processes and motivated experiences over time.

However, the key understanding that this thesis aims to present is in the focus found in the domain of knowledge elicitation in HCI. HCI is considered by some to be a branch of software engineering. This differs in the construction of knowledge elicitation applications as found in other branches such as Expert systems knowledge retrieval and artificial intelligence (AI) systems (White, 1997), though both HCI and AI relate in a manner of speaking to cognitive models. HCI orientated KE is based on the tenets of experimental psychology, whereby the knowledge elicited is constrained to human definitions and measurements, as reported in Burge (2001) and illustrated by Burton et al. (1995).

There are many ontological views of knowledge acquisition methods in HCI, of which many authors in the field of HCI (Preece et al., 1994; Shneiderman, 1998) have cited for the teaching of HCI. Burge's Table of Knowledge Elicitation Methods in table 3.1 (Burge, 2001) provides an overview of the common KE techniques found in HCI.

The subsequent section expands on this to explore the models of the most widely used techniques used in HCI.

Table 3.1: Burge's KE Techniques Grouped by Interaction Type

Category	Examples	Type	Results
Interview	Structured Unstructured Semi-Structured	Direct	Varies depending on questions asked
Case Study	Critical Incident Method Forward Scenario Simulation Critical Decision Method	Direct	Procedures followed, rationale
Protocols	Protocol Analysis	Direct	Procedures followed, rationale
Critiquing	Critiquing	Direct	Evaluation of problem solving strategy compared to alternatives
Role Playing	Role Playing	Indirect	Procedures, difficulties encountered due to role
Simulation	Simulation Wizard of Oz	Direct	Procedures followed
Prototyping	Rapid Prototyping Storyboarding	Direct	Evaluation of proposed approach
Teachback	Teachback	Direct	Correction of Misconceptions
Observation	Direct Observation Indirect Observation	Direct Indirect	Procedure followed
Goal Related	Goal Decomposition Dividing the Domain	Direct	Goals and subgoals, groupings of goals
List Related	Decision Analysis	Direct	Estimate of worth of all decisions for a task
Sorting	Card Sorting and Affinity Diagramming	Indirect	Classification of entities (dimension chosen by subject)
Laddering	Laddered Grid	Indirect	Hierarchical map of the task domain
20 Questions	20 Questions	Indirect	Information used to solve problems, organization of problem space
Document Analysis	Document Analysis	Indirect (usually)	Varies depending on available documents, interaction with experts

3.4 Methods of HCI Knowledge Elicitation Practices

3.4.1 Surveys

Survey forms and questionnaires are usually an indirect form of eliciting knowledge. Typically it is used in HCI observation experiments as a pre and post knowledge elicitation. The activity of collecting and transferring this knowledge is often time consuming (Backstom & Nilsson, 2002).

In conducting surveys, three things are necessary – a) the set of questions, b) a way to collect responses and c) easy access to the demographic group you wish to test. (Kurniavksy, 2003). Fielding surveys and retrieving and analyzing results has always been an archaic and time consuming process in HCI. There are several widely reported templates for acquiring different types of HCI user data, such as the well known Quality of User Interface Satisfaction (QUIS) by Chin et al (1988), and the Computer System Usability Questionnaire (CSUQ) by IBM (Lewis et al., 1995).

Surveys can be similarly open and closed question based, but also allow us to enquire scalar results giving indicators of quality in positive and negative statements. Self-filling surveys can be time efficient for the HCI researcher to deploy, and results from closed questions, which are the most popular type of survey in HCI, can be fast to analyse. However a drawback to this is when they are completed in the absence of the HCI researcher, thus ambiguity in interpreting the questions can become an issue. Piloting a survey often aids in overcoming potential linguistic and semantic interpretation issues of questions (Preece et al, 1994).

Open answers tend to elicit unanticipated information which can be very useful for early design. Existing types of survey sampling techniques include face-to-face, paper and pencil based telephone surveys where the researcher will fill in the results (which become more of an interview style), and recently computer assisted and web based surveying techniques. The statistical strength of surveys is in the selection of participant groups to target within pre-designed result conditions, and in the number of participants that can be targeted. An example prototype of a mobile digital method for creating and conducting questionnaires is explored in appendix B.2.1.

3.4.2 Interviewing

This verbal process elicits knowledge from users on a set information topic based on their expertise in the domain in question. It is useful for obtaining behavioural reasoning and background knowledge but is not always reliable. Interviews can be categorized as structured or unstructured. Structured interviews elicit responses from users, by using a series of closed questions that have to be answered based on given solutions. This enables the user data to be analysed quicker but is not necessarily as informative as unstructured (open ended) interviews. Open ended interviews enable the user to explain more freely without being bound to set option answers, and thus describe more varied responses.

Preece et al. (1994) suggests that interview processes are most effective as semi-structured based on a series of fixed questions that gradually lead into more in-depth ones. This then allows for open ended follow-up responses to possibly create new dynamic questions based on prior structured responses (Macaulay, 1996). This follow-through model of enquiry is a means to further elicit a particular dimension of information, to possibly connect with other information artefacts elicited or to prove the isolation of its own information artefact. On-site stakeholder interviews allow researchers to bring about a vivid mental model of how users work with existing systems and how new systems can support them (Mander and Smith, 2002).

Interviews are useful when combined with surveys or questionnaires, as they can be used to improve the validity of data by clarifying specific issues that were raised in the survey or questionnaire. An example prototype of a mobile digital method for managing interviews is explored in appendix B.1.1.

3.4.3 Diary Method

Diaries are useful for HCI practitioners to keep a chronological track of user actions based on what the user perceives as important things to record. There are two types of diary study that HCI practitioners use; synchronous and asynchronous. The synchronous model for a diary based study is not new in the field of Psychology, as demonstrated by the Experience Sampling Method (ESM) (Csikszentmihalyi, et al., 1977; Csikszentmihalyi & Larson, 1987). It uses a mechanism to physically remind a user at set time intervals to either answer a set of questions (ESM survey) or fill in their diary (ESM diary) of what is occurring at that time. The asynchronous diary model is more widely used in HCI, whereby a participant will make diary notes when there is either an issue with the activity they have been given, or whenever they are content that they are doing something well (Schniederman, 1998).

Recent developments into online instant messaging, communication forums and web based discussion boards have given rise to the technology called Blogging. A blog is an online log (diary) which is held in the public internet space (usually on a collective blog site) and accessible to all readers. From the HCI perspective, Blogging allows HCI based diaries to be created and observed from anywhere on the planet by many practitioners. Nokia's LifeBlog technology enables blogging on mobile phones to also be shared online.

3.4.4 Focus Groups

This activity is useful for eliciting cross-representative domains of knowledge from several stakeholders/users, in an open discussion format. Sessions are moderated often by a HCI researcher and tend to be informal by nature, centering on the creation of new topics from open questions.

A common challenge is to stimulate the ideas and reasoning behind a design enquiry. Bruseberg & McDonagh-Phil (2001) demonstrate that through the process of discussion, collective views become more significant than individual ones. Evidence shows that the optimal number needed for a mixed experience focus group is between 5 to 8 participants, with group size being inversely related to the degree of participation (Millward, 1995).

Nielsen (1994) reports that computing technologies can aid in the remote abilities of focus group conferencing; however there are still difficulties in allowing a moderator to steer the discussion effectively and ensure that individual participants are not allowed to dominate the groups collaboration.

3.4.5 Observational User Testing

HCI Observation methods (also referred to as usability observation testing methods) elicit user knowledge from the interactions that take place when a user interacts with a prototype or final system. It can be direct, whereby a researcher is present and can steer users to particular points in an interaction. This tends to utilise video camera equipment and note taking to successfully investigate the sequence of events and the timeline of user actions e.g. "getting from point A to point D may require steps B or C".

The other model of observation is indirect or remote, whereby all user actions are captured electronically. An advantage of that is that even if the researcher's focus is elsewhere, interesting events may be captured. For example, "a user hovers over a button indecisively for a duration of time" – implying several causes such as linguistic problems or navigational flow issues, which can be reinvestigated at interview. Also by being indirect, the researcher is not needed to be present and there is no visible sensation of being video recorded.

Remote observation has been explored empirically by Ames et al (2004) showing that there is no significant difference in usability issues detection acquired through remote as compared to direct observation. Thus remote observation is a viable technique alternative for HCI practitioners to conduct the method with. In addition, their experimental tests showed that none of the participants would prefer local lab based studies if remote testing was possible.

Both direct and indirect models can be in real time or recorded but it is best for a HCI practitioner to be on hand in order to enquire further details through interviews. Discretion in recordings is paramount, something which ubiquitous HCI will explore in the future. As Lund (1997) describes, a user who may appear more apparently productive in visibly lab style settings may actually resume a normal pace in the work place thus giving false data. Also indirect observation may have gains over direct observation in terms of financial, political and practical access to participants.

A prototype tool developed in this thesis for indirect asynchronous observation is presented in appendix B.2.2. This tool allows for the recording of all onscreen activity and speak-aloud audio. Two other prototypes relating to the use of mobility with video observation and capture in HCI KE are discussed in appendix B.1.2 and appendix B.1.3.

3.4.6 Card Sorting

This technique uncovers the hierarchical structure in a set of concepts by requiring users to categorise sets of pre-made cards (closed card sort) or in some expert domains of use, with participant-designed cards (open card sort). Card sorting (also referred to as Pile Sorting) is typically done by physically having several cards of information placed into groups by a participant or teams of participants that are physically present. These groups are then given a category name based on the participant's perceptions (Zaphiris & Kurniawan, 2001). Cluster analysis is used in closed card sorts to spot clear structures and optimum groupings comparing the baseline of the pre-made cards.

It is expected that the characteristics of participants chosen to take part in card sorting experiments may influence the output quality of the categorisations. For example expert categorisations of problem domains are often favoured over novice categorisations (Maiden et al., 1995). Chapter 5 will cover this methodology further with an in-depth case study.

3.4.7 Affinity Diagramming

The Kawakita Jiro (KJ) diagrammatic method (Kawakita, 1975), also known as Affinity diagramming, is a team based knowledge elicitation (KE) technique. It is used for grouping information into categorical domains (Nielsen, 1994), and bears similarities to the user actions within open card sorting. Users write down items of knowledge or descriptions on sticky notes, and then organize the notes into groups before creating group headings.

The key distinguishing features between card sorting and affinity diagramming are:

a) Card sorting's use of statistical cluster analysis to compare a group of individuals choices in categorisation. In affinity diagramming however, the practice is enforced in teams usually working on a shared whiteboard (Figure 3.2) or large piece of paper. They are encouraged to communicate their reasoning verbally, thus collaborative team decisions upon consensus and agreement lead to category cluster formation (Beyer & Holtzblatt, 1998).

b) The card sorting method usually implies pre-made cards for use, whereas affinity diagrams tends to require user creation of the card entities themselves. This is not always the case, especially where there are detailed descriptions to categorise. It is noted that both techniques also apply to other objects other than cards such as pictures, and physical items, but card sorting tends to be more textually orientated.

Both of these methods are valid experimental approaches to acquiring categorisation metrics of user mental models. However, both of these methodologies are not always practical in physical form, due to of geographical dispersion in user collaboration, materials and spatial requirements, especially when eliciting on-site stakeholder knowledge. Chapter 6 will cover this methodology further with an in-depth case study.

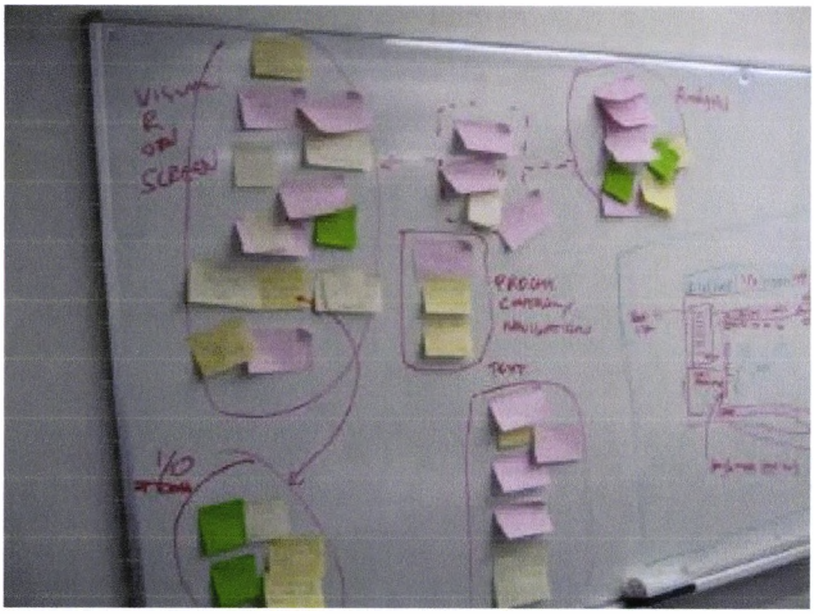


Figure 3.2: Paper based affinity diagram presented on a whiteboard

3.4.8 Paper Prototyping

The practice of low-fidelity sketch prototyping as a HCI KE methodology uses simple materials and equipment to create a paper-based simulation of views to an interface, artefact, concept or system. Its aim is to explore early user requirements and visualizing layout, accessibility and potential aesthetic approval of design ideas. In particular, pre-implementation usability problems can be quickly identified (Catani & Biers, 1998) and empirical testing with direct user involvement aids in the user centred design process in fitting requirements (Beyer & Holtzblatt, 1998).

Though there are more complex HCI prototyping techniques, low fidelity approaches often reveal substantially the same set of usability problems as high fidelity conditions (Virzi, 1998). Though the methodology lacks standardisation, Rettig (1994) distinguishes between high-tech and low-tech views, and the more commonly modeled categories are of low, medium and high fidelity prototypes (Greenberg, 1998).

Rudd et al (1996) also distinguishes prototypes according to horizontal and vertical prototypes, with vertical representing deep functionality of a limited view to the final output, and horizontal giving a wide overview of the full functionality of the system but with a weaker depth of understanding. Hall (2001) discusses the benefits of using various fidelities of prototypes. Low-fidelity horizontal prototypes in particular will be covered in detail in Chapter 7, with an in-depth case study.

3.5 Existing Cyberscience Tools for HCI KE

At the time of writing, it is clear from available literature and commercial software that user-centred design HCI KE tools are if at best, still in their early infancy. Often existing manual based KE techniques incorporate some form of electronic data capture (e.g. tape recorder for interviews) but this is rarely done systematically.

3.5.1 Paper Prototyping Tools

Several groups have recently contributed to the development of desktop and browser based tools that can aid in knowledge elicitation. Examples include the GUIR team which has produced tools such as their DENIM projects (Lin et al, 2000; Walker et al., 2002) and SILK (Landay & Myers, 1996) that are used specifically for the web (Figure 3.3). Also their Suede system (Klemmer et al., 2000) is a speech based Wizard of Oz Prototyping tool based on speech dictation interfaces.

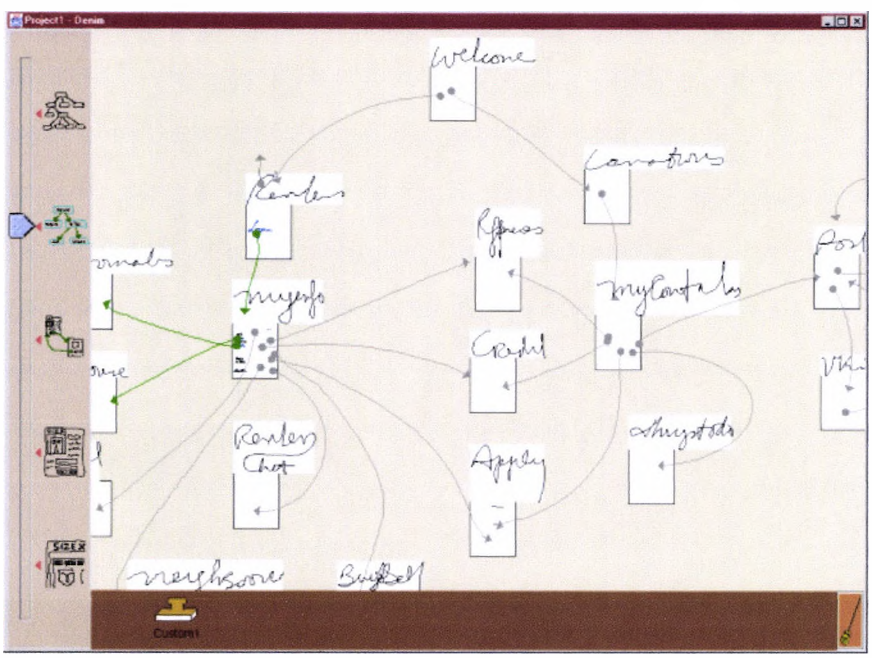


Figure 3.3 Denim demonstrating low fidelity "overhead view" of website navigation relationships

GUIRs Topiary (Li et al., 2004) allows storyboarding to be viewed on PDAs to conduct prototyping of location enhanced applications, depicting spatial location elements. NIST's WebMetrics suite by Scholtz & Laskowski (1998) is a suite of web browser tools constructed specifically for web developers working usability testing on heterogeneous and geographically dispersed users.

3.5.2 Remote Observation

Several commercial and open-source applications exist for remote observation (remote usability testing), for use by HCI practitioners. Some of the synchronous applications, which combine video, audio, and screen capture, include NetMeeting, Camtasia, WebEx, and VNC. The use of such remote observation tools to conduct HCI KE has been reported by HCI practitioners (Scholtz, 2001; Olmsted & Horst, 2003).

3.5.3 Card Sorting

There are several electronic card sorting tools available to HCI practitioners. Already mentioned is the popular NIST suite of tools which includes the WebCat web based card sorting tool (Scholtz & Laskowski, 1998). WebSort (2003) is a commercial web based card sorting tool, which allows desktop browsers with Macromedia Flash capabilities to perform remote card sorts. IBM's EZ Sort (2002) with cluster analysis is a highly popular freeware tool which enables cluster groupings to be visualized fast. It also comes with USort, a Windows 95 based software tool for eliciting the categories. UzCardSort from MozDev group (2004) and Classified for windows (Gaffney, 2004) are other desktop based card sorting tools. An electronic method for analysing paper card sorts via barcodes are described by Hudson (2004) and the accompanied Card Sort tool.

3.5.4 Affinity Diagramming

Affinity Diagramming can be conducted with Microsoft Visio, PowerPoint and Corel's CorelDraw amongst other visual diagrammatic tools; however they do not allow the user to capture the headings in a HCI-orientated analytic way, e.g. to compare categories. More importantly, use of these tools presumes that the participants have a formal understanding of the usage of the tools' available functions and user metaphors. In short, they are not designed with the principles of user-centred design specifically for undertaking and simulating the actions within affinity diagramming in HCI.

3.5.5 Questionnaires

Questionnaires have become straightforward to create and distribute to participants of HCI experiments, via a number of products (IMSISOFT, 2004) and programming languages (Perl, 2002) for various operating systems. Many of these can generate form-fill style questionnaires in addition to creating templates and databases for reusing questionnaires and storing user data. The electronic questionnaires can either be printed or placed online as web browser based input pages.

3.6 Mobile Interactive Knowledge Elicitation (MIKE)

At this point, this thesis introduces the theory and model of Mobile Interactive Knowledge Elicitation (MIKE). This thesis defines MIKE tools as

> "MIKE: User Centred Design tools for supporting HCI cyberscience, enabling combinations of mobile computing technologies to be used for the simulation, interaction and digital elicitation of HCI user-centred knowledge, at anytime, and anywhere."

An important question to query at this point is simply why not stick to standard non-electronic based procedures? Existing paper based systems and manual data collection in knowledge elicitation are easily convenient and effective methods of acquiring the target quantities of data for qualitative analysis with minimal expenses. However, the acquired knowledge learnt from society is of a higher significance when it comes from large domains rather than specific experts (Brown, 1999). In addition to this, the time spent in executing data analysis and translating functional but non-electronic information into digital format amasses to a significant proportion of human man-hours.

A list of benefits that digital mobile tools in knowledge elicitation could provide us with include:

1. On-site knowledge elicitation - to be able to acquire on-site real time HCI data as and where it affects the users will enable more convenient access to user participants, and potentially equal or higher quality of user centred data to be analysed.
2. Digital precision capture – the ability to record the absolute results above and beyond human error controls.
3. Archiving capacity and retrieval speed – large scale storage solutions function as a medium for storing vast quantities of elicited data, with response times far faster than retrieving paper based material in a physical storage library.

4. Faster and more advanced analysis than humans can facilitate – statistical functions (Martinez-Bejar et al., 1996) and knowledge rules such as those found in expert systems (White, 2000) can determine iterative computational sets of solutions based on knowledge elicited from end users.
5. Simulating and expanding on existing models – by allowing HCI to develop in new directions that are not possible without electronic aids.
6. Consistency of use – formalization of outputs from tools place integrity in a systematic set of processes that are available for use in resolving a set of problems.
7. Asynchronicity and the potential for unsupervised HCI measures – Enabling HCI KE to be carried out at the users' leisure, and lowering the task load of the HCI observer/practitioner by formalizing the methods of unsupervised experimental activity electronically.
8. Geographical assertion and broadening the scope of KE method usage – Integrating mobile internet facilities and the ability to communicate data, MIKE tools can have operate with individual users and also share data with collaborative groups. This has the aim of improving the quality of KE data by allowing globally wide demographics to participate if it is desired.

3.7 Chapter Summary

This chapter has presented an overview of Knowledge Elicitation in HCI. It presents us with an interpretation of Knowledge Elicitation Theory, and how it applies to HCI in user centred design and evaluation processes. Key definitions for Knowledge Acquisition, Knowledge Elicitation and Mobile Interactive Knowledge Elicitation set the theme for the rest of the chapters in this thesis. Existing methods are described, and current electronic methods are discussed.

The benefits of introducing mobility into HCI knowledge elicitation for on-site stakeholder user elicitation set the context for further research in this thesis. Several case study designs are included in appendix B, as precursors to the main research direction. Finally, 3 subsequent key chapters (chapters 6,7 and 8) are to be central to the research question, covering the methods of Card Sorting, Affinity Diagramming and Paper Prototyping. The next chapter leads into exploring HCI further by investigating the origins of Knowledge Elicitation in the context of pedagogical epistemologies, and the principles of learning and knowledge acquisition.

Chapter 4: Review of Learning Psychology and Pedagogical Epistemology

4.1 Introduction

A better understanding of the potential for MIKE tools to enhance HCI can be facilitated through a careful study of other domains relating to HCI grounding theories (e.g. learning psychology and pedagogical epistemology). This chapter furthers the exploration of MIKE based tools (chapter 3) by diverging conceptually to conduct a deeper understanding of the nature of user-centred knowledge, and how users come to acquire it. Therefore subsequent sections of this chapter attempts to examine, as a second literature review, some of the key concepts from learning psychology and pedagogical epistemologies (Cotton, 1995; Eysenck, 2000). The aim of this is to refine the potential theoretical application of a HCI grounding theory, given the motivation of mobility in tools for HCI.

4.2 Conditioning

The area of classical conditioning developed from the late 19th century with the renowned Russian psychologist Ivan Pavlov. His studies from 1898 on "psychic reflexes" on the behaviourist data from his experiments on primates and animals concern the generation of stimuli responses and their appropriate reflexes.

Pavlov's findings presented two important theories to the psychology of learning; unconditioned reflexes (UR) where inherited, instinctive and innate habits "are nothing but a long chain of conditioned reflexes" (Pavlov, 1927) and as such take place without a need for learning new concepts, and conditioned reflexes (CR) which are acquired through time and experience. An important point made from this work was that unconditioned stimuli (US) is generated after a conditioned stimuli (CS) is made. According to Pavlov, this response does not occur without a learning process occurring.

Skinner's work (1938) has emphasis in the psychology of learning by demonstrating operant conditioning as opposed to Pavlov's classical conditioning. In operant or instrument based conditioning, a set of principles derives how people learn through the reinforcement and appreciation of their consequences. He determined that it is important to focus primarily on positive reinforcement to shape behaviour and that the learning process should be short and expand out of previous histories of behaviour. Learners tend to find discovery of a concept itself to be a motivation for reward.

In Skinner's experiments, motivation has been shown to be enhanced with supervised progress explanations and in most circumstances a learner should be given an opportunity to investigate the most likely path to success.

From this theory Skinner (1938) defined a scheme known as "programmed learning". This can be found in modern school-orientated teaching practices and indeed is found in current day CAL (computer assisted learning) tools. Each student is given an opportunity to progress at his or her own pace but the method is relatively slow in preparation. Its strong point is when a subject area is particularly challenging and demands a class of students to be at varying levels of ability.

Gilbert (1962) developed a methodology in programmed learning under a branch entitled instructional sequencing, for the analysis of behaviour and design of training aids. It was found to be a successful approach to instructional problems particularly orientated to the industrial training field. This methodology was termed "Mathetics", and it

> "classified behaviour as composed of combinations of three basic structures: chains, multiple discriminations and concepts".

Programmed learning developed with the core principles that Gagne (1974) proposed, in which eight types of learning were defined and arranged in order of simplicity, from Pavlov's straightforward conditioned responses to complex problem solving;

1. **Signal learning** e.g. Pavlov's classical conditioned response
2. **Stimuli response learning** e.g. Skinner's operant conditioning
3. **Chain learning** e.g. the linking of two or more stimuli responses
4. **verbal associations** e.g. learning terms by linking of verbal sequences
5. **Discrimination learning** e.g. responding to similar stimuli that differ in a systematic process
6. **Concept learning** e.g. ability to generalise and classify common categories.
7. **Rule based learning** e.g. relationship patterns and the chaining of multiple concepts even if not previously encountered.
8. **Problem solving** e.g. solving problems by use of principles, highest level of cognitive process.

The significance of this hierarchy allows us to identify the prerequisites that should be completed to facilitate learning at each level and provide a common grounding for the sequencing of instruction. In addition to this, his theory outlines nine instructional events and their corresponding cognitive processes:

1. gaining attention (reception);
2. describing the objectives (expectancy);
3. stimulating recall of prior knowledge (retrieval);
4. presenting the learning materials (selective perception);
5. providing learning guidance (semantic encoding)
6. eliciting performance (responding);
7. providing feedback (reinforcement);
8. assessing performance (retrieval);
9. enhancing retention and transfer (generalization).

These events serve as a formally defined basis for designing instruction and selecting appropriate media (Gagne, Briggs & Wager, 1992). Gagne (1987) also addresses the role of his theories in instructional technology.. Learning hierarchy models that demonstrate the decomposition of complex tasks into simpler atomic tasks led to Gagne's (1987) Cumulative Learning Theory becoming the basis for Hierarchical Task Analysis (HTA) which is a common method of practise in HCI.

In comparison with Gagne's learning hierarchy, Flavell (1963) explains that Piaget's analysis (1952) differs in adults from children's intellects showing that the simplest forms of knowledge acquisition occur with concrete operational thought (7 to 12 year olds). Learning as Piaget explained begins with individuals requiring solutions to problems and that people assimilate, accommodate and collaborate to find new knowledge at point at which solutions are demanded.

4.3 Discovery

Bruner (1960) explores the optimisation of learning by discovery. The importance of first hand experience, learner centred approaches and development of critical abilities are emphasised in discovery learning. The process of discovery learning is facilitated by reinforcing the need to revisit existing knowledge when faced with new knowledge. By strategic trial and error learning, concepts are reinforced with observation and pattern-like recognition. This is also noted to be the last phases of Gagne's learning hierarchy.

Ausubel (1968) presented us with reception learning, another key principle in allowing humans to discover new knowledge. Ausubel's theory is concerned with how individuals learn large amounts of meaningful material from verbal and textual presentations in a non-strenuous and natural school setting rather than under the more tense conditions that a lab experiment may provide.

Two main principles for organising the content of subject matter have been reported by Ausubel: progressive differentiation – where ideas are followed by gradually increasing the level of detail and integrative reconciliation – where new ideas become associated consciously to previously learnt material (subsumers). A subsumer is material that enables existing concepts to co-exist and integrate with newer concepts. However "obliterative subsumption" as Ausubel postulated, should also be considered as cognitive links forgotten over time and disassociated from new material, but new cognitive structures can be built from the remnants of old ones.

4.4 Intelligence

Intelligence and memory are the most considerable factors in a person's learning ability in acquiring and understanding of new knowledge. The intelligence of a person does not imply the level of education of a person, but rather how much complexity in learning a person can acquire. By comparison, memory demonstrates a person's capacity for retaining accurately stored knowledge and their observation capability. Intelligence experiments have a scaling system for measurement; Stanford-Binet tests (1937) which led to the development of the controversial I.Q. tests, were created to measure the intelligence ratio between the mental and chronological ages of an individual.

Spearman (1904) concluded that intelligence was the ability to identify relationships and logical connections between facts. Intelligence in this context is made up of two factors, G and S factors. G refers to general intelligence that is not affected by education e.g. experiences and instinct, and S factor refers to specific capabilities that come about as a result of education.

Several other noted psychologists have devised models to categorise human intelligence. Thurstone & Thurstone (1963) devised the primary mental abilities test, which suggests that intelligence, can be defined as a combination of seven primary mental abilities which supports Spearman's G factor theory:

1. Spatial ability
2. Perceptual ability
3. Numeric ability
4. Verbal meaning
5. Memory
6. Verbal fluency
7. Inductive reasoning

Sternberg's (1982) model of componential intelligence relates intelligence to three internal mechanisms of the mind. Firstly meta-components are the features of intelligence that are required to resolve a problem. Performance components are then used to perform the solution, and finally the Knowledge Acquisition component acquires new knowledge and then integrates that with what is already known.

4.5 Memory

Knowledge acquisition in learning processes is not very powerful if there isn't a medium for holding that knowledge. Ebbinghaus (1885) found that over-learning would give a more accurate memory retention. His three basic processes in the human memory model are encoding, storage and retrieval.

Three different types of memory are available, short term, long term and sensory memory. In Miller (1956), the short term memory is cited to

> "be optimal when holding only five to nine pieces of information for less than 30 second periods of time."

Baddeley (1966) also determined that words which are semantically similar lack precision in memory, and suggested that uncommon words and terminology in long term memory are remembered by definition of their meanings.

Organisation of material was investigated by Tulving (1968), who suggested that we group information in terms of their primary relationships. We then further remember them by secondary methods such as by category or by association.

Curzon (1990) describes a method which would aid the thinking and learning process which can be applied to teaching preparation;

1. Stages are required, e.g. an introduction, development and a conclusion.
2. Information should be presented close to the time of the learning session to ensure short term memory reinforcement of knowledge acquisition.
3. Subjects have a similar focal point within a learning session as each dimension presented will also reinforce the knowledge acquisition.
4. Closure allows a learner to finish their task with a premise for further study asynchronously, in their own time.

These contribute to Ausubels' subsumption theory (1968) that what a learner already knows should be further established. Variables that can be explored from this include information overloading which affects closure and the reliability of recent information, and also disruption variables by location and group size, and motivation e.g. capturing knowledge of interest (intrinsic) or under pressure (extrinsic).

4.6 Symbolic Interaction

Manis & Meltzer (1978) considers interaction theories via social activity to be an important part of the learning process. They consider human behaviour to be observable at two levels, symbolic and behavioural. Our communication and manipulation is required through interaction to understanding the range of symbols and symbolic semantics that humans are presented with. For example, learning through discussions and the use of related trigger props.

Observing an interaction tends to assume that a complete analysis of human conduct will capture all of the symbolic meanings that occur chronologically. However, Manis & Meltzer (1978) point out that in addition to this we must capture variations in ongoing patterns of behaviour that reflect the symbols. Symbols are intended, unintended; verbal, nonverbal; complex and often hierarchical. Associative symbols include nonverbal gesturing, verbal utterance, mode, mannerism and emphasis of speech, which can all affect our interpretation when translating an interaction symbol in the real world. This is also related to the works of Polanyi (1958) on tacit behaviours. The fundamental principle of symbolic interaction is that

> "the investigator must see the world from the point of view of the subject of the investigation"
>
> (Manis & Meltzer, 1978)

of which discovery learning is enhanced by a student's own motivation as discussed before. They proposed three principles for symbolic interaction that must be adhered to before an interaction investigation is considered complete;

- Symbols and their interaction should be as close together as possible before an investigation.

- Meanings and the reflective nature of self definitions should be captured – an investigator needs to indicate how shifting self-definitions are reflected in ongoing patterns of behaviour.

- The investigator must link symbols and conceptions of self definitions with social views and relationships that have a comparative similarity with those symbols and conceptions.

4.7 Situated Cognition

Situated Cognition is a learning theory that describes a method in which learners use generalizations to help transfer knowledge from one situation to another. Situated learning environments allow learners the

"... ability to retrieve relevant information when needed"

(Choi and Hannafin, 1995).

It promotes the transfer of knowledge to day-to-day real life situations by providing practical experiences of real situations, inferring *memory* and *symbolic* learning theories. Choi and Hannafin (1995) state that there are four key concepts related to the design of a situated learning environment: Context, Content, Facilitation, and Assessment.

Learning is thus seen as "an internal mental process in which knowledge is acquired and stored for use at will in any circumstance" (Wilson, 1993). To do this, it is important to bring together the individual and the environment (Moore et al., 1994). The use of knowledge when combined with reflecting on the environment of its acquisition bears relevance to the theory of Constructivism.

Table 4.1 Framework for Situated Cognition (Choi and Hannafin, 1995)

Framework	Principles
The role of context	Everyday cognition: people reason intuitively based upon experiences within specific contexts; use a variety of methods to solve problems Authenticity: coherent, meaningful and purposeful activities that represent the ordinary practises Transfer: situated learning environments are more likely to transfer to real-life problem solving
The role of content	Knowledge as tool: students acquire knowledge as well as a sense of when and how to use it Content diversity and transfer: concepts need to be represented via various content; necessity to apply knowledge in various setting to discriminate similarities and differences among settings Cognitive apprenticeships: to provide the opportunities for the learners to internalize learning and develop self-monitoring and self-correcting skills. Anchored instruction: to create authentic, problem-rich environments that encourage exploration and diversity of perspectives
The role of facilitation	Facilitation methods: situated learning environments attempt to help students to improve their cognitive abilities, self monitoring and self-correcting skills; encourage active learning and provide opportunities to internalize information; facilitation is less directive, more continuous, and highly interactive Modelling Scaffolding Coaching, guiding, and advising Collaborating Fading Using cognitive tools and resources
The role of assessment	Problems and issues: in order to be useful in promoting higher thinking skills, testing needs to shift from domain referenced evaluation to assessments; emphasis needs to be on the ability to diagnose manage cognitive growth rather then achievement

4.8 Constructivism

Constructivist learning theory is associated with the work of Jean Piaget (1952) and Lev Vygotsky (1978). Constructivists argue that knowledge is not transmitted, but constructed. Each individual must reconstruct knowledge and this learning process happens within a material environment, a culture and a supportive community of practice. Thus we refer to the construction of new knowledge by the learners themselves, whereby the learner is thinking about learning and that constructivist pedagogy entails interaction with sensory information and the behaviour of self constructed knowledge that is built up through experience (Jonassen, 1994).

Hein (1992) proposed nine principles of learning that relate to constructivism:

1. Learning is an active process of constructing meaning from sensory input
2. People learn as they learn, as well extracting what they need from the content
3. Constructing meanings is a mental process
4. Language and learning are intertwined
5. Learning is a social and human interactive activity
6. Learning is contextual
7. It is not possible to gain new knowledge without having some structure from previous knowledge to build upon
8. Learning takes time and iteration
9. Motivation is an essential and thus illustrates the need for reasoning and questioning.

Of constructivism, McConnell (1994) defined knowledge as;

> "...a process of knowing, in which we engage with our reality and through dialogue with others and with ourselves, we give meaning to the world. This process acknowledges that there are different forms of knowledge, including tacit or personal knowledge and experiential knowledge"
>
> (McConnell, 1994)

Thus constructivistic learning practices challenge the notion that knowledge is "an identifiable entity with some absolute truth value" and that

> "...technology enables the development of higher order thinking skills when students are taught to apply the process of problem solving and are then allowed opportunities to apply technology in development of solutions."

> (Cognition and Technology Group: Vanderbilt, 1992)

In Brown (1999), the then director of Xerox Parc Research stated controversially in favour of constructivism that the populous community are the increased experts in reality, and not the individual expert participants;

> "We began to realise that no one person was the expert. The real expert was not a person but was the community mind. If we could find a way to support and tap the community mind we might have a whole new way to accelerate learning and to capture and structure knowledge assets in the making and do this with virtually no overhead."
>
> (Brown, 1999)

4.9 Constructionism

While constructivism defines learning as the building of knowledge structures inside of one's head, *constructionism* suggests that the best way to ensure that such intellectual structures form is through the active construction of something outside of one's head, that is something tangible, something shareable.

Seymour Papert worked with Piaget in the late 1950s and early '60s. Papert's work extends Piaget's theory of constructivism and knowledge to the fields of learning theory and education.

> "Constructionism, the N word as opposed to the V word – shares constructivism's connotation of learning as "building knowledge structures" irrespective of the circumstances of learning.It then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe."
>
> (Papert, 1991).

The key assertion of constructionism theory is that constructivist learning happens especially well when people are engaged in constructing a physical artefact, something external to themselves. Constructionism remains an ongoing entity within Piaget's theory of constructivism. When people construct theories and knowledge in their minds from artefacts, this knowledge enables them to build even more sophisticated artifacts, which iterates into greater knowledge in a self-reinforcing cycle.

Where constructivism can be expressed as learning by doing, constructionism is learning by making. Papert (1991) is critical of how constructivism may be interpreted to mean the construction of knowledge without a context of use. This is in disagreement to Hein (1992) who as stated in section 4.7, claimed that (6) "learning is contextual".

This disassociation of knowledge without the context of use may contribute to weaker understanding, coercive curriculum and negative attitudes towards learning. Papert's work are covered indepth in his books *Mindstorms: Children, Computers and Powerful Ideas* (1981), *Constructionism* (1991), *The Children's Machine* (1993) and *The Connected Family* (1997), which illustrate more than four decade's worth of research in learning with computers. Stager (2001) describes the stages of constructionism in software interaction processes as "tinkering, prototyping, testing, building, debugging and the presentation of a finished product".

Resnick's work subsequently investigates further the theories of Constructionism. In 1996, he illustrated his stages of Constructionism (Resnick, 1996) as a) Discussing Constructions, b) Sharing Constructions and c) Collaborating on Constructions, applied in distributed Constructionism (as cited in Zaphiris et al., 2002).

Much of the work done today in the area of Constructionism focuses on social and distributed constructionism as mechanisms to model in various outwards and connective learning environments. Social and Distributed Constructionism give new models of use in the awareness of constructionist knowledge transfer, which can be modelled in computer network formats (e.g. web-based forums).

What is interesting about Constructionism is that it can in some respects maintain a very close coupling of physical and digital representations. A key scenario would be to have a true sense of direct manipulation (Shneiderman, 1998), where the user feels as if they are interacting directly an objective construct rather than manipulating just the symbolic representation of the construct (Fishkin et al, 2000). In fact, the Digital Manipulatives concept (Resnick et al, 1998) takes this model into the physical world by integrating the digital representation directly within the physical objects used to construct new objects.

Ackermann (1996, 1999), suggests that to facilitate learning efficiently, a learner must be able to reflect upon, objectify and reason about the domain, not just to act within it. Bertelsen (1998) has discussed the issues of construction of design artefacts in relation to HCI practices;

> "A prototype can both be understood as a design artefact and as object of design. Design artefacts are mediating three main design functions: getting knowledge and understanding about what is designed, i.e. conception; communicating and co-operating during this process; and constructing the new artefacts forming the considered world."
>
> (Bertelsen, 1998)

This thesis further defines this physical-simulation and inner-mental modelling of constructionism as *artefact-driven constructionism*, so as not to confuse the issues surrounding the current research being undertaken elsewhere in social and distributed constructionism contexts.

4.10 Activity Theory in a Constructionism Context

Though broad in scope, Activity Theory (Leont'ev, 1978) explains that a subject is related to the constructed and object world by mediation with activity. Harris (2005) states that

> "People do not simply passively absorb, and react to, stimuli from the 'outer world'; they actively explore and transform their material and social environments... Human activity is understood as a structured, dynamic, and self-regulating system, motivated by needs and objects." (Harris, 2005).

Burd (1999) demonstrates that Activity Theory interlinks with Constructionism in the view of Software Engineering principles (figure 4.1).

Leont'ev (1978) as a key authority on the topic describes further that activity is a molar, and not an additive unit of the life of the physical, material subject. He went on to suggest that

> "Human activity does not exist except in the form of action or a chain of actions." (Leont'ev, 1978)

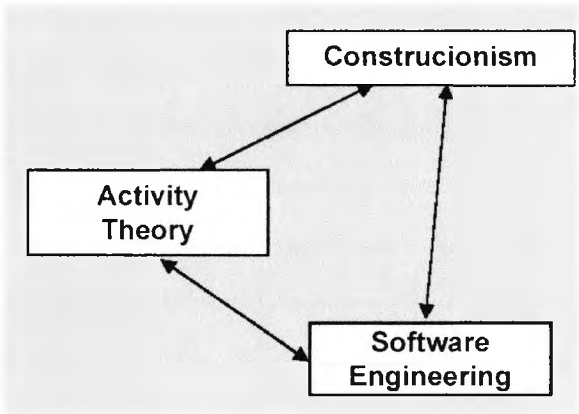


Figure 4.1: Constructionism with Activity Theory in Software Engineering (Burd, 1999)

Engeström's maintains however that Activity theory in general has a few noted differences to constructionism theory. He explains that:

> "Activity theory is at its best in analyzing such poorly understood processes of developmental transformations over time. Expansive learning is energized by historically accumulated developmental contradictions within and between activity systems, and it is triggered by disturbances and concrete innovative actions." (Engeström, 2000)

The originators of Activity Theory presented some highly abstract general propositions of the nature of human activity. The most basic one is Vygotsky's argument that all human interaction with the world is mediated, either by material tools or by immaterial signs (Figure 4.2; Vygotsky, 1978).

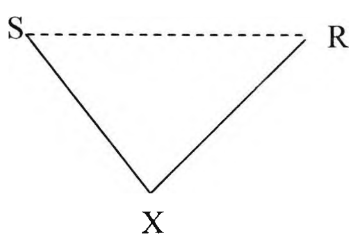


Figure 4.2: Vygotsky's general presentation of mediated action (S:Stimulus, R: Response, X: Mediation by tools and signs)

Engeström (1990) developed Vygotsky's and Leont'ev's abstractions into an applicable model of the systemic structure of human activity (table 4.2). In Leont'ev's model (1978), the elements of an individual action of work are the subject (individual person), the object, the mediating instruments and the goal.

Table 4.2: Engeström reporting Leont'evs three level model differentiating between non-conscious operation, individual action and collective activity.

Unit	Directing Factor	Subject
Activity	Object/Motive	Collective
Action	Goal	Individual or Group
Operation	Conditions	Non-conscious

Leont'ev (1978) emphasises that the motive of a collective activity is in its shared artefact constructs – or more specifically, in what the construct transforms into during the activity e.g. the motive of a building construction activity is to transform the raw materials into an office.

Beguin and Rabardel (2000) demonstrates this empirically in the case of modelling "paper-and-pencil" prototyping design with software tools. Their results showed that the computer-assisted design process in addition to the paper context also appeared to demonstrate clear activity periods during which sketches were made. In the case study reported, six "generative" time periods were graphically identified.

What was interesting about these periods was that the first three periods were exclusively generative, whereas the last three periods concerned only backtracking and assessment. Their work expands further to reason that the explanation for this change in activity is that when working on the computer, the designer is faced with two tasks. Firstly there is the design task, with both experience and uncertainty to determine the quality of the design output. Secondly there is the evaluative and validation task, to mediate and thus refine the qualitative aspect of the existing design tasks.

The notions of artefact-driven constructionism, that ideas and new knowledge are reflected from the tangible interactive and manipulative nature of artefacts, gives importance in selecting a pedagogical model to apply to the mobility factors of mobile tools for HCI. The levels of freedom to create and manipulate tangible artefacts as conceptual knowledge structures are of significance as metaphors with mobile interfaces that are touch and pen-based. Given that touch and pen-interaction can in fact be measured with mobile software methods, this gives a unique research opportunity to explore a measurable context of constructionism as applied to HCI. The models of situated cognition, constructionism and activity theory outlined in this chapter gives a basis for further exploring the inner understanding of how HCI participants create new knowledge when faced with tangible media. These constructionist concepts will be expanded on further in a newly designed framework of constructionism for HCI described subsequently in chapter 5.

4.11 Chapter Summary

We have explored several of the key learning theories from pedagogical psychology and drawn them together into aspects of learning through the theory of constructivism and constructionism. The direction of artefact-driven constructionism as defined in this chapter has been shown to relate with ideas from Activity Theory and Situated Cognition applies to the context of mobility in exploring how participants may elicit knowledge given their environment.

As Beguin and Rabardel's (2000) work illustrates in context of design activities, it can be observed in particular from empirical testing that Constructionist activity has stages that can be identified, namely; Generative, backtracking and assessment. Three concepts from the pedagogical standpoint have already been identified;

1. Generative Activity,

2. Mediation by consensus, and

3. Refinement by assessment, which potentially leads to the creation of further activities to construct new knowledge and/or improve existing knowledge.

From this understanding of these key pillars in Constructionist activity, the subsequent chapter will deal with the creation of a framework for measuring and analysing the stages of user constructionism over time, in a HCI KE context. This will be done in order to direct the state of the art in Mobile HCI KE to acquire new pedagogically grounded measures based on this theory.

Chapter 5: A Framework of Artefact-Driven Constructionism for HCI

5.1 Introduction

This chapter follows on from the literature review of key theories in pedagogical psychology (Chapter 4). In lieu of Constructionism, we have explored the artefact based nature of Constructionism and its relation to the methodology of Activity Theory. However, there is a difference between understanding in principle these concepts and empirically measuring them. This thesis therefore indicates a need for a conceptual framework that can bridge these two process. In extending this work, we describe a Framework of Artefact-Driven Constructionism for Human-Computer Interaction (henceforth "Framework of Constructionism for HCI") that will enable empirical modelling and measurement of constructionism. The application of the grounding theory discussed in chapter four sets the scene for applying this Framework of Constructionism for HCI KE methods. Chapter 6-8 will put this framework into practise by applying it to three HCI KE scenarios.

5.2 A Framework of Constructionism

As reported in chapter 4, Kelly's Personal Construct Theory (1955) places emphasis on learning with experience. This agrees with the temporal nature of constructionism. The notion that an "idea" can be considered a node in the formulation of a logical "construction" enables us to model the constructionist process of creating and manipulating *artefacts*.

New knowledge is potentially created by the users constructing tangible artefacts during the knowledge elicitation activity and using it to define new artefacts or redefine existing ones, and so forth. This chaining effect has already been described in cognitive modelling by others who have defined it as part of the principles within Activity Theory (Leont'ev, 1978; Vygotsky, 1978).

More specifically Leont'ev's model (1978) distinguishes creation of knowledge as activity, built up over time by actions and operations. In this understanding, "Activity" is defined as "the engagement of a subject towards a certain goal or objective" (Ryder, 1998; Luria, 1981). Vygotsky contributed to Activity Theory by describing activity that is mediated through the use of artefacts.

In general, artefacts are both a constructed set of initial activities but also a product of an activity, and can be modified throughout the timeline of an activity. As Bertelsen (2000) denotes:

"design artefacts are boundary objects because they adapt to different situations of application and at the same time maintain identity, thereby mediating divergent needs and viewpoints."

(Bertelsen, 2000)

Bannon and Bødker (1991) describe this format of mediation as a critical part to understanding artefacts and distinguishing them from each other. Beguin & Rabdarel (2000) similarly uses this idea of mediation to explain the artefacts within the cycle of construction as a combined result of generative activity, mediation and refinement stages as reported in chapter four.

5.3 Introducing Constructionist Metrics to HCI with TIC states

This thesis proposes that artefacts as constructs have been created out of cycles of iterative tangible knowledge, either from an individual self or from others collaboratively. It can be represented in a framework that describes an internal cognitive construction cycle of a single knowledge entity which is created from several key stages (Fig.5.1);

i) Decisions (Generative Activity and first innovation)

ii) Mediation (Backtracking, pausing for reflection)

iii) Refinement (Assessment and innovation, leading to modifications)

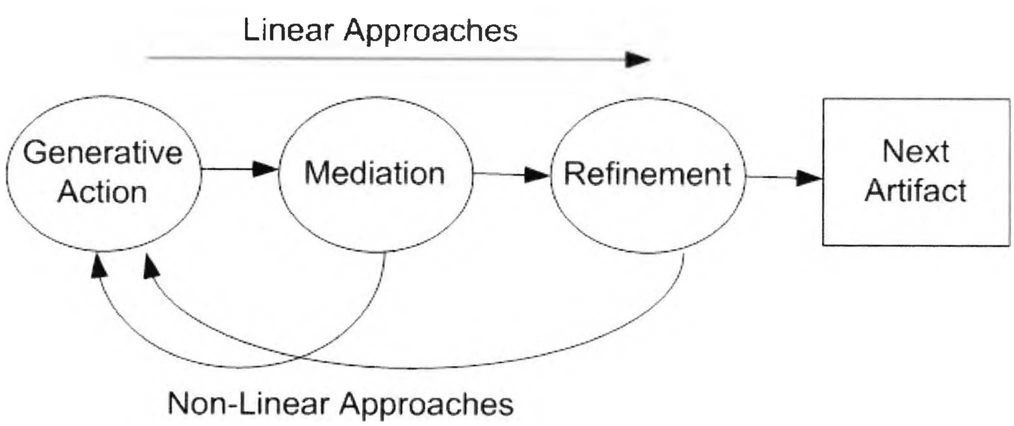


Figure.5.1 Linear and non-linear approaches as a Temporal Iterative Construct (TIC) state

This thesis describes this construction cycle as a *Temporal Iterative Construct (TIC) state*, as it represents a single iteration of constructionism occurring at a point in time. Upon refinement several artefacts can become reinforced by further Decision stages, leading to subsequent branching of Mediation and

Refinement within (recursive constructions). Decision making as an activity can thus branch into 3 dimensions; Addition (First Set), Modification (Mutate or Get and Set) and Removal (Delete).

5.3.1 The Temporal Manipulative – Mediation Points

In addition to these, a fourth variable, a "Mediation Point", can be described as a point in time when a generative activity (Decision) halts for an arbitrary period (like a rest), and then continues onwards in the timeline with mediation and refinement either leading on to a new artefacts construction or to modification of the existing.

This mediation point is in line with Resnick's (1998) terminology of a Digital Manipulative in constructionism, items are separated by time and as such can also be referred to as a Temporal Manipulative. This temporal manipulative is a key factor in this framework for measuring TIC states in constructionism. Without it there is no sensible measure for historical comparison of artefact construction. Temporal measures have been shown to give indicators of performance and predictive models in the other HCI theoretical contexts (Dix et al, 1992).

This mediation point is thus important to us to aid in distinguishing sums of artefacts as a single artefact in a construct. For example, sketching a prototype view of a DVD movie menu interface may show one artefact collection as a navigation block which has icons, labels and a button style; a mediation point will separate this as one artefact before the user has considered a next artefact to be created e.g. a background menu image.

5.3.2 The Temporal Distance between Two Ideas

Mediation Points can vary significantly based on the arbitrary period. For example, in sketching a drawing, an arbitrary period set to one second (figure 5.2) will infer that most strokes of the pen will be individual constructs and thus not as representative of the symbolic understanding of the construct.

Exploring the practical temporal distances in human ideas is beyond the scope of this thesis, and remains in the domain of experimental psychology. However, it can be determined that there are two temporal variables to be arbitrarily observed here; firstly the time taken for a single idea to be constructed and second, the time between ideas formation (as recognised in this thesis as separated by mediation points).

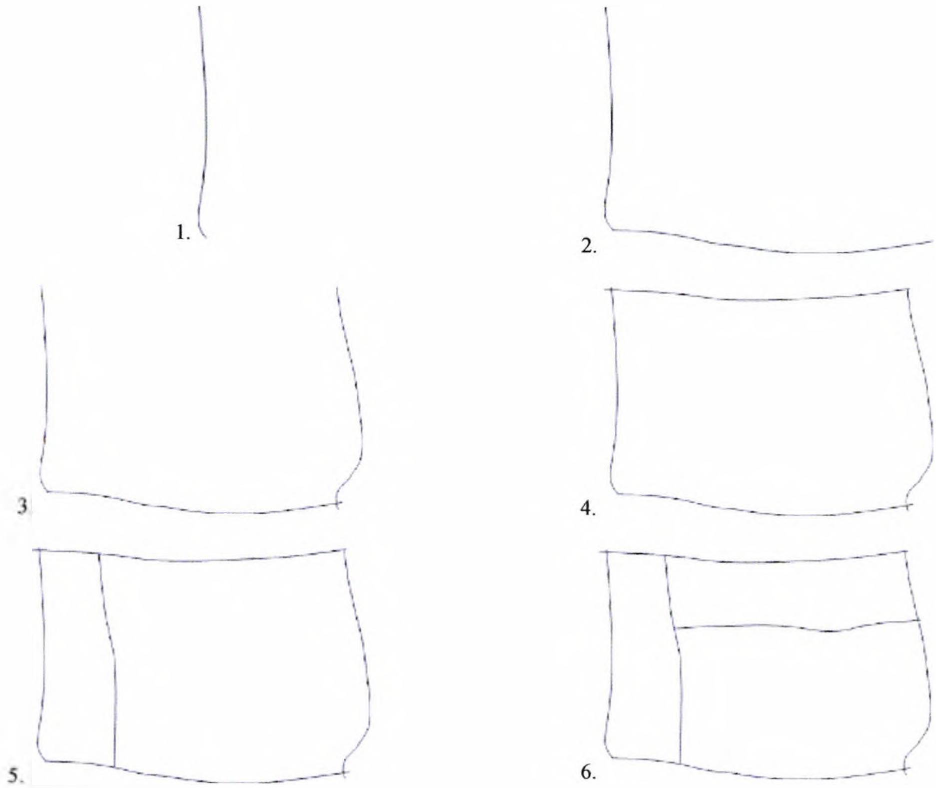


Figure 5.2 A one second arbitrary period to separate mediation points potentially infers uncharacteristic artefact constructs until the final construct view

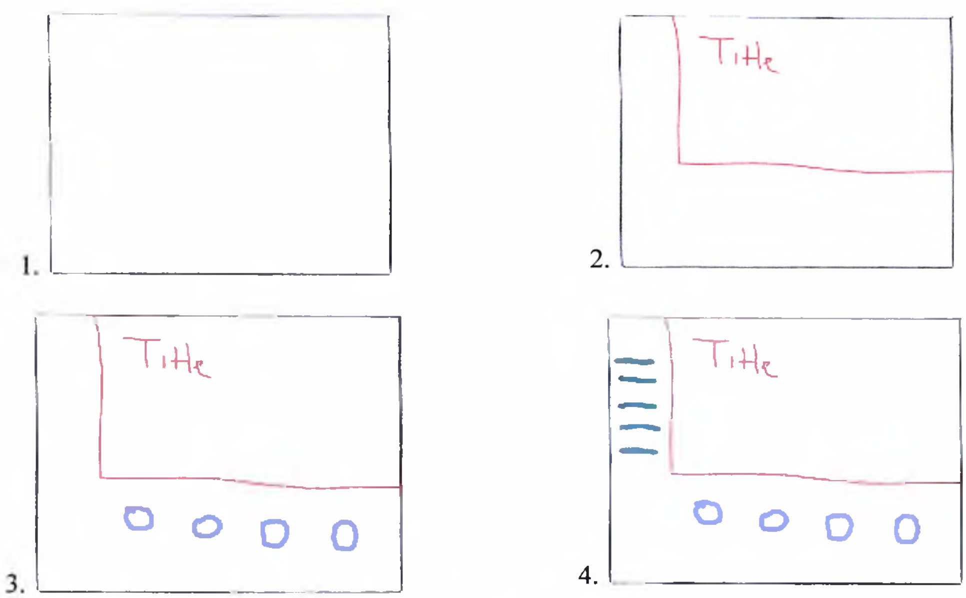


Figure 5.3 Longer arbitrary periods and activity property changing incurs mediation points

5.3.3 Constructionist Spatial Incursions

Several events within a generative activity can be measured individually or viewed as a series of activities e.g. as a cluster of constructionist activities. A cluster of constructionist activity can be determined to be in a combination of events, some of which are chained, or alternatively continually changing. These cause an incursion and change in the construction properties themselves, for example adding, modifying, adding then deleting the artefact in question.

These clusters are interlinked with the Temporal Manipulative discussed prior, which gives rise to potential behavioural explanations to the constructionist processes when separated by mediation points. The resulting view of the construction of several artefacts through TIC states in this manner gives us a measurable indication of expertise and capability in the scenario of use.

Table 5.1 describes all possible event patterns needed to describe constructionism through combining TIC states within this temporal view of generative activities. Figure 5.4 demonstrates these framework event patterns to describe a time-independent view of two examples in a linear sequence; the first is of a confident construct with positive refinement, and the second of a not so confident construct with uncertainty.

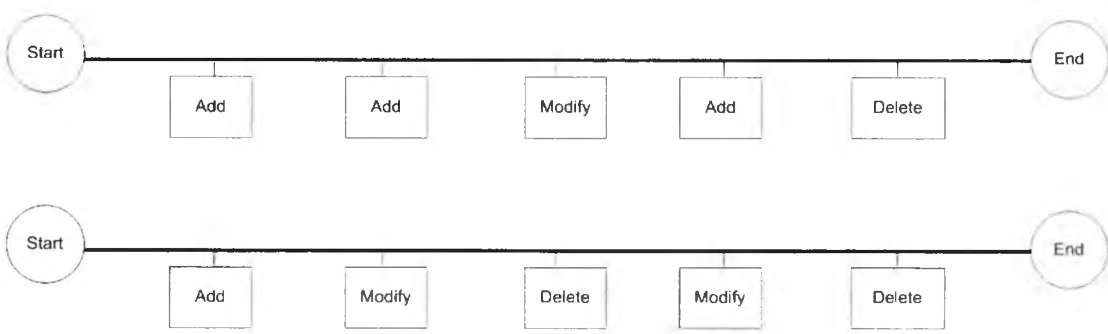


Figure 5.4 a confident and a non-confident view: Mediation point separated artefacts in a time-independent view of constructionism

Table 5.1. Event patterns framework within an internal construct upto 3 sequences

Name	Type	Value	Explanation
Ta	Total Time	Shorter time	Confident but lacking mediation or In a hurry
Tb	Total Time	Longer time	Strong mediation but not necessarily confident (could be indecisive)
Aa	Addition	lots, in a short time	Strong confidence, Instinct and implies using personal domains of knowledge
Ab	Addition	Few, in a short time	Not confident at task, relies on mediation
Ac	Addition	Lots, in a long time	Strong confidence, attention to detail (methodological approach)
Ad	Addition	Few, in a long time	Not confident at task, doesn't rely on mediation.
Ma	Modifications	Few, in a short time	strong confidence, weak mediation (possibly pre-final refinement)
Mb	Modifications	Lots, in a short time	Mediation and refinement stages, either indecisive or debating, strong agreement
Da	Deletions	Few	Confident in output
Db	Deletions	Lots	Either non-confident, or understanding/ expertise is being corrected under mediation
AM	Additions and Modifier Pair	Lots	Atomic expertise – strong sense of refinement /perfectionist
MD	Modifiers and Deletion Pair	Lots	Suggests mediation and resolution towards positive refinement stage
AD	Additions and Deletion Pair	Lots	Either non-confident, or understanding/ expertise is being corrected under mediation
MA	Modifier and Addition Pair	Lots	Constructive refinement
DM	Deletion and Modifier Pair	Lots	Destructive refinement
DA	Deletion and Addition Pair	Lots	Replacement of expertise – strong sense of corrected knowledge
AMA	Add, Modify, Add triplet	Lots	Constructive review and continuation of expert behaviour
ADA	Add, Delete, Add triplet	Lots	Deconstructive review, but still continuation of expert behaviour
ADM	Add, Delete,	Lots	Deconstructive and uncertainty in

	Modify triplet		existing knowledge
AMD	Add, Modify, Delete triplet	Lots	Refinement with negative assessment
MAD	Modify, Add, Delete triplet	Lots	Refinement with negative assessment
MDM	Modify, Delete, Modify triplet	Lots	Uncertainty in refinement
MDA	Modify, Delete, Add triplet	Lots	Positive refinement after uncertainty
MAM	Modify, Add, Modify triplet	Lots	"Picky" behaviour
DAM	Delete, Add, Modify triplet	Lots	Positive refinement with "picky" behaviour
DMA	Delete, Modify, Add triplet	Lots	Regaining confidence in expertise
DMD	Delete, Modify, Delete triplet	Lots	Uncertainty in expertise
DAD	Delete, Add, Delete triplet	Lots	Uncertainty in expertise

5.3.4 Application to HCI Techniques

By examining the way current HCI knowledge elicitation methodologies (see chapter 3) are applied to create tangible knowledge artefacts (e.g. prototyping requires dynamic manipulation and evolution of artefact creation whereas linear card sorting (Mohamedally, et al, 2003) is an individual based single state creation) I formulated three distinct levels of interactivity constructionism.

The first level, Inert Constructionism in HCI infers no interactivity between users and limited interaction in their task (Chapter 6: Linear Card Sorting), with knowledge starting from initially set (known) domains. This was introduced purely as a non-temporal starting point in describing the learned experiences of the individual without outside influences (hence the terming Inert). The second level, Semi-Dynamic Constructionism in HCI infers interactivity between users, but again limited interactions with their task (Chapter 7: Affinity Diagramming). Finally the third level, Dynamic Constructionism infers interactivity between users, and with their task, including its destruction as well as creation (Chapter 8: Paper Prototyping). Semi-Dynamic and Dynamic Construction both infer significance of temporal information in the construction of new knowledge.

Several Knowledge Elicitation techniques in HCI can be seen to elicit user-centred data through the use of tangible artefact based iterations. They reinforce and create new knowledge that represents requirements and designs through the use of tangible artefacts. The use of constructing artefacts outside of ones head is also relative to metaphors of spaciousness and freedom. The tangible nature of using pen and touch based mobile devices and handheld metaphors provides the scope for applying Constructionism to mobile tools for HCI.

The selection of the following three techniques is based on personal interest and the availability of pedagogical scenarios with classes to experiment with in the teaching of HCI content. Using HCI classes is described as adequately expert empirical participants, with enough randomness in quality of expertise and an approximate level of education those in industry with the experiences of HCI practitioners. especially regarding their potential for mimicking their tangible nature of dealing with paper-based artefacts, in mobile software.

Linear card sorting, as described in more detail in chapter 6, regards artefact constructs (as in card groupings) only upon Addition (A) activity and thus the knowledge gained is inert. Using closed card sorting, an initial domain of knowledge is given rather than interpreting a starting point of knowledge. The constructs of the card groupings come from individuals and are compared with cluster analysis to gain a publicly cumulative view of the construct idea. Since this technique is constrained in user actions and has a single cycle of iterations for knowledge construction, it is selected as an experimental model for Inert Constructionism. An alternate KE technique that could have been described as inert would have been the FreeListing methodology, but this is not as tangible in nature as manipulating cards.

Affinity Diagramming (chapter 7) can be both textual and graphical but its quality and expertise representation is affected by collaboration of knowledge with several participants. It allows Additions (A) and modifications (M) to take place. Deletions are however not typically allowed unless there is a duplication of card data (e.g. from common terminology). Constructionist metrics will be able to elicit the temporal review of all possible decisions made by the team of participants throughout the duration of the affinity diagram's construction. It is henceforth selected as an experimental model for Semi-Dynamic Constructionism. An alternative KE technique for semi-dynamic constructionism could have been hierarchical task analysis (HTA) (Shneiderman, 1998). This would enable the temporal decisions leading upto the refinement of creating the branches of tasks to be seen but is non-tangible by nature, and can be facilitated without the use of groups.

Prototyping (chapter 8) is a richly visual view of constructed artefacts. In the HCI context, prototyping is usually done in teams of several participants to allow consensus of input and refinement. It allows Additions (A), Modifications (M) and Deletions (D). Prototyping is strongly temporal to analyse with the potential application of this constructionist framework to elicit all design changes on the history of the prototype design. Low fidelity prototyping as a software model can simulate gesture and iconic representations of paper and ink, leading to less need for computer-based metaphors (deep menus and option boxes etc) and more time and ability to focus on the idea creativity. The model of constructionism used in this technique is richly symbolic and infers a wide variety of potential changes, thus it is selected as an experimental model of Dynamic Constructionism. An alternative KE technique for dynamic constructionism could be storyboarding (Synder, 2003), which can take prototype views and manipulate them tangibly on screens to represent the flow of actions. Table 5.2 shows the dimensions of these three knowledge elicitation techniques which this thesis will carry further.

Table 5.2 Three key techniques with variations of Constructionist Metrics; Inert, Semi-Dynamic and Dyamic.

Linear Card Sorting	Inert Knowledge	Individual Based	Static Data Analysis	Textual Representation
Affinity Diagramming	Semi-Dynamic Knowledge	Group Based	Temporal Data Analysis	Textual in Visual Representation
Low-Fidelity Paper Prototyping	Dynamic Knowledge	Group Based	Temporal Data Analysis	Graphical Representation

5.3.5 Advantages and Disadvantages of Constructionism in the domain of Mobile HCI KE

Applying the context of constructionism to HCI Knowledge Elicitation is one step to defining new models of understanding in the HCI community. Innovating on this however is the synthesis of these models with creating new mobile HCI Knowledge Elicitation techniques based on the metaphors that these HCI techniques provide.

The significance of mobility in this respect is as follows; Existing paper based KE methods are obviously quick, cheap and practical. Low fidelity ideas are captured efficiently and deployment of the methods are readily available.

However, office materials and space need to be available. User knowledge outputs are not effectively recorded on paper in a consistent and shareable form, and intermediate decisions made are not recorded on paper (e.g. how they arrived at their final knowledge representations). Whilst desktop and internet based solutions will gain potential user bases and acquire precision in results beyond paper methods, there is still the key issue of on-site stakeholder knowledge elicitation.

An additional advantage of software mobile KE is the ease of applying pedagogical epistemologies to it. Examining deeper on an epistemological level to facilitate an improvement of HCI methodology, chapter 4 began by investigating the pedagogical background of how humans learn, represent and recall their knowledge. Using the existing models derived over the last century, it has come to be appreciated that key psychologists in the field (see chapter 4) have defined set theories that also apply to the HCI field of study. These theories have centred on the experiences, intuitions and knowledge of users.

As reported in chapter 4, Kelly's Personal Construct Theory (1955) places emphasis on learning with experience. This agrees with Papert's (1991) model of constructionism over time, as we build up our experiences through tangible interactions with others in forming ideas. The tangible property of thinking "outside of ones head" by use of materials to reinforce knowledge is covered well by Papert (1991) and Resnick (1996). Under the concepts provided by Situated Cognition theory (Choi & Hannafin, 1995) also reported in chapter 4, eliciting knowledge in a particular environment of context has significance to the importance of the knowledge from the subjects being examined. This metaphor of spaciousness and freedom to interact with tangible knowledge artefacts in Constructionism gives this thesis a grounded confidence in applying it in context to mobility in HCI methods.

Beyond this epistemological view, some of the other significant advantages to mobile software constructionist methods are:

1. Portable and mobile, facilitating on-site stakeholder knowledge elicitation is key. On-site knowledge elicitation affects the quality of user knowledge and also allows researchers to align user data with a vivid mental model of how users work with existing systems and how new systems can support them (Mander and Smith, 2002).
2. Not requiring large equipment, e.g. boards, and can share output data views with others remotely via the wireless internet.
3. User environments, e.g. the drawing boards can be resized near unlimited to give large "virtual" space even though field of view is not as large as whiteboard.
4. Virtually unlimited stationery resources e.g. cards, ink; it will all be virtual.
5. All decisions are tracked and can be rolled back anytime, e.g. to compare what people think at different temporal instances.
6. The software models will be able to automate analysis of constructionist data e.g. in exploring the framework of constructionist metrics; the paper evaluation methods are cumbersome and time consuming to collate and analyse.
7. Non-editable outputs can be shown to anyone conveniently and shared across the internet e.g. as jpg/gif images.
8. Metaphors for the tangibility of the existing paper methodology needs to be useful enough to be usable and wanted.

Some of the noted disadvantages to mobile software constructionist methods are:

1. Obviously expensive to deploy to large communities of users without the respective mobile technologies, the use of constructionist metrics provides a trade-off for that expense in terms of time to process large quantities of data, which over time is worth man-hours.
2. When doing team based knowledge elicitation, several user participants will require access to one device, unless more are available. However this is also true

of practical application of traditional paper based methods, e.g. that a single paper pad is shared by a team to create a paper prototype.

3. Even with metaphors for existing practises and modelling the flow of actions in executing a knowledge elicitation exercise, there will intuitively be a small learning curve, but still a learning curve over paper and pens.

5.4 Chapter Summary

Through studying the theoretical model of constructionism and how it relates to the construction of visible artefacts of knowledge by user, a Framework of Constructionism for HCI has been designed to improve the methodologies of electronic measurement of constructing knowledge in user-centred HCI Knowledge Elicitation. Temporal and spatial variables which affect the measuring of user-centred constructs have been discussed.

The Framework of Constructionism for HCI KE has been outlined for exploration using three designed layers of constructionism, Inert, Semi-dynamic and Dynamic. Potential explanations to aid the creation of new metrics in constructionism have been suggested as a pre-cursor for extending the domain of this research to other fields. The research direction taken into context with constructionism is to now factor towards innovating in the field of Mobile HCI methods, as explored prior in chapters 2 and 3. Chapters 6, 7 and 8 will incorporate the methods grounded in this chapter to explore constructionist metrics in mobile HCI conditions, through the design and development of new tools based on the framework described in this chapter.

Chapter 6: Inert Constructionism with Mobile Linear Card Sorting

6.1 Introduction

This chapter introduces the model of inert constructionism in HCI KE, by investigating its application in HCI based card sorting. In the previous chapter Inert Constructionist was described as Constructionism whereby user actions are minimal and without any external collaborative involvement. A study of the card sorting technique was conducted, and a new variant of card sorting was devised based on the principles described by Inert Constructionism. This variant is termed Linear Card Sorting, as opposed to Non-Linear card sorting which refers to the existing shuffling practice of current-day card sorting.

Following this study, a web-based card sorting tool was developed to expose the potential benefits of Inert Constructionism in a HCI context. Subsequently, after trialing the new methodology, the web based prototype tool was transformed into a mobile (PDA based) card sorting tool through Participatory Design (PD). This tool demonstrates a user tested and on-site mobile experience of card sorting.

The tool was further developed through PD sessions and the end resulting mobile solution was deployed in a series of experiments to validate the use of inert constructionism in a HCI KE technique, as described in Chapter 5.

6.2 The Card Sorting Method

Card sorting is an individual based knowledge elicitation technique for grouping information into categorical domains (Nielson, 1994). It is useful to HCI specialists as a technique for creating and analysing categorisations of domains of knowledge and it is considered one of the best usability methods for investigating a user's mental model of an information space (Martin, 1999).

Traditionally, card sorting is done by physically having several cards of information placed into groups by a participant. These groups are then given a category name based on the participant's perceptions (Kurniawan & Zaphiris, 2003). It has been demonstrated by Rosch and Mervis (1975) that objects in a dissimilar category are the most representative of their category.

It is expected that the characteristics of participants chosen to take part in card sorting experiments may influence the output quality of the categorisations. For example expert categorisations of problem domains are often favoured over novice categorisations (Maiden et al., 1995).

In a regular non-linear categorisation experiment the participants may read any of the cards at any time, before or after being sorted into groupings. They are often encouraged to participate in small groups synchronously and communicate their knowledge with each other to explain their card groupings. The mental modeling of the card sorting process is attributed to the topics of mental work presentation and conceptual categories, as described in the field of cognitive psychology (Eysenck, 2001). This is in general beyond the scope of this thesis.

More importantly they can de-allocate cards from one category group and move them dynamically to others to match changing opinions. This is functionally appropriate for quality categorisation in expert domains of knowledge (Maiden et al. 1998) whereby there are long cycles of mediation and refinement in arguing the higher level case for precise cluster groupings.

Lassaline & Murphy (1998) reported that the importance of increasing similarity between cards within a category makes learning easier; conversely, as similarity between cards from different categories increase, learning becomes more difficult.

As mentioned in section 3.5.3 there are several existing electronic card sorting tools that implement the current-day non-linear model. Naturally their benefits are in the number of users that they can elicit categories from, and the analysis of large sets of data.

However this non-linear rationale can lead to a tendency for participants to bias their sorting by spending more time comparing certain cards rather than others for a number of reasons e.g. number of cards, popularity and level of awareness of the categories, group communication, complexity of mentally associating similar cards, sometimes even position and verboseness of the cards' categories. Also having the participants collaborate in grouping the cards runs the risk of reaching a consensus that is not an accurate reflection of any one individual's perceptions.

With constraints of mobile devices e.g. PDAs having limited visibility and issues of navigation and interaction accessibility (Weiss, 2002), the argument is given that non-linear card sorting is not a pragmatic method to simulate the categorisation process reliably on a PDA as the physical non-linear form requires space (e.g. a table or a blackboard) for visual analysis.

The adaptation of card sorting methodology in developing Linear Card Sorting as an HCI method is generalized in the context of this thesis as a simpler user model befitting card sorting of first impression knowledge, and with limited visualization requirements. It aims to demonstrate that inert constructionism can yield potentially useful first impression knowledge elicitation results for HCI, without requiring further mediation/refinement stages as per non-linear card sorting.

6.3 Introducing... Linear Card Sorting

Although traditional card sorting is primarily associated with the prior mentioned standard non-linear categorisations of items, in certain cases categorisations without comparison biases are necessary, for example, Preece et al (1994) explored the use of suggestion and priming participants beforehand with domains of information to limit their responses in HCI data collection. This technique stems back historically in pedagogical psychology to the ideas of Pavlov's conditioned responses (1927). This is especially important in factoring categories of new and relatively inexperienced domains of knowledge. As Dix described (Dix, BHCI conference 2003) priming and tacit knowledge is an enforcement procedure in knowledge elicitation. From this discussion it was apparent that this is an area for further research exploration in card sorting methodology.

Linear card sorting is thus defined in a HCI context when it is considered important to elicit the participants' first evaluation of each card they come across. Using the model of inert constructionism to model this, this implies knowledge that is constrained by minimal amount of physical actions e.g. shuffling and deleting, and without the ability to refer to others for consensus.

The suggested protocol for conducting a linear card sort is as follows;

1. Categories are aggregated and formed without comparison of subsequent cards.
2. However they can view their prior cards in categories (categorisation history) to remind them of what they have placed where, so that a history is constructed.

3. Once a card is sorted into a category, whether into a new category or an existing one, the category can be renamed but it cannot be moved or deleted.
4. Similarly the cards themselves cannot be moved or deleted once viewed, minimizing the number of steps to complete a categorisation experiment, in line with inert constructionism.
5. Progression through the different cards is done in a purely linear fashion and should not involve other participants.

These rules of activity place constraints on the existing technique but enables inert constructionism to be facilitated in a measurable form.

This form of non-tacit behaviour (Polanyi 1958) maintains the accuracy of response given with minimal bias and presents an enhanced conditioning for the card sorting technique. Tacit knowledge is an important factor in experimental methods, which is sometimes not taken into account in group experiments. It functions as background knowledge in assisting a focused task. Humans have their own unique history of patterns of categories, theories, methods, feelings, values and skills become our conceptual judges. This is an informal act of the mind and can not be replaced by a formal operation, thus integration of ontological forms of knowledge is a personal skill in itself and can not be rendered unusable.

The significance of defining linear card sorting is to specifically orientate a variation of card sorting that is suited towards non-expert categorisation and first hand exposure knowledge, which has not been reported in HCI before. Users in a field of knowledge that they aren't entirely familiar with are presented with the discovery of new information (Bruner, 1960), e.g. a student listening to a lecture being given for their first time, Gagne's (1974) 7th rule in his learning hierarchy (table 3.1) dictates that a learner will apply existing rules based on chaining of prior knowledge regardless of whether the information presented is new.

Ausubel's (1968) reception learning also suggests that each piece of new information becomes either associated with an existing piece of knowledge (subsumer) or becomes a new piece of knowledge waiting to be increased in complexity. A linear methodology to card sorting would demonstrate Spearman's G factors (1904) as denoted in chapter 4, as opposed to his S factors which would be more applicable to non-linear categorisation.

In fact linear information processing is not a new practice in pedagogical experimental psychology and psychoanalysis; the controversial Rorschach inkblot test (Rorscharch, 1921) and its derivatives elicits the verbal responses of categorising sequential objective entities as cognitive images until a new response is exhibited in the participant revealing a contrasting cognitive image. Thus in line with the expansion of HCI methodologies from exploratory experimental psychology, linear card sorting has a position within HCI that has a future to be explored in further context of applications.

Facilitating linearity and sequential responsiveness to categorisation also ensures closure of existing information with a defined end-point, in this case based on first impressions. Experience and knowledgeable intuition are utilised allowing new information to be streamed under non-finite circumstances to become categorised, e.g. incoming books to a library classification system.

There exists instances whereby humans categorise elements only once at first instance without non-linear/random shuffling comparisons. For example as a student's revision method, the scenario might be that having read an article, a student learner would ideally file a term paper into a category (say in a folder slot), and proceed to work through each article they have been given during classes, either filing in existing folders or creating new folders. Analogously as a user browses pages, they find an interested page and then either place it in an existing category in their browser bookmarks, or create a new category.

The sequence in which cards are presented in both non-linear and linear methodologies naturally presents what one view might define as a deficiency, by biasing the influence of the sequence in which the card contents were arranged. However another view might define it as a controlled aim, enabling groups to be consistently measured, and by creating constraints on the amount of variations possible before all information is elicited into categories. This is relative to Pavlov's (1927) conditioned responses, and priming the participant by orientating the needs to gain a suggestive solution. This could be especially true if the elicitation process aims to compare with an already set solution to the category hierarchy.

Our first reported knowledge elicitation study demonstrates our theory of linear card sorting in a real world revision scenario with a paper-based comparison of linear vs. non-linear variables in a controlled experiment. This was done to verify that individuals can facilitate inert constructionism on a genuinely useful derivative of the existing card sorting technique.

6.4 Comparing Linear Vs Non-Linear Card Sorting

A controlled experiment with 24 participants was run to demonstrate whether linear card sorting was a practical approach to knowledge elicitation in HCI. In order to keep the knowledge domain under a controlled scenario, a class of students from an undergraduate Computer Graphics class took part in card sorting 30 key computer graphics phrases based on material in advance of their current teaching notes. This was done to ensure that every member was considered a non-expert in their field yet their interest was already strong enough to maintain their maximum throughput in the sorting exercise – e.g. they would learn from it and find it useful for their course revision. A questionnaire was taken to determine their suitability for the experiment based on their existing subject knowledge – if they could answer some highly technical questions they were not chosen to participate, and also with a heavier ratio of male to female in the class, more male participants had to be excluded to keep the experiment as balanced as possible. The remaining group of twelve students was split equally into two groups of six, with four male and two female in each group.

The first group was asked to card sort the phrases non-linearly under a controlled time limit of 25 minutes. Collaboration among the participants in each group was allowed. The second group was asked to card sort linearly and individually as fast a time wished but without communicating with other members of the group until they had already grouped all of their phrases, which were by then unchangeable. Both groups had instruction sheets on how to begin and the rules of their particular sorting.

After the experiment, a post-questionnaire was given to the participants. The linear experiment was completed in 17 minutes, as there were fewer actions to perform whilst the non-linear experiment was still being debated and cards moving from groupings up until the deadline of 25 minutes.

The second study reported is an end user cycle of deploying our linear card sorting method electronically via a web based interface as published in prior work (Mohamedally et al., 2003b), with the objective of attaining results in a test scenario from potentially geographically dispersed users.

6.5 Other Variations of the Card Sorting Paradigm

The competence and accuracy of results of inert constructionism within linear card sorting, relies on the domain of knowledge resulting from the participants' exposure and experience. Thus, there is a realisation that it is perfectly viable to attain multiple correct and pseudo correct categorical formations from the scope of a card sort unless a higher controlled measure of a definitive hierarchy solution exists. In general all cards have to be sorted into a category before a card sort is considered complete. To compare the benefits of the inert constructionist model in the form of a mobile linear card sorting tool, the following variables were measured for experimental comparison;

Expert Categorisation – Utilisation of participants who are considered to be field specialists in the particular domain of knowledge. The benefits of this are in their knowledge of accuracy of categorical hierarchy and modelling interpretation.

Non-Expert Categorisation – Using participants of a random nature, of mixed knowledge domains of intuition, trends and preference, eliciting first impression based sets of categorical hierarchies. Their mental model is the subset product of intuitive learning by instinct and their given knowledge for comparison of cards. Personal history and symbolic associations of the cards information may also factor in inducing correlative results.

Non-Linear Categorisation – Practical experimental approach in traditional card sorting and affinity diagramming, supporting the ability for participants to shuffle the cards, mediate between choices and make refinements as well as remove prior actions, and thus change their minds as they think about the results that they propose. They are allowed to manipulate the cards until their grouping is completed.

Linear Categorisation – a constraint is added to the categorisation process in that once the cards are shuffled, they cannot be reshuffled, and as you encounter each card, it has to be placed into a category before you can move on. The sorted cards are then held in the categories created and may not be manipulated into another group – however the naming of the group may be changed to reflect the addition of new card entities. This ensure that only first impressions are measured, from a particular shuffled direction of reading the cards, and that upon complete viewing of all cards on the first time they each will belong to a category group. This thereby minimises the number of steps taken to complete the categorisation.

Group-Based Categorisation – Traditionally the key function of affinity diagramming is accomplished with a group of participants working together. They are allowed to communicate their ideas, but they work synchronously until they have all finished mediation and refining the process of categorisation. Whilst this should enable a higher form of accuracy based on shared reasoning and debate, it introduces strength of opinion and bias of participants. This human effect of bias includes over-communication, timid behaviour, and agitation leading to lack of team ability.

Individual Based Categorisation – Traditionally the key function of card sorting is accomplished on an individual basis, without intervention or communications from other participants. The accuracy of categorical hierarchies is therefore the inert product of the participant solely.

Paper/Physically Tactile Based Categorisation – involves using pieces of paper, cards with the information descriptions written or drawn on them to be categorised. In addition to these, actual physical objects can also be grouped together.

Electronic and Simulation Based Categorisation – With intervention of digital aids results and decisions can be interpreted in card sorting and affinity diagramming exercises via electronic software methods. This is important when constructing scenarios for large audience sorting, and geographically dispersed sorting. Also considering that card sorting and affinity diagramming can be of a non-finite or extremely large number of cards, it becomes more appropriate to hold the categories digitally for statistical analysis purposes.

6.6 Case Study A - Linear Card Sorting via the Web

The original motivation of this system came from a taxonomy review of the current state of the art in mobile HCI research to find a research deficiency in chapter 2. The requirements derived from the taxonomy experiment suggested that the tool should present the capability to allow for large numbers of participants to take part in card sorting sessions, and also investigate the use of first experience knowledge domains in card sorting. Card sorting is usually undertaken by relatively small groups of participants. The larger the number of participants, the more refined the categories will become (Martin, 1999). As reported prior several existing card sorting tools are available for web browsers (section 3.5.3), facilitating knowledge elicitation. A web-based linear card sorting tool was constructed to test the methodology before constructing a mobile implementation. This would allow participants to log into a website URL, facilitate the card sorting via a web page applet and then send the results back for analysis.

To facilitate inert constructionism with linear card sorting as a software method, a Java web-page applet was constructed to deploy to users. The specification required us to construct a simple to use tool that would allow HCI specialists and others to aggregate group constructs from large numbers of participants via the internet without them having to be physically present or monitored. A key requirement of this tool when compared with other existing card-sorting tools (section 3.5.3) was that the data received should be sent in a format ready for cluster analysis in a 3rd party statistical tool.

Cluster analysis is a powerful technique for processing the strategic groupings of information from a number of sources (e.g. participants' data). It does this by calculation of perceptual strengths between pairs of cards. As defined by Clustan (2003) its object is to

> "...sort cases (people, things, events, etc) into groups, or clusters, so that the degree of association is strong between members of the same cluster and weak between members of different clusters."
>
> (Clustan, 2003)

Each cluster thus describes, in terms of the data collected, the class to which its members belong; and this description may be abstracted through use from the particular to the general class. It may reveal associations and structure in data, which though not previously evident nevertheless are sensible and useful once found. The results of cluster analysis contribute to the definition of a formal classification scheme, such as a taxonomy finding, and statistical modeling of data sets.

Many statistical packages such as SPSS™ and Statistica™ will convert category datasets into matrices of similarity or distance scores. However this is not an automated process, and in most cases it would require extreme hours of manual input labour to gather large amounts of participant data. A popular automated cluster analysis tool is available in the form of IBM's EZCalc.

IBMs' EZCalc cluster analysis tool involves constructing a matrix that computes either distance scores or similarity scores. If done otherwise by hand, this would take several hours per participant. The result of the scores matrix is a tree diagram that displays the relative groupings (clusterings) of concepts.

It is noted that EZCalc comes complete with its own card sorting implementation as a standalone tool named USort (together they are named EZSort). However like some other card sorting tools, it is not a web based system and therefore requires full user installation with administrator privileges to attain its user data, which many potential participants may not find appealing.

6.7 Implementing a Linear Card Sorting Web-based Tool

The web-based linear card sorting tool was developed in Java 1.1 thereby becoming multiplatform. The cards data themselves needed a format that would be easily maintainable by all foreseeable administrators of the experiment for any scenario they wish. As such, the cards were chosen to be held in a simple text formatted file.

An SMTP transfer mechanism (RFC 821, 1982) was incorporated directly into the applet allowing it to email the users data itself as a micro email client rather than rely on third party email scripts or plugins. This allowed administrators of our card sorting tool to specify direct mail servers for processing incoming test data as well as minimise the maintenance requirements of reconfiguring the tool for other card sorting tests.

Performance and user operations were also of a high priority to use. It was important to construct a robust architecture that could facilitate potentially large card sets (the linear model devised should be able to handle non-finite amounts of data) but still be used responsively fast with a relatively quick learning curve. Thus;

- String optimisations were included throughout the system to increase the performance of GUI text display responsiveness.
- The card sorting algorithms were designed to utilise data vectors as linked lists for processing dynamic allocations of objects in memory and enabling the processing of potentially memory-finite amounts of cards to be sorted rather than any fixed amount of cards.
- The user interface of the main card viewing screen was designed with HCI principles in mind. For example minimising distance between user information and user actions, confirmation and error recognition and colour coding important

actions so as to be as comfortable as possible for as many possible demographics of participant users.

Fig 6.1 shows the main card viewing screen of our tool in action.

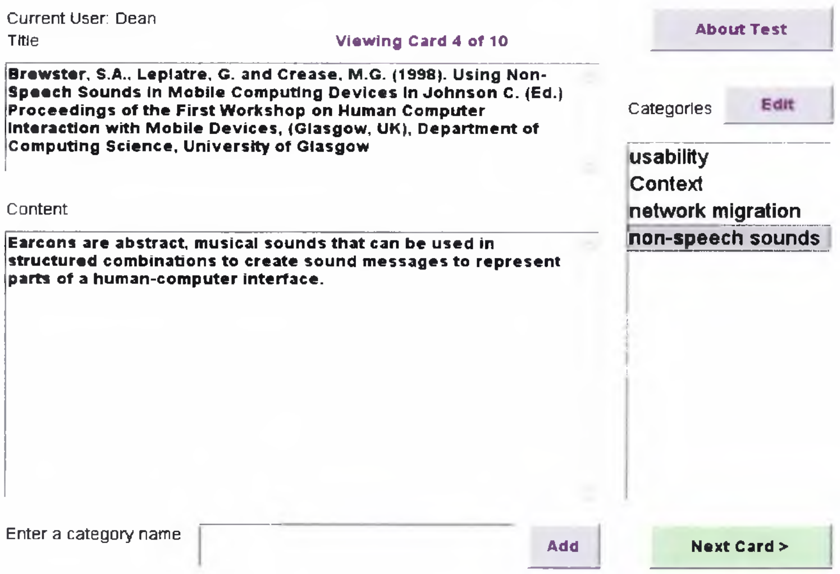


Figure 6.1: Linear Card Sorting web based interface screenshot

6.8 Piloting the Web based Linear Card Sorting Tool

To prepare the web tool for deployment, a pilot expert user test with six HCI specialists in the Centre for HCI Design and one external School of Engineering (City University London) engineering specialist was conducted. In this pilot expert experiment participants were asked to use the web based linear card sorting tool in order to categorize mobile HCI literature (see section 2.2). First a pre-test questionnaire (appendix C.1) was presented to the participants followed by an informal interview to:

- Evaluate their prior knowledge of the card sorting technique
- Present them with our linear card sorting technique
- Engage them in initial thoughts on categorisation of the field under test

Subsequently they were given a printed short description which referred to the same material as found in the web tool's online help documentation to verify whether they did require assistance beyond that which the tool could provide.

After answering any clarification questions they raised, they were asked to use the tool to perform the card sorting task. Throughout the experiment they could raise any points of interest or complaints. Finally two post-test questionnaires were given; firstly to collect information about their general impressions of tools for HCI knowledge elicitation (appendix C.2), the second for insights on the pilot test e.g. their ease of use and understanding of the method, and if there were any modifications to be made (appendix D.1.2).

The pilot study was effective at pointing out GUI arrangement issues, which were consistent to all of the HCI expert participants. Other than that, most of the participants completed the test faster than expected. In an expert test prior with a HCI lecturer as the participant, an average of 12-15 minutes was estimated for the time to completion. In addition the participants in the pilot study completed it within a range from 6-13 minutes. Aside from their comments and commendations on its design and simplicity of use, some of them were expecting the non-linear card sorting paradigm that they were familiar with, and not this particular technique of card sorting. They were able to card sort effectively based on their first-experience decisions. The expert suggestions to correct and enhance the features of the first iteration were undertaken, such as GUI navigation issues and uses of colour.

6.9 Iteration 2 of the Linear Card Sorting Web-based Tool

A second experiment was conducted, to deploy our web based tool to 20 computer literate undergraduate students (11 male, 9 female) from a variety of universities. The purpose of this test was to verify the tool's capability to function in a geographically dispersed environment and yet still be capable of eliciting a suitable size of card sort data. The goal was not to fully evaluate the usability of this tool, as such a test was outside the scope of this research. The scenario for the card sort was again the taxonomy of mobile HCI papers.

After taking a pre-questionnaire (appendix D.1.1), the students were verified as running Java enabled browsers on a variety of computers such as Apple Mac, Windows and Linux based. All of the participants chosen had over 5 years experience with using the internet as well as owning a mobile phone with WAP access, a PDA or a laptop. Their age ranged from 18 to 24.

None of them were already aware of the card sorting method, although eleven of the 20 participants had already participated in some form of experiments before. After ascertaining their backgrounds and field interests in mobile technologies, their first hand exposure of computing and knowledge of popular mobile technology was utilised to categorise the academic papers from the Mobile HCI community (ACM Mobile HCI 1998-2003).

Upon receiving acknowledgement to participate in the experiment, each user was directed to a website which would enable them to start an experiment session. Once logged in, a selection of abstracts and their titles from the academic papers were viewable linearly as cards. An example of such a card is shown in Figure 6.2.

Title: Johnson, P. (1998). Usability and mobility; interactions on the move. Dept. of Computer Science, QMW.

Abstract:

The developments in wireless communication, distributed systems, and increases in the power and interactive capabilities of hand-held and portable devices, provide us with the possibility to have wideranging and continual access to computing resources in a variety of contexts. These technological changes make increasing demands on the quality of the user interface and offer the potential to further progress the functionality of computing devices. However, this makes human-computer interaction all the more central to the design and development of such mobile systems. The case remains that functionality does not exist for the user if that functionality is not usable.

Figure 6.2: An example of a card used in this study

As the users navigated each card they were allowed one of three options before continuing; to add a new categorical name and place the card in that name, to edit a categorical name or to view the history of previous cards in a category. Upon completion of their experiment, they would click a finish button to transmit the results and receive an acknowledgement of its success. Subsequently, a post-questionnaire (appendix D.1.2) was given as a website URL for them to complete so that valid feedback could be acquired on the effectiveness of their role in the experiment.

By ensuring the domains of the categories were for each experiment at the same one of four semantic levels (design, implementation, evaluation and theoretical) the range of eliciting the participants knowledge was evenly semantically spread across the cards (Rugg et al., 1992).

Table 6.1 gives an overview of the results from a simple post questionnaire created to elicit general ease of use, in terms of the interface issues of using the card-sorting tool (1 to 5, with 5 being strongly agree and 1 strongly disagree).

Table 6.1: Post questionnaire results on the 20 users, mean based on the 1-5 Likert Scale with Standard Deviation in parenthesis

Question	Mean (S.D.)
Did you find the tool easy to understand what you were meant to do?	3.6 (0.68)
Did you find it easy to navigate the interface and use its facilities?	3.85 (0.37)
Did you accomplish the task set comfortably?	3.8 (0.41)

In the post questionnaire (appendix D.1.2), all of the participants denoted that they had no need to refer to the help file; the process was simple enough for them all to use. Seventeen of the twenty participants consider card sorting useful for their field of work and nineteen out of twenty reported having learned something new about mobile technology in doing linear card sorting.

Figures 6.3 – 6.6 shows the cluster analysis of the taxonomy groupings for the 20 participants. Appendix A.2 shows the taxonomy created by methodology categorisation.

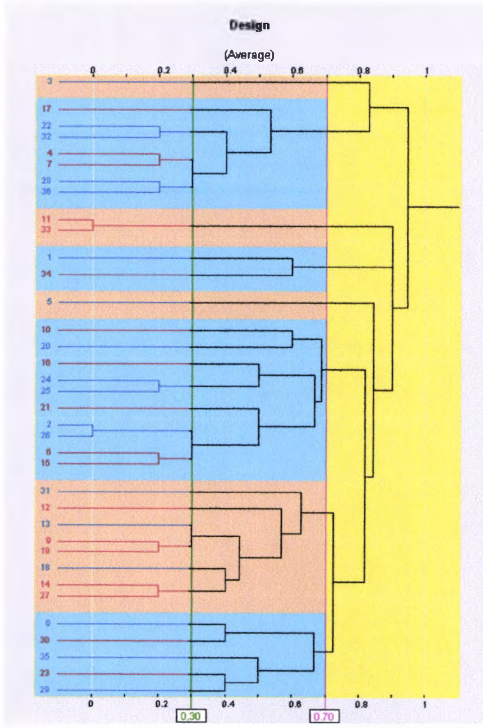


Figure 6.3: Design cluster

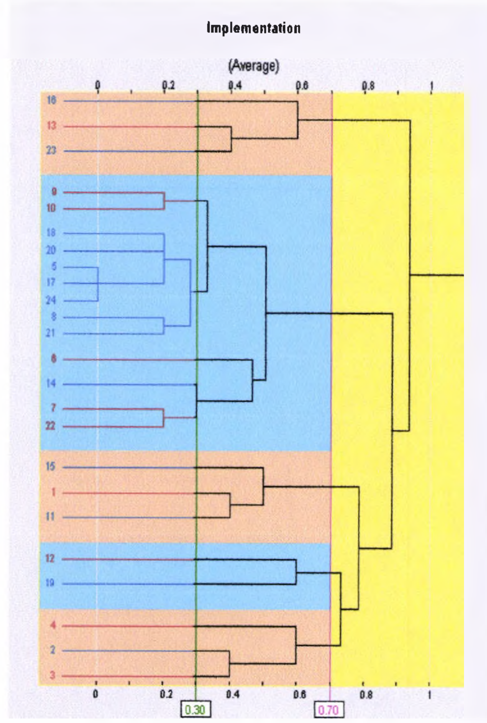


Figure 6.4: Implementation cluster

In combining the cluster names together, several problems were noted. "Mobility", "mobile applications" and "pdas" were all vague descriptions used to classify a range of topics that would normally be compared and reduced to a common term by expert opinion.

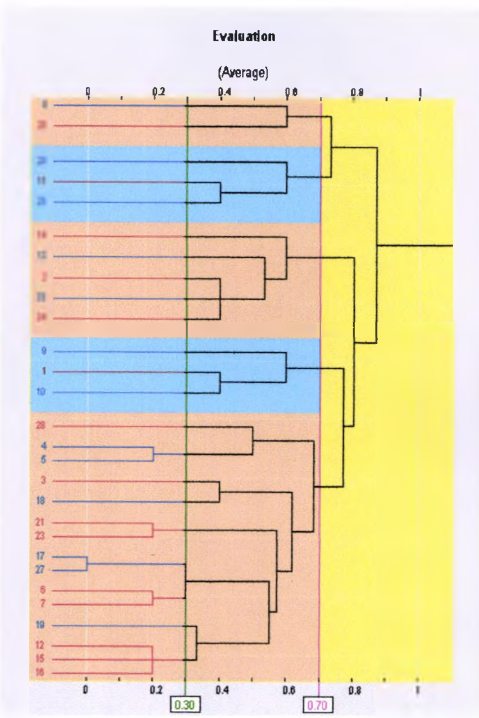


Figure 6.5: Evaluation cluster

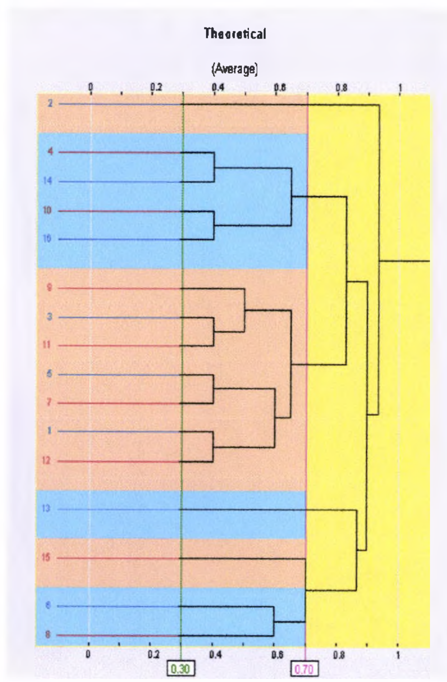


Figure 6.6: Theoretical cluster

The data elicited from the participants their awareness of PDAs and mobile technologies, even if they are not familiar with technical terminology. On several occasions it was observed that the participants reused some of the terms (such as "Contexts of use" and "location awareness") used in the abstract itself to define the category header, potentially due to the topic being out of their scope of understanding.

This linear card sort was successfully undertaken by geographically distant participants. It also demonstrated that the web based technology built does facilitate inert constructionism without the necessity of having administration/researchers present. Each of these clusters represents a statistical cumulation of individual constructs which remained inert i.e. they represented the individuals' knowledge over the course of the card sort process.

This attribute denotes a strong sense of constructive purpose, as the participant can acknowledge their task and facilitate the construction of the categories based on their first-hand experiences.

The results of their post-questionnaire demonstrated that none of the participants requested further instructions or needed to access the help documentation. This is important as the experiment may fail if the participants cannot grasp the idea of what the inert constructionist approach to the experiment is asking of them. Three of the 20 participants found the tool to have a strong learning curve and couldn't foresee a use for it, but the remainder found it comfortable. All of the participants managed to achieve completion of the test.

6.10 Participatory Design of CAKE – A Mobile Tool for Card-sorting in Asynchronous Knowledge Elicitation

Prior KE tools have arguably been hindered by the lack of a user centred design approach, in which complexity and presentation of options were arguably not optimally adjusted for non-supervised data collection. Participatory design sessions where conducted with HCI researchers from the Centre for HCI Design, City University London. They elicited changes to be made in the features of the web-browser version to the PDA screen format.

A focus group session with the HCI researchers constructed an affinity diagram that would show what features the experts felt were needed. The consensus of this affinity diagram is shown in figure 6.7.

Affinity Groupings for a Card Sorting tool

Basic Functions

- adding and deleting cards in text file
- loading the cards into an application
- structuring cards in the application

Categorisation

- categorise cards
- counting the cards
- move categories
- ability to reorganize cards within categories
- ability to reorganize cards across categories

Viewing

- view all cards simultaneously
- minimize/maximize/hide
- ability to see all categories
- textual description of all groups

Optional features

- note taking facilities
- searching
- printing
- textual indication of action (hints)

Figure 6.7 Affinity Branches in the User Centred Design of a Card Sorting Tool

Subsequently the focus group created several paper prototypes to achieve design ideas on the user interface layout of the tool (appendix D.1.3).

The motivation for designing the interface for the mobile KE software implementation takes into consideration Bruner's (1966) instructional basics:

1. Demonstrate the predisposition towards learning (to use the system),
2. Present the structure of knowledge so that the learner can readily grasp it,
3. Effectiveness of sequences of information presentation, and
4. The pacing of rewards and punishments (messaging and error handling).

Structuring knowledge acquisition processes aid learning by simplifying, constructing propositions, and increasing the manipulation of information. The implementation is designed to allow potentially large numbers of participants to be invited to take part in card sorting experiments asynchronously (in their own time).

In order to explore this motivation in a mobile constraint environment (Weiss, 2002), an investigation within the research domain of mobile HCI software found no prior dedicated mobile card sorting tools for HCI in commercial availability or academia. To my knowledge CAKE is the first mobile card sorting tool reported in HCI literature (Mohamedally et al., 2003b).

The design and configuration of systems that work well for users and actually support their work rather than hinder is almost an art. Good software design ideas are neither obvious nor are they effective when based on technological innovations alone. Thus factoring all of the existing requirements from the full screen web version into a PDA's display primarily required a back-to-basics look at constraint visual interaction on PDAs.

It was important to recognise that even though the model of card sorting theory had been simplified under the asynchronous linear model to accommodate non-expert levels of interactions, there was still a significant amount of user end actions that required decision making such as organizational layout of the software options and making the navigation functions as common sense as possible. Therefore, a standard paper based expert affinity exercise was conducted to isolate areas of concern that handheld usability factors (Weiss, 2002) take into consideration in terms of navigation and access to functionality (figure 6.8).

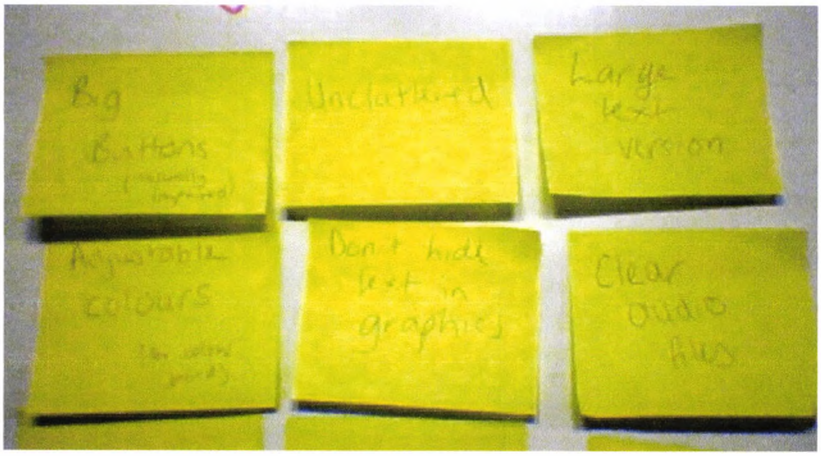


Figure 6.8. Expert affinity diagram exercise to elicit important design choices of CAKE

The results of this exercise allowed us to denote that readability of the cards and method of navigation were the most important end user variables to monitor in its design. A scalable font was chosen and buttons were made touchable in size. Second to that, as most PDA users already know how to transfer document files to and from their PDAs, enabling them to upload simple text documents as the cards file was considered an elegant solution to a world gone awry on a multitude of proprietary file formats. And with the presence of a user switched-on connected wireless network, CAKE can be configurable to upload its card sorted data to a webserver, else utilise a local memory card to save to for later portable analysis.

The user interface of the main card viewing screen was designed with constraint mobile HCI principles in mind (Weiss, 2000; Shneiderman, 1998). For example minimising distance between user information and user actions (figure 6.9), confirmation and error recognition as well as integrated available help enhancing the learning conditions as they discover for themselves how to use it without supervision, and colour coding important actions so as to be as comfortable as possible for as many possible demographics of participant users. Centralised viewing is of importance in terms of layout of GUI entities as user eye focus will be in the middle of the screen/orientated towards the centre of the hand (assuming the PDA is in the hand). Considering this centralised viewing concept, the Window-Per-Task design pattern was utilised (Grand, 2000) in development.

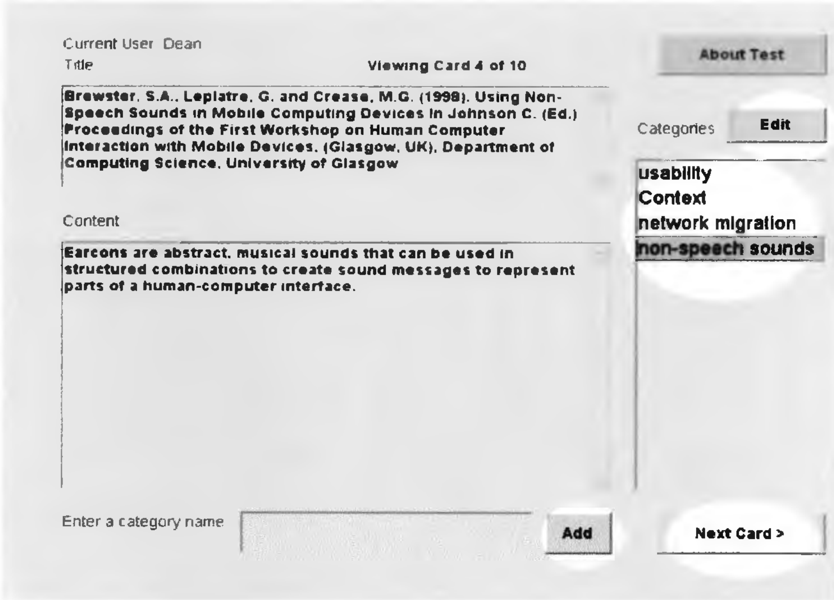


Figure 6.9: Highlighting key areas for the minimisation of user information and user actions in the web-browser version

A screenshot of the final mobile version is shown in figure 6.10. In addition the same software was debugged on a Java environment on WindowsXP (figure 6.11) and was also tested on a PocketPC emulator, shown in figure 6.12.

CAKE can be installed either via wireless network connection, by syncing the PDA, or by copying from a PC to a memory card in turn to the PDA. Once installed and chosen to run, a selector for a current card sort will be visible to choose a text document of cards. If a WiFi wireless network is already available CAKE can be opted to retrieve the card data online from a web address.

Alternatively a CAKE user can write their own cards file directly on the PDA by using their PDA text editor and choosing to save as a standard TXT document. The file format for a card file has only one rule, and that is each card is separated by an empty return.

Figure 6.10: CAKE on Zaurus SL-5500

Figure 6.11: PDA emulation on a Java desktop (WinXP)

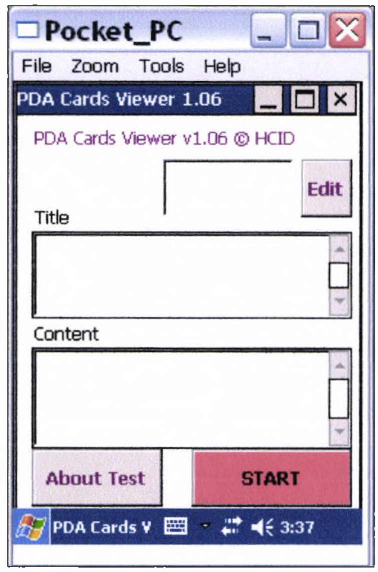


Figure 6.12: PocketPC emulation test of the initial screen interface

In order to use CAKE a user is presented with the first card from the card file they have selected/connected to. They may choose to view existing categories (in the case of the first there are none), or they can add a new category. Once a card is added to a category, they are taken to the next card to add to a category, and subsequently will go through all of the cards until they have finished.

Once they have completed the exercise they may choose to save the categories locally in a file onboard the PDA, or they can press transmit in a WIFI network to send it to an email address for use in EZCalc format for cluster analysis. Appendix D.2 has example output from CAKE in the EZCalc structured format.

An initial pilot evaluation of the wireless capabilities of CAKE was conducted with five participants at a Starbucks™ coffee shop via a T-Mobile Hotspot™ wireless (802.11b) roaming account (T-Mobile, 2004). In this session a short evaluation scenario of CAKE was used with the task of café brain storming through a list of software implementation activities related to their field of consulting work to see if it would help organize their software management. The evaluation was independent of any supervision. The results from this categorisation were uploaded to a webserver email script via the wireless zone in the café. The details of the cards were not made known to us as it was a public evaluation and the cards themselves were written onboard their PDA's text editor. Only the category names and their weightings were transmitted and were cluster analysed later through IBM's EZCalc.

6.11 Case Study B – Evaluating with CAKE

This section describes the investigation process for devising and conducting the evaluation of the inert constructionism part to the constructionism framework for HCI reported in chapter 5, with the use of the software tools devised in section 6.9.

6.11.1 Participants

The comparative series of card sorting experiments were conducted with a class of final year undergraduate students taking an optional course in Advanced Human Computer Interaction. In order to compare the variations of card sorting, the interpretation of a number of fair and restrictive controls is required. As a prerequisite of the students' course, they all have had to successfully pass an introduction course in HCI in their prior year and therefore are considered as knowledgeable to semi-knowledgeable experts in basic HCI (also on the basis of them choosing advanced HCI as a module to study in their final year).

6.11.2 Stimulus Material

Key topics from relative chapters from the student's introductory HCI class notes (figure 6.13) where chosen as the card sorting data source for the expert experiments. The non-expert experiments were based on card data from topics and content from upcoming unseen notes in their current advanced HCI module (figure 6.14). As a control, the same card sets were given for all expert experiments, based on past knowledge and the same cards for non-expert experiments based on pre-emptive knowledge. Both the expert and non-expert experiments had 25 cards each.

Card sorting as a HCI method itself was not introduced to the students in their introductory HCI course, so their engagement in card sorting activities was considered to be non-primed to the experimental protocols that they would receive as tasks.

1. Icons and Graphical Representations 2. Clicking and Dragging 3. Force Feedback 4. Paper Prototyping 5. Cursor Control and Pointing devices 6. Command Prompt and Text Menus 7. Wizard Of Oz and High Fidelity 8. Tactile Interfaces	1. Orientation and Aspect Information 2. Web Accessibility Initiative (WAI) 3. Screen Assistance 4. Personalisation and Themes 5. Alternative Text Tags 6. CSS Stylesheets 7. Link Targets and Parent Containers 8. BOBBY certification

Figure 6.13: Sample of topics in basic HCI chapters used for expert Experiments

Figure 6.14: Sample of topics in advanced HCI chapters used for non-expert experiments

Table 6.2 illustrates our experimental variations. Each of the groups had instruction sheets on how to begin each of the experiments, and the rules of each particular sorting method. Examples of these instruction sheets are in appendix D.3. They were then given 50 minutes to complete the two experiments that they were assigned.

6.11.3 Apparatus

A Sharp Zaurus linux SL-5500 PDA and a HP IPaq 4150 PDA were utilized to conduct the PDA based solution to the electronic based card sorting, running the CAKE software as designed in the participatory design sessions. Paper cards were supplied for the alternative techniques.

After a brief help-screen introduction that gave the participants instructions on how to navigate the cards and allocating categories in the Linear Card Sorting model, they began their experiments firstly as a group using one PDA between them all. In the individuals PDA exercise they had to take it in turns to complete the experiments each.

Table 6.2: Experimental variations of card sorting

Group No.	Expert Experiment Cards	Non-Expert Experiment Cards
1	Exp 1: Non-linear technique (**standard**), non-electronic cards, group experiment	Exp 2: Non-linear technique (**standard**), non-electronic cards, group experiment
2	Exp 3: **Linear** technique, non-electronic cards, group experiment	Exp 4: **Linear** technique, non-electronic cards, group experiment
3	Exp 5: Linear technique, **electronic** cards, group experiment	Exp 6: Linear technique, **electronic** cards, group experiment
4	Exp 7: Non-linear technique (standard), non-electronic cards, **Individuals** experiment	Exp 8: Non-linear technique (standard), non-electronic cards, **Individuals** experiment
5	Exp 9: **Linear** technique, non-electronic cards, **Individuals** experiment	Exp 10: **Linear** technique, non-electronic cards, **Individuals** experiment
6	Exp 11: Linear technique, **electronic** cards, **Individuals** experiment	Exp 12: Linear technique, **electronic** cards, **Individuals** experiment

6.11.4 Procedure

In all, data from 12 groups were collected. Six groups of 5 students each participated in two variations experiments during a class session, leading to 60 card sorting measurements. Each group first conducted an expert variant of card sorting, followed by a non-expert variant of card sorting. For individuals experiments, participants were numbered one to five and considered as a "group of individuals" to maintain a comparison with a standard group of five. Those groups who were conducting individual experiments were told explicitly not to communicate with others while they conduct their own exercise, whereas those in groups were allowed to communicate their ideas across to their group members.

6.12 Inert Constructionism with CAKE

CAKE elicits first-experience artefacts of user knowledge, in the form of categorical formations within the scope of the rules of inert constructionism reported in chapter 5. This is constructed in textual form and the category formations are static for the duration of the knowledge elicitation cycle, i.e. only addition (A) processes occurs, with no modifications (M) or deletions (D).

Inert Constructionism is reported in chapter 5 as a static measure based on the single cycle of iterative knowledge construction, starting with a set initial knowledge domain. For this reason, the entire series of card sorting experiments in this case study utilised closed card sorting rather than the open card sorting form (which uses a non-set initial knowledge domain). As such, the data collected in the web based and mobile based CAKE sessions reports individual classifications as Inert Constructs which are then cluster analysed by a common theme. These clusters are not measured by temporal manipulation, in line with the designed model for inert constructionism reported in chapter 5's framework of constructionism.

6.13 Study Results

In order to compare the results from these experiments, EZCalc was utilised. Thus in statistical clustering it was necessary to cluster by card numbers rather than name terms, as shown prior in figures 6.13 & 6.14. Appendix D.4 gives examples of the data collected.

Since the CAKE PDA tool automatically generates EZCalc compatible data, only the non-electronic experiments needed to be manually entered into the system. Under normal card sorting conditions it is not viable to compare elicited experiments when the cards' domain of knowledge is somewhat vague and prototypical. However as the choice of cards data were taken from existing HCI textbooks (Preece et al., 1994; Shneiderman, 1998), there was a controlled "higher expert" scope of results to compare these experiments against.

In these tests, group based card sorting is generalised as less categorically diverse than individual based card sorting, when considering a set number of participants in a group vs. cluster analysing the categorical formations from a group of the same number of individuals. Bias and convincing others to change their minds may be reasons that affect the group when there are dominant and timid participants in a group.

Linear card sorting vs. non-linear card sorting is comparatively similar when dealing with expert data in groups, whereby all participants are familiar with the terms. With non-expert data in a group however, linear card sorting revealed a significantly more accurate cluster set than found with traditional non-linear card sorting. The reason for this is generally believed to be that dominant and coercive effects occur when instinctual choices and personal educated guesses outweigh the arguments set by dominant group members “who sound like they know the right answer”.

Both individual based linear card sorting and individual based non-linear card sorting showed significant cluster dispersion eliciting the closest knowledge domains of participants. Therefore traditional group communication orientated card sorting is experimentally challenged in these cases as a weaker elicitation method than individual based card sorting when it comes to eliciting the variety of categorical domains. It was therefore found to be better to card sort as individuals and statistically calculate to gain wider ranges of categorical hierarchies.

For individuals working on their own, electronic linear card sorting is comparable to paper based linear card sorting (figures 6.16 & 6.17). The data showed that both expert and non-expert card sorting with the PDA led to diverse hierarchies, leading to suggest that the PDA method was not a drawback to the existing methods. This interpretation stems from the level of constraints placed on conducting linear card sorting. CAKE benefits the KE process by providing means to digitally capture and analyse card sorting data. In addition the mobility of the device provides a benefit in not requiring large desk space for card manipulation.

Group based electronic linear card sorting demonstrated a weakness in comparison to individual based electronic linear card sorting in that participating as a group around a small device did not elicit the knowledge of all the members, and that the member who uses the device ultimately has final say on what category to input into the software.

The choice of terminology in category naming was of varying quality. Due to communication allowed in the standard non-linear exercise, the category names were acutely more scientifically named whether their basis was understood or not e.g. they attempted to contribute expert behaviour. The category names formed from the linear exercise were varied between technical to non-existing made-up terms.

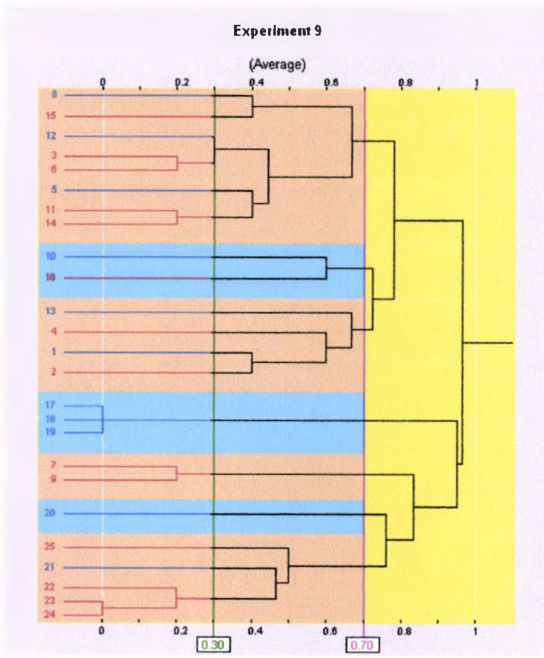


Figure 6.16. Cluster Experiment 9

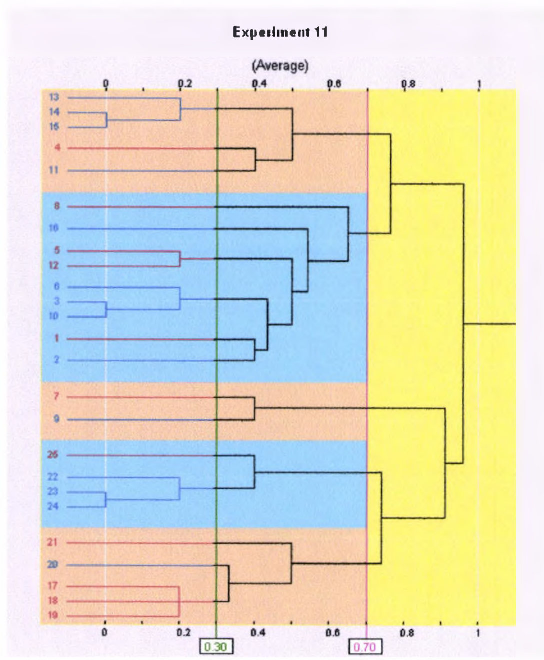


Figure 6.17. Cluster Experiment 11

6.14 Conclusions to CAKE

An in-depth user centred design process with several iterations led to the design and development of CAKE as a card sorting mobile cyberscience tool. The case study evaluation of the tool demonstrated that CAKE performs linear card sorts successfully having compared and cluster analysed the empirically collected data.

In exploring Inert Constructionism with CAKE, as demonstrated by the category formations in linear card sorting, CAKE demonstrated that successful inert constructs can be created electronically through the use of mobile tools. These constructs represent the individual capability to create and reinforce the first impressions ideas in categorisation.

6.15 Chapter Summary

This chapter described the design and evolution of CAKE – our mobile implementation of inert constructionism to card sorting. Having designed a new tool to represent the pragmatics of inert constructionism, a comparison with the existing card sorting technique was carried out. This experiment demonstrated that linear card sorting is a viable alternative to existing card sorting methods. Furthermore, Inert Constructionism in the form of linear card sorting via a web based tool demonstrated that there is scope for geographical dispersion and unsupervised asynchronicity in the technique.

Following this, a qualitative comparative experiment was conducted to verify the useful quality of inert constructionist data in HCI. In this experiment over 60 card-sorting measurements were elicited. This demonstrated that linear card sorting has diverse categorisation formations on par with non-linear methods. Though the advantages of first-intuition data is not fully explored psychologically as this is beyond the scope and field of this thesis, it demonstrates the extension of the theory of card sorting to include a new type of user data, from their first intuitions.

Several key applications of CAKE are shown as:

- Contextual enquiry of categorisation, such as leading to taxonomy creation.
- Idea brainstorming between mixed experiments of experts and non-experts alike.
- Feasibility studies eliciting primer type exposure whereby previous data can affect how new data is arranged.

Several key advantages found in the case studies in this chapter augmenting the use of KE with this mobile knowledge elicitation implementation are:

- Data capture can be achieved asynchronously and can be without the requirements for expert presence if conducted remotely. It can also be reviewed at any point once categorised and stored, as a reminder listing of categories.
- Compilation of data values can be either in real-time if a supporting wireless network is present and selected, or compiled on device for cluster analysis.

- Test administration becomes dynamic and without the need for a HCI facilitator by electronic instruction – an administrator can update new elicitation experiments to in-the-field experimenters and participants via wireless networks.

The following chapter investigates the role of constructionism in HCI further by modelling semi-dynamic constructionism within the context of mobile affinity diagramming.

Chapter 7: Semi-Dynamic Constructionism with Mobile Affinity Diagramming

7.1 Introduction

This chapter aims to continue the exploration of Chapter 5's framework of constructionist modelling in Mobile HCI KE methods by presenting Semi-dynamic Constructionism as a model that can be observed within Mobile Affinity Diagramming. In chapter 5, the framework of constructionism was reported to model the activity of constructionism within HCI methods (Table 5.1) and chapter 6 presented how this model can be use to model inert constructionism.

A similar methodology to Card Sorting is the Jiro Kawakita (KJ) diagram method, more commonly known as Affinity Diagramming. In Affinity Diagramming, organisational activity is proposed as a type of constructionism. This type is explored as semi-dynamic constructionism, whereby the knowledge is no longer individual based as found in inert constructionism (e.g. Card Sorting).

Collaborative teams work on the construction of new knowledge and organisation of thoughts through syntactical and textual artefacts. It is semi-dynamic because the organisational activity is still restricted by its physical inability to remove completed artefacts (e.g. whole clusters of existing categories), instead the participants are only able to construct and modify the organisation of existing card elements. Secondly, mediation periods can be observed in the temporal view of the activity whereby participants are reaching a consensus agreement (McGarty, 1999) for their organisational structuring of card elements, reviewing cards, or resting between states.

The ease of use of applying the methodology using mobile software has not been reported in HCI literature. In addition, representing the temporal nature of the technique has only been reported through video observation methods, which often do not capture the essence of fine tuned changes to the affinity diagram structure. In this chapter, semi-dynamic constructionism is presented to describe novel HCI measures to explore participants' confidence in their affinity diagramming. Empirical testing of several developed mobile tools for Affinity Diagramming support, for HCI practitioners, is reported in this chapter. This experimental modelling concludes by inferring a general relationship with the modelling of semi-dynamic constructionism within affinity diagramming in HCI.

7.2 Problem Domain

Card sorting and Affinity Diagramming are both participant-based knowledge elicitation techniques for grouping information into categorical domains (Nielsen, 1994). Their origin as useful KE techniques in social psychology can be found in Kelly's Personal Construct Theory (Kelly, 1955). They have been demonstrated as useful HCI KE techniques (Burge, 1998) based on the quantity and speed of knowledge acquired (Burton et al., 1990). They are useful to HCI specialists as techniques for creating and analysing categorisations of knowledge and are considered amongst the foremost usability methods for investigating a user's (and groups of users) mental model of an information space (Martin, 2003; Nielsen & Sano, 2004).

An affinity diagram method in HCI methodology brings a group of people together in a room with a board or wall with which to write out cards or observations/ideas and group them into clusters. The group take it in turns to mediate and decide on their choices for positioning their cards in groups, and then the group will debate consensus on the cluster groupings to determine the refinement of the category headings.

Previously reported research with electronic card sorting (Mohamedally et al, 2003b, Mohamedally et al., 2004b) provided an interesting support for electronic based knowledge elicitation (KE) and information architecture (IA). It enabled remote participants to construct mobile card sorting clusters (Dong et al., 2001) with which to provide a means for geographically dispersed participants to create card set category formations.

In chapter 6, experimental scenarios from professionals, researchers and students, with card sort data (Figures 7.1 & 7.2) were observed from both electronic and non-electronic techniques. From this it was determined that the analysis stage procedures assign significant weighting to categorical formation and comparison, but the construction history of the cluster decision making process goes largely unnoticed in practice.

Figure 7.1 & 7.2: A HCI practitioner creating and conducting a card sort in progress with post-it notes

In affinity diagramming however, the practice is enforced in teams which are encouraged to communicate their reasoning verbally, thus team decisions collaboratively lead to category cluster formation until consensus is reached. The card sorting method also tends to imply pre-made cards for use, whereas affinity diagrams tends to require user creation of the card entities themselves, thus all activity is non-inert in construction as new knowledge is continually created.

It is noted that both the card sorting and affinity diagramming techniques can apply to other objects other than cards such as pictures, and physical items, but card sorting tends to be more textually orientated and is based on printed cards.

Both of these methodologies are experimental approaches to acquiring categorisation metrics of user mental models, in linear and non-linear practices of use (figure 7.3). The existing paper based affinity diagramming method is obviously quick, cheap and practical. Low fidelity ideas are captured efficiently with this. However, office stationary materials and space need to be available. Outputs are not effectively recorded on paper in a consistent and shareable form, and intermediate decisions made are not recorded on paper (e.g. how they arrived at those grouping structures).

7.3 Case Study A – Mobile Affinity Tools Design

This section describes the design investigation, development and evaluation of several tools to support mobile affinity diagramming.

7.3.1 Initial Investigation

Firstly, direct observation of several existing paper based card sorting and affinity diagramming exercises was conducted during HCI taught classroom scenarios (figure 7.3). The class of approximately 30 postgraduate HCI students as well as the teaching support staff were made aware that they were about to be recorded for the 30 minute duration of the technique, and gave their full consent to reporting this data.

Digital video observation was captured using MP4 based PDA and mobile phone based cameras. These were deemed to be discreet enough to limit visibility to the class, even though they knew they were being recorded the recording devices used were small enough to be unobtrusive, thereby lowering tensions of the experimentally motivated process. The purpose of observing the class's execution of the affinity diagramming technique was to enable the reporting of first-hand visual and collaborative activity sequences in the methodology. This identified the majority of potential user activities as key stages of constructionist activity i.e. decision making, mediation and refinement of categorical information (figure 7.4), reported similarly prior as a TIC state in section 5.3 (see figure 5.1).

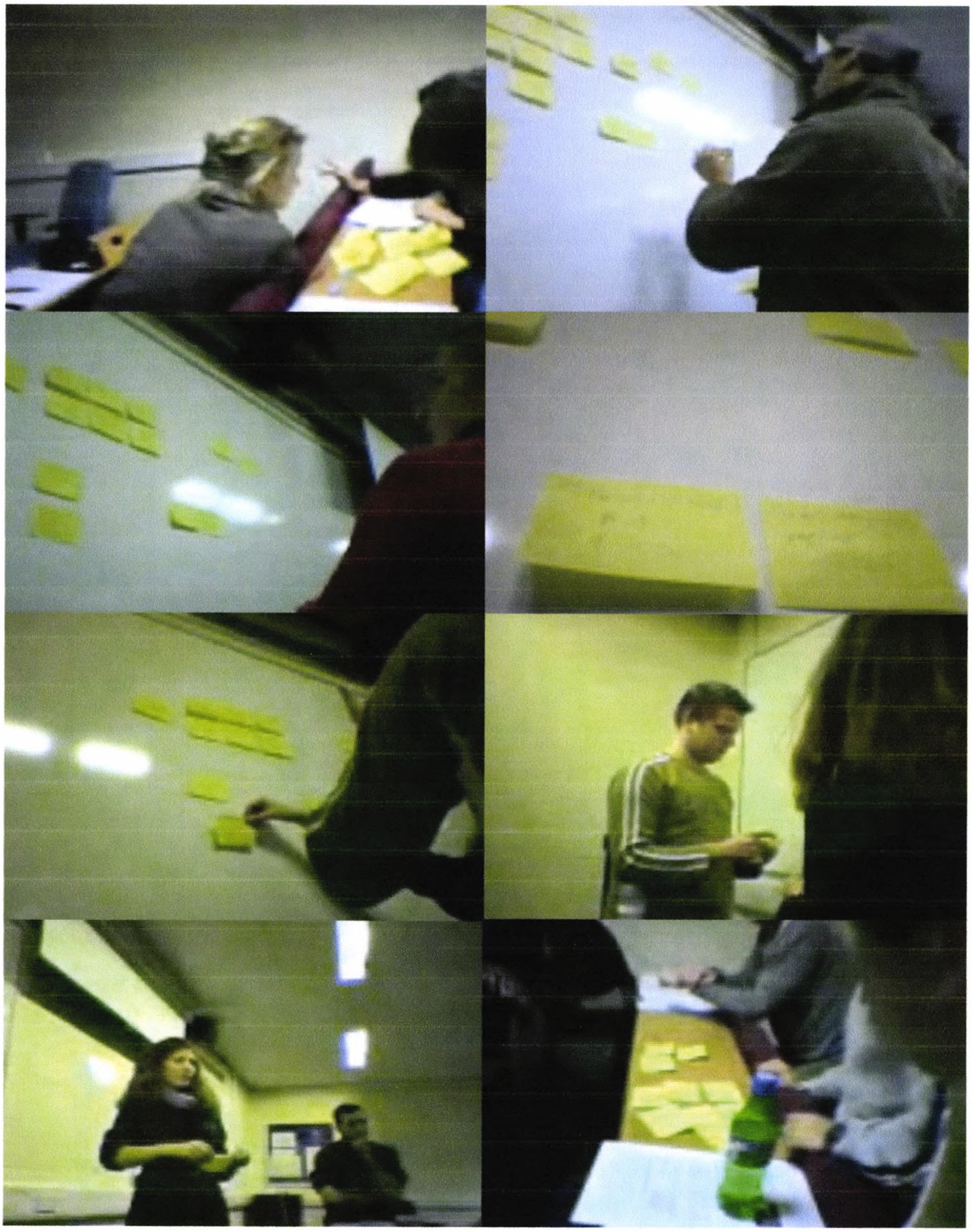


Figure 7.3: video observation identified stages of constructionism while conducting HCI affinity diagram conducted in a classroom scenario

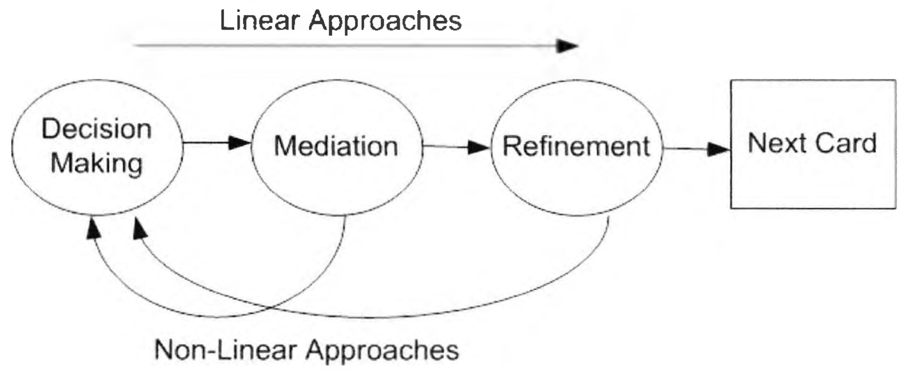


Figure 7.4: linear vs. Non-linear key stages of categorisation as a Temporal Iterative Construct (TIC) state

The video observations aided in initial requirements solicitation. It was shown that the use of a visualisation space makes the affinity diagramming method visually rich in comparison to card sorting.

After the participants had created their cards in their group, the use of this space was shown to be split into two main focal points. Firstly, the arrangement of atomic clusters was usually identified by use of "rough areas" where participants can put particular created cards to one side, discuss and mediate, and then refine their grouping and category name. Secondly, these "rough areas" would then be combined back into a main affinity workspace, to further construct the various groups and branches of the affinity diagram. This practical approach simplified the methodology until all remaining cards from the participants had either been used or due to replication by others, removed.

The requirement of a large space to work on posed a significant obstacle in creating a mobile design for the methodology. Technologically, this need required a high resolution interface, with which most mobile solutions would not achieve practically e.g. the small and low resolution screens of PDAs and SmartPhones. At the same time the participants' activity placed strong emphasis on constructing the affinity diagram and creating an agreement consensus on the represented grouping clusters. There was a visible need for people to sit around the visualisation space and discuss their options and argue their cases, whilst sharing the tangible nature of the cards in their hands. This is a key factor of constructionism theory, as knowledge is created and reinforced through the tangible efforts of others (Papert, 1991).

There was less emphasis on the accuracy of their post-it notes notation during their cards creation task, though the vocal members in groups attempted to raise suggestions and awareness of concepts in coming up with new card ideas to create. The informal protocol of the affinity diagramming was not so rigid as to have every participant contribute linearly, but rather encouraged "join in and drop out at any time" behaviour within the teams, debating focus of grouping categories in a non-linear manner.

7.3.2 Expert Participants

Participatory design (PD) sessions were then conducted with 4 HCI practitioners and lecturers. The 4 experts (1 male, 3 female) are members of the Centre for HCI Design, City University London as of 2004. They each have had a minimum of 5 years experience with computing and the internet, and a minimum of 2 years experience in HCI either in academia or professionally. They have all been involved with teaching related computer science and HCI material at some point in their academic careers.

They were each given a consent form which they had to sign, and a pre-questionnaire to fill out to elicit their awareness and relative experiences with using HCI software tools (appendix C). An analysis of the pre-questionnaire showed that all of them were familiar with a wide variety of HCI techniques already, including card sorting, affinity diagramming and paper prototyping, as well the more regularly used techniques such as interviews, surveys and user testing/observational studies.

7.3.3 Design Procedure

The practitioners were then introduced to the concept of pen actions, gestures and onscreen handwriting as a potential interface to the tool. Using these attributes, low fidelity paper prototypes (figures 7.5, 7.6; in more detail in appendix E.1.2) were created by the practitioners to elicit potential user interface designs. This aided in defining options and a functional breakdown of tasks to simplify and minimise the number of user actions. It also provided the identification of a separation of logic for the key activities that a software solution could provide to HCI practitioners.

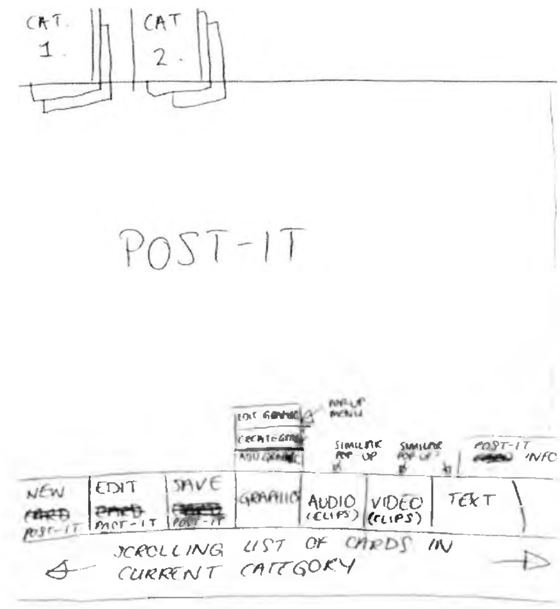


Figure 7.5: first expert paper prototype of the affinity diagramming methodology in software

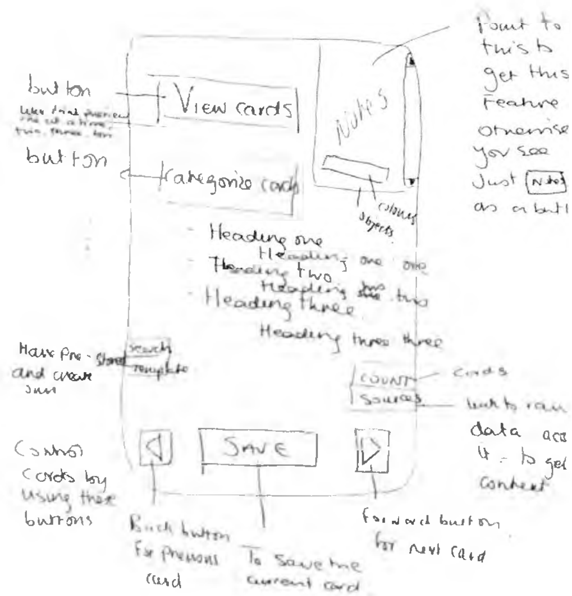


Figure 7.6: second expert paper prototype of the affinity diagramming methodology in software

Having identified the key factors within these paper prototypes, the HCI experts explored further with an affinity diagramming session to elicit common design requirements. This enabled opinions to be collated and provided an opportunity to enquire as to the priority of certain key facilities, which were agreed afterwards in a focus group discussion to reach a consensus of important requirements. These key attributes are shown in table 7.1.

Mobile pen-based input devices such as PDAs and tabletPCs are already "part of the HCI users toolkit" prevalent for multiple uses. The TabletPC platform was chosen above PDA and SmartPhone devices, having debated their technological limitations with regards to visualisation space, and usability in a physically close team-based activity. A tabletPC is a hybrid laptop and PC device in a relatively small form factor, with electromagnetic pen-based interface. At first glance, some of the key capabilities it will allow HCI practitioners;

- facilitates ink based technologies for simplifying user activity and minimising training
- It has a wide visualisation space for a mobile device (1024x768 resolutions and much higher, including projector output via VGA cables) to allow small teams to work with each other on an artificially scalable virtual board

- the memory and processor requirements of the hardware provides more than adequate storage and processing of affinity diagramming data
- provides the mobility for on-site use by HCI practitioners, the tablet form factor is easily "passable" physically to other users in a team and is designed not to be obtrusive (especially if converted into its' slate mode of operation).

Table 7.1: Expert affinity categories after focus group consensus, of HCI practitioner requirements for mobile affinity diagramming tools.

Category Title	Cards created and clustered together
Basic functions	- load cards - process cards e.g. make changes/ correct mistakes on cards - load graphics and own drawings to the post it notes/cards - add text to the cards/post it notes
Categorisation options	- categorise cards - view post it notes within a category - reorganize within and across categories with card picking - add new/delete categories - edit category name - move category windows (backward or forward) - restructuring cards - drag and drop capabilities
Viewing/navigation of cards	- view all post its/cards - multiple views - one card at a time view (slideshow navigator) - arrows showing movement of cards between different groups - back/forward/save buttons - zoom view/overview
File/edit operations	- add, copy, paste, edit, save, delete, print notes - save screenshot of affinity diagram for emailing to others
Progress information in real time	- textual indication of action e.g. "moving card 3 into group 2" - textual description of all groups

From this expert session it was identified that constructing affinity diagrams on a TabletPC was best to be logically split into two applications to mimic the two sets of participant's activities – firstly the creation of cards in a group, and secondly the organisation and clustering of these cards. Thus the mobile software to be designed is separated into these two logical functions; firstly a card creation tool, named **CATERINE** (Categorical Rich Ink Notes Editor) and secondly a card organisational and clustering tool named **SAW** (Software-based Affinity Workspace). A third tool, **MATE** (Mobile Affinity Temporal Evaluator) was also developed for analysing the SAW data over time as affinity diagrams are created, thus providing a means to evaluate the semi-dynamic constructionism within affinity diagramming.

From the video observations of the initial investigation (figure 7.3), and the expert affinity diagram observed from the HCI practitioners (table 7.1), it is determined that whilst the regular flow of the technique is linear (cards created, then organise them), the informal nature of the affinity diagramming technique allows for participants to create more cards whilst the organisation and clustering is still ongoing, thus by design, it was agreed in the focus group that these two tabletPC software applications should be integrated and interoperated with each other. This process of switching between two or more applications or views to a software interface that is cohesively tightly coupled and share their data is commonly known in computer science as *round-tripping*[1].

7.4 CATERINE – Categorical Rich Ink Notes Editor

CATERINE (Categorical Rich Ink Notes Editor) is a TabletPC based pen orientated writing and drawing tool designed to mimic the basic functionality of using a pad of post-it notes. It differs by enabling the freeform drawings and handwritten text written by TabletPC pen to be editable (scaled, moved and transformed geometrically) as well as mimic how an eraser would erase by "rubbing" the pen over existing ink lines.

The software is designed with facilities for different virtual pen types (round/calligraphic), line widths (pencil, biro, felt tip etc) and colours to enable the creativity of the user to become more meaningful and symbolic in creating the cards ready for use in the affinity diagramming workspace SAW (section 7.5). These rich ink notes are stored as time-stamped ink-based GIF files, which can be re-opened at anytime in CATERINE for further editing and manipulation. This is especially important as a history list view with thumbnails is provided to view prior designed cards from a single session (figure 7.7).

[1] This facility is enabled in the release version of the software developed and reported in this chapter; however it was purposefully disabled in the experimental method reported later, as an experimental control.

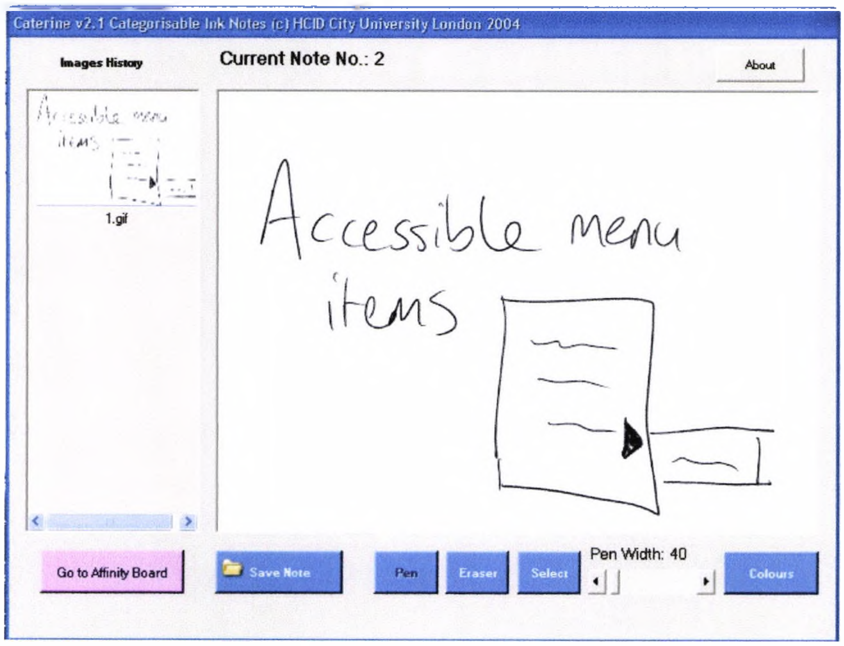


Figure 7.7: Creating visual ink notes for use in SAW tool with TabletPC's mimics making post-it notes

As they are GIF files, they are also capable of being shared across the internet (e.g. emailed). An additional feature developed for the benefit of HCI practitioners is the capability to auto-generate a website with these ink-based cards so that others can view it as a website over the internet, and then re-use the ink-based GIF files as cards for their own affinity diagramming.

7.5 SAW – Software-based Affinity Workspace

SAW (Software-based Affinity Workspace) is a non-linear categorisation TabletPC based tool for users to organise both visually drawn and textual element objects (as created in CATERINE) into groups on a user-scalable virtual board (figure 7.8). This is achieved through the use of dynamic scrollbars that a) appear only when more space is needed and b) extend the visualisation space near indefinitely as affinity cards approach its edge borders. Using such a technique has practical benefits over management of large visual boards to stick physical paper notes on, especially for later analysis and collaborative review. Using the pen action to double tap a card on the board enables the card to be reviewed at full drawn size. Users may also import other image types such as JPEG, TIFF and BMP formats.

Participants in an affinity diagramming exercise with SAW will mediate and refine the choices of their actions and decisions, until they are satisfied with their categorical structures in groups.

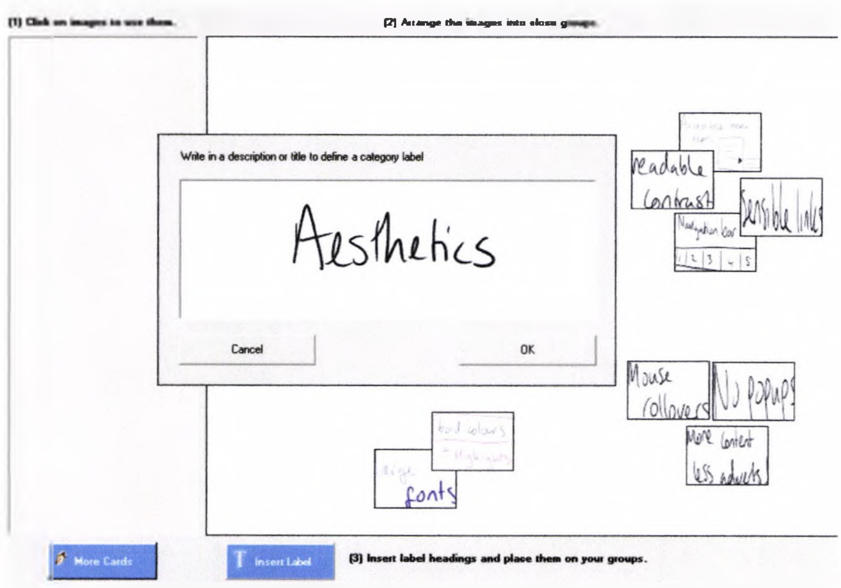


Figure 7.8: SAW main board incorporates a resizable virtual board, and card handling with pen recognition of gestures and handwriting-to-text for labelling groups

The TabletPC ink recognizer enables users to handwrite their labels using a TabletPC pen without the need of a keyboard. The handwriting is then auto-converted into textual category headings. This was achieved through use of the MS VisualStudio.Net 2003 TabletPC 2005 SDK libraries.

This interaction model mimics the physically tangible model of categorisation in both card sorting and affinity diagramming closely; e.g. by picking up and moving cards (pen drag motion), bringing cards to the front of a pile (pen single click motion), looking at cards more closer (pen double click motion), and removing cards (pen eraser button).

These pen actions have the added advantage of providing a resource of data for digitally logging all motions and actions, and record-keeping of the cluster formation in progress, as well as being fast and convenient for using a pen in a one-handed mobile or stationed environment. The tool also features cloning cards (figure 7.9) for multiple group instances – something that paper cannot replicate quickly and easily (without drawing it out again/ photocopying).

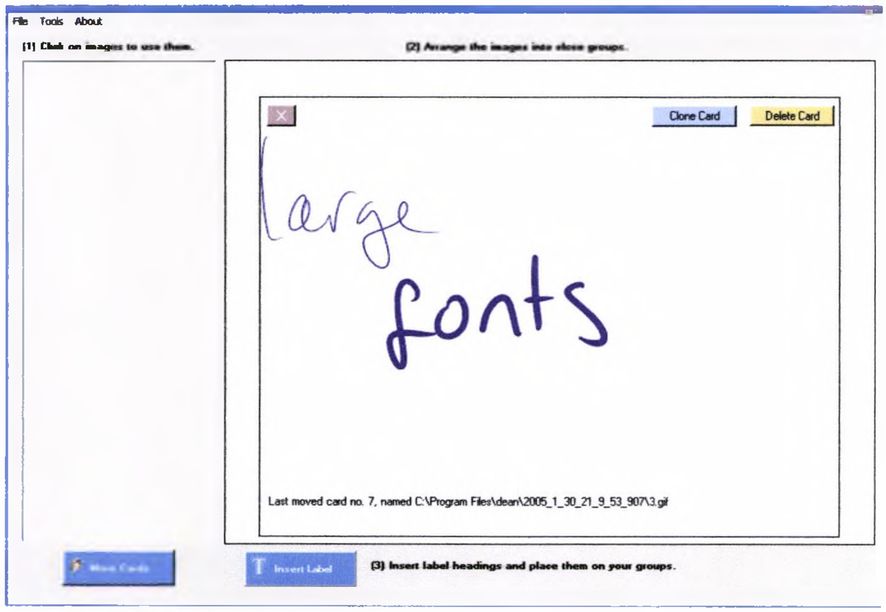


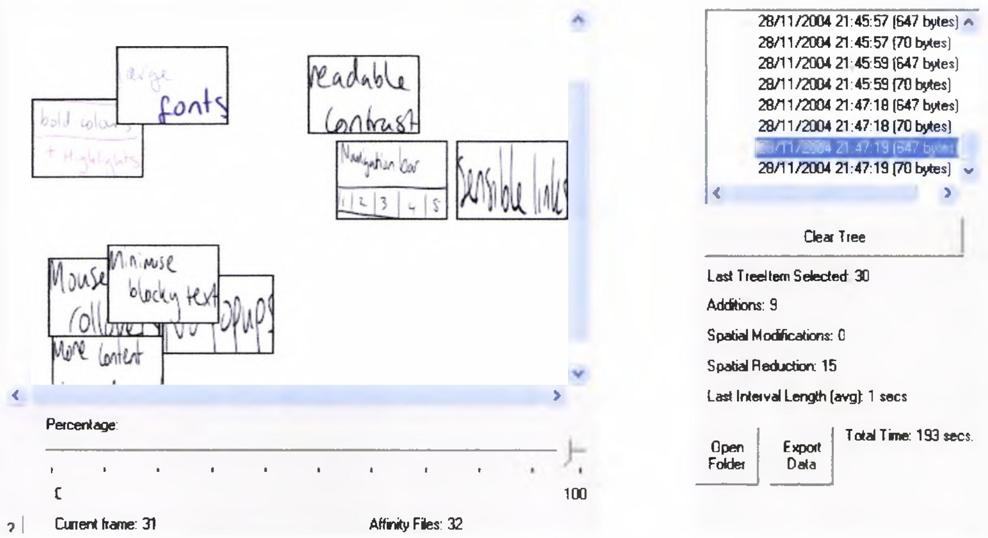
Figure 7.9: SAW card viewer allows the affinity diagram to have cloned cards, or the complete removal of selected cards

7.6 MATE – Mobile Affinity Temporal Evaluator

The MATE tool is designed so that HCI practitioners can be able to review and evaluation all non-linear decisions, e.g. to compare what users actions occurred in the decision making of clusters at different temporal instances. This allows the HCI practitioner to review the entire history of the affinity creation, and elicit particularly interesting affinity stages such as key moments during mediation consensus and refinement facilitation (figures 7.10 & 7.11).

As SAW records every organisational action on the Affinity Workspace, this data is re-read into a timeline based model whereby the practitioner is able to flick through each stage of the affinity diagram creation. Being non-linear, the practitioner can jump either several selected steps before or after a view to the affinity board, or they can run through it in non-linear fashion. This was requested from the expert focus group as a feature for use with on-site experiment sessions.

Data is provided in the interface to denote the time and activity levels at each point. The accumulation of this data is exportable to an Excel™ compatible spreadsheet, outputting the construction history of the affinity diagram. This process is demonstrated in a case study described in Section 7.7.



Figures 7.10 & 7.11: Temporal review timeline within MATE enables affinity user activity metrics to be calculated for review and querying

7.7 Case Study B – Evaluating with the Affinity Tools

This section describes the investigation process for devising and conducting the evaluation of the semi-dynamic constructionism theory as reported in chapter 5. This is achieved with the use of the software tools devised in sections 7.4, 7.5 and 7.6.

7.7.1 Participants

In order to better understand the application of constructionist assessment in affinity diagramming, the scenario testing of the tools and the theoretical framework were undertaken with a group of 40 mixed MSc & BSc participants recruited from an HCI module, taught at City University London.

An introduction to the experimental method and a consent form was given and signed by all of the participants. Following this, a pre-questionnaire (appendix E.3.1) was then given to acquire the participant's demographic details and an understanding of their use of mobile technologies. Their demographics showed 82% were of age group 18-29, and 18% aged 30-39. Subsequently, 86% said that they had not used tools specifically for HCI methods before; only 14% said that they had. The gender demographics were approximately 3:2 ratio male to female, with 59% male, 41% female. The mobile usage data from this questionnaire are reported in figure 7.12.

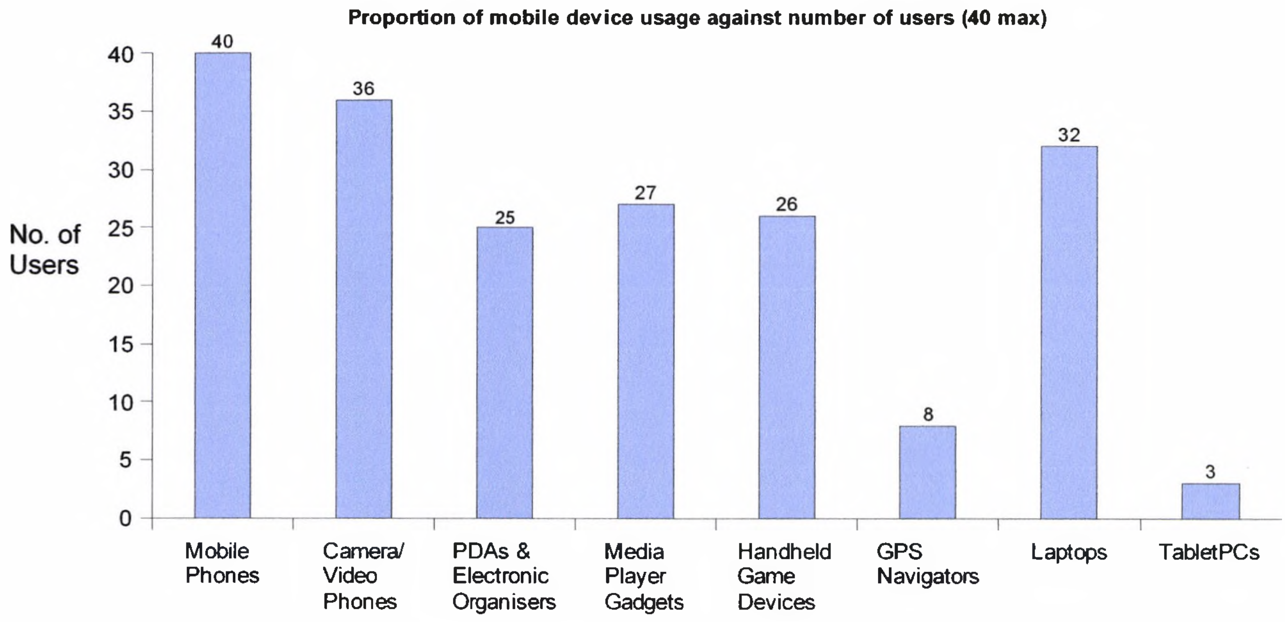


Figure 7.12: SAW Participants Demographics

All of the experiments were group based. The main experimental method was separated into two with half the class assigned to facilitating the software based method and the other half facilitating the existing paper-based affinity diagramming method for comparison.

By use of an expert assessment marking scheme, a team of HCI lecturers and teaching assistants were given the task to evaluate the quality of outputs from both the paper and software methods, and to give a score indicator on the correctness of the participants' outputs. For the participants using CATERINE and SAW tools to create and organize affinity cards on a virtual affinity workspace, the MATE tool would be able to use the constructionist framework to give temporal qualitative data on the confidence in categorisation. This enables a comparison to be made between the constructionist framework results and those from an existing expert HCI marking methodology.

7.7.2 Apparatus

The participants who were selected to participate in the software method were invited to utilise the CATERINE and SAW tools. These tools were configured to behave as one software application, with roundtripping between CATERINE and SAW disabled such that only one round of card creation would be allowed before entering the affinity workspace. This was done as a control to ensure a symmetry of execution with the paper based participants. The software participants utilised 4 TabletPCs (1GHz+, each with 512Mb RAM running Windows TabletPC 2005). As the demographics data in figure 7.12 shows, very few of the participants had used a TabletPC mobile device before, although various devices as phones, PDAs and media players were quite prominently used. This data was useful to know as it means a general presumption that the participants were somewhat gadget-savvy and therefore should potentially be able to become accustomed to a new mobile device with relative ease.

A brief introduction to its software functions and capabilities was given, and the TabletPC pen in particular was demonstrated to the participants, to make clear how it could be used. Large A1 sheets of paper, pads of sticky post-it notes for creating cards, and a selection of felt tip pens and pencils were utilized for the paper-based affinity diagramming participants.

The experiment was held in a large auditorium lecture hall and students were invited to move about and collaborate in their groups by sharing the tabletPCs, to simulate as best as possible the aspects of mobile freedom and the informal nature of affinity diagramming.

7.7.3 Experiment Procedure

The participants were given instructions on the experiment they were about to take part in (appendix E.2). Half of the class conducted software affinity diagrams whilst the other half conducted paper based affinity diagrams. Working in small groups, the software participants, numbered groups (at randomly chosen based on the location of their seating in the classroom; 3,4,5,6 and 8) utilised the 4 TabletPCs (Toshiba and Acer branded) in turns in their classroom location. The remaining groups (numbered 1,2,7,9 and 10 based on the remaining positions in the classroom) conducted the paper based method, on a separate side of the classroom. The affinity diagramming scenario was conducted based on teaching materials for Web Accessibility Guidelines.

The scenario was chosen as a measure to gain a view of what the students considered to be key web accessibility guidelines to incorporate in their designs for a coursework on web design, based on prior expert reading on their part. They were requested to create a list of guidelines from scratch in their teams using the software tools, and then organize them into category classifications.

They were then required to mediate and debate in their groups whether their clusters were correctly placed, with the option given to move cards around and re-do cards, ending with the creation and consensus agreement of the cluster headings. Upon completion of the diagrams, the different groups were shown the others solutions to demonstrate the variety of levels of refinement that groups can give using an affinity practice.

The groups utilised the mobility of the tabletPC in sharing actions and making refinement decisions while in their groups in the classroom, without other groups becoming aware of their results until afterwards when it was discussed as a class what the groups had found. Each group was given 40 minutes to complete the task. Figures 7.13, 7.14, 7.15, 7.16, 7.17 and 7.18 illustrate the activities in this experiment. Appendices E.3.2 and E.3.3 shows outputs from the paper studies while appendices E.3.4 and E.5.2 shows output from the SAW tool.

After the affinity diagram experiment was completed, the software users were given a Quality of User Interface Satisfaction (QUIS) survey (Chin et al, 1988; Slaughter et al, 1994; Appendix E.4.2) to elicit their review of the user satisfaction with the software tools.

Figure 7.13: Paper participants mediating their choice of cards around a table

Figure 7.14: Software participants mediating their choice of cards around a tabletPC

Figure 7.15: Paper participants refining their categories on a whiteboard

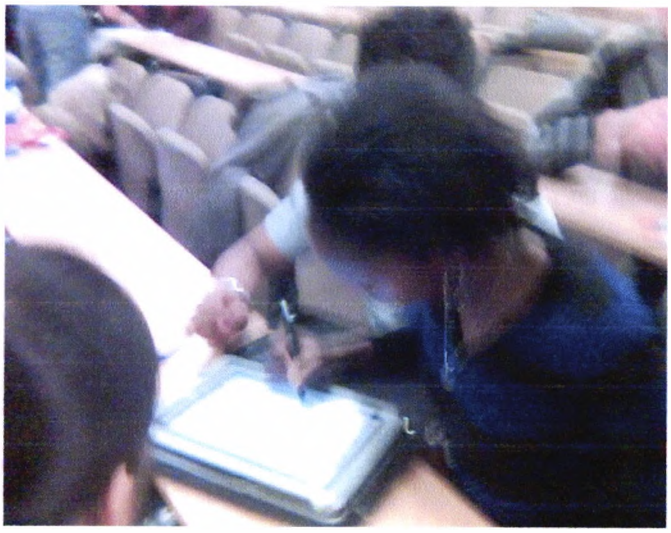


Figure 7.16: Software participants refining their categories on a TabletPC

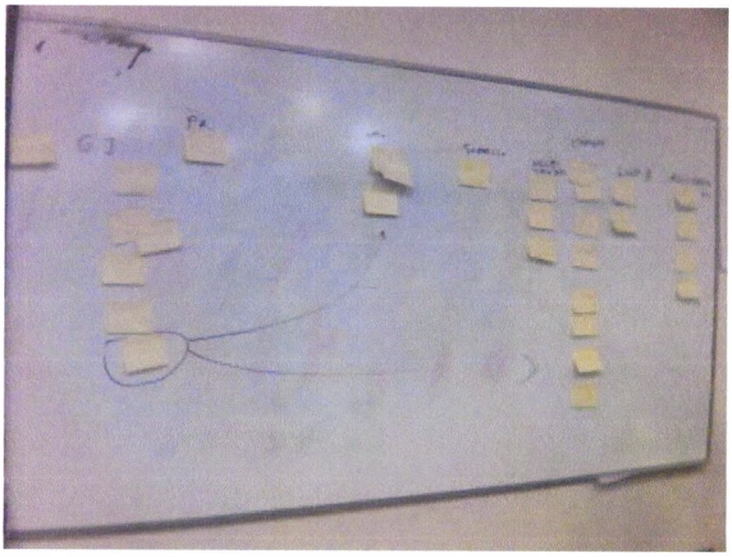


Figure 7.17: Paper based output presented on a whiteboard

Figure 7.18: Software based output from SAW presented as a JPEG output from the software

7.7.4 Analysis Method

For HCI lecturers, practitioners and researchers, the method for evaluating paper based affinity diagrams tends to focus on comparing visual representations and semantic representations. Table 7.2 shows the Centre for HCI Design's own expert assessment criteria as devised and validated through years of use by lecturers in the department, used to evaluate this scenario's affinity diagrams for the HCI class.

Expert marking of the affinity diagrams, both software and paper based, were conducted with two HCI practitioners marking the software views, and a different two HCI practitioners marking the paper views, such that bias of software against paper expert comparisons could be avoided. All four HCI practitioners are academics or researchers at the Centre for HCI Design, City University London, with several years of experience in the HCI field.

Table 7.2: HCID department's Affinity Diagram Expert Assessment Criteria

Affinity Diagramming Expert Assessment Criteria
1.Verboseness (technical wording)
2. Clarity of Expression
3. Correctness to content (e.g. Web Accessibility Guidelines)
4. Appropriate Headings for grouped relationship
5. Innovation within categories
6. Overall performance rating mark out of 10 for effort

7.7.5 Scenario Results

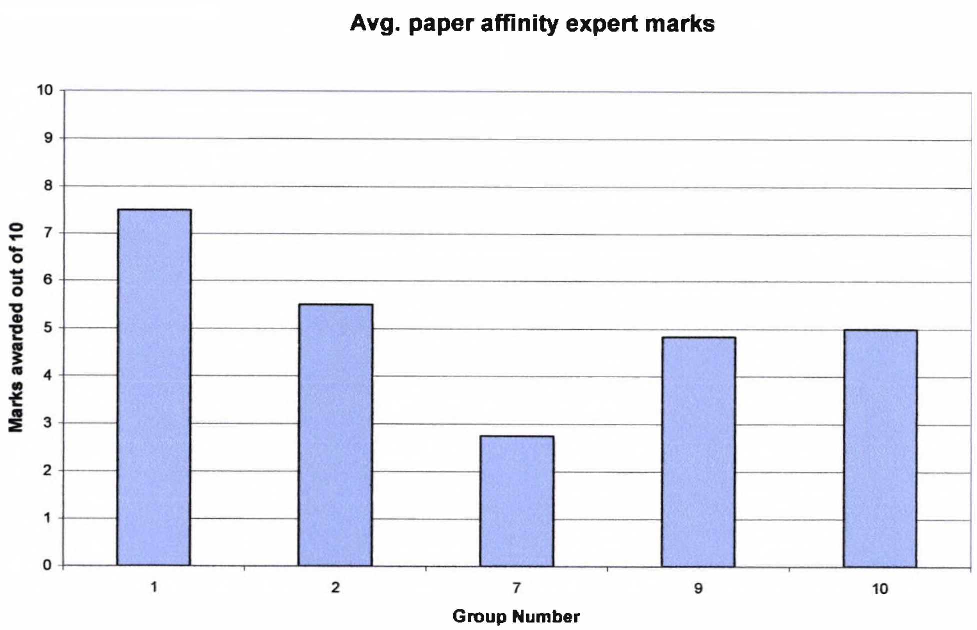


Figure 7.19: Paper based affinity diagram groups marked with the expert assessment criteria

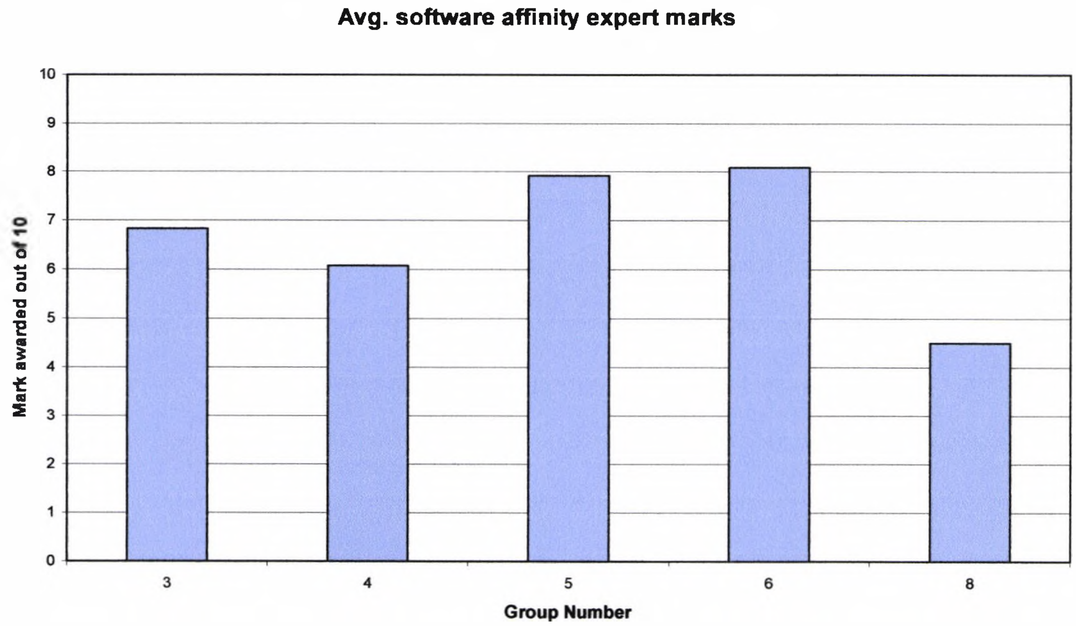


Figure 7.20: Software based affinity diagram groups marked with the expert assessment criteria

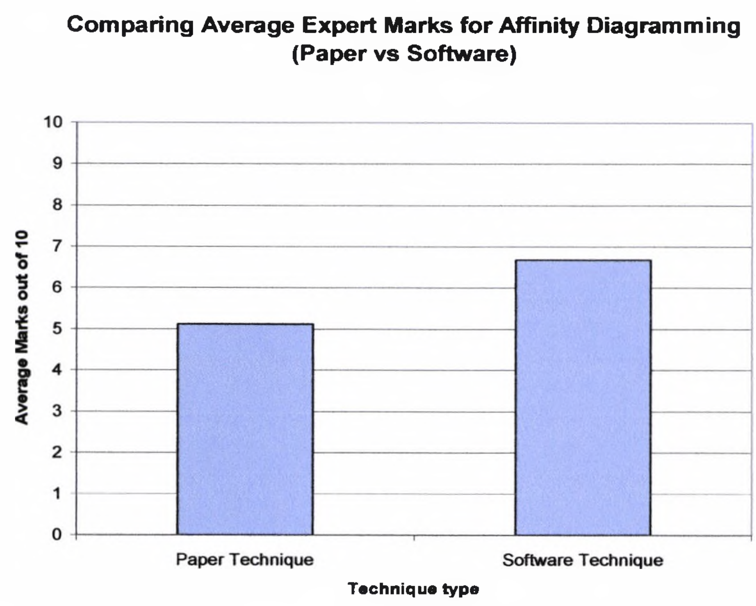


Figure 7.21: Means comparison of Paper vs. Software based affinity diagramming with expert marking

No significant difference was found between the expert assessment marking of the paper based affinity diagrams and the expert assessment marks of the software based affinity diagrams ($t(4) = 1.37 > 0.05$). This indicates that using the TabletPC software was not a negative influence on the practical methodology of affinity diagramming.

Terminologies for cluster headings varied from technical to simplistic language in both the paper and software methods. This was found in the post-experiment class discussion to be due to key phrases being remembered by the students from their actual course notes and extended reading lists, and is not considered to be relative to either paper or software methods alone.

In their teams, the participants' discussion facilitated the constructionist activity in promoting a contributory sense of active knowledge. Confused categorical placement and terminologies were clarified quickly by team members enquiring why a particular organisational activity choice was made, forcing a mediation process to aid reinforcement of self-reasoning.

These organisational activities and mediation processes form the key asset for the MATE tool to enquire and analyse the trends in activity over time within the software based affinity diagrams.

7.8 Empirical Testing of Semi-Dynamic Constructionism in Software-Based Affinity Diagramming

This section continues the data analysis of the experimental methods in section 7.7, further into the thesis aims of understanding constructionism in HCI. As mentioned in section 7.1, affinity diagramming is thought to have two key variables of constructionism that make it semi-dynamic in nature – firstly, the organisational activity of sorting physical cards into groups based on debate and consensus agreement within teams. Secondly, it looks at the mediation periods within arranging groups of cards whereby the team would be collaborating new ideas for the categorisation process, or thinking of how to refine their existing categories. It does not have the ability of completely removing entire concepts (e.g. whole clusters of cards) or (in section 7.7 experiment's case) of adding new card content significantly once the cards have been made, as observed in the initial investigation in section 7.3.1. An example of the data from a single instant within a SAW based affinity diagram is given in appendix E.5.1.

Unlike Inert Constructionism as defined in chapter 5 and used in exploring Chapter 6's case study, Semi-Dynamic Constructionism does not imply a pre-set initial knowledge domain, akin to open card sorting and more importantly, affinity diagramming e.g. cards are constructed by the participants. For these reasons this thesis has defined affinity diagramming as a model of semi-dynamic constructionism, as the sharing of idea-created knowledge as artefacts to create new knowledge is prevalent in the activity.

7.8.1 Measuring Constructionism in Affinity Diagramming with MATE

The MATE tool is used to explore constructionism in a measurable context of the software based affinity diagrams (created with CATERINE and SAW tools). Comparing the results from figure 7.20, with the total time taken (figure 7.22) and the organisational activity (constructionist activities – figure 7.23) shows that there is a potential relationship for further exploration (figure 7.24) especially over the temporal view of organisational constructionist activity.

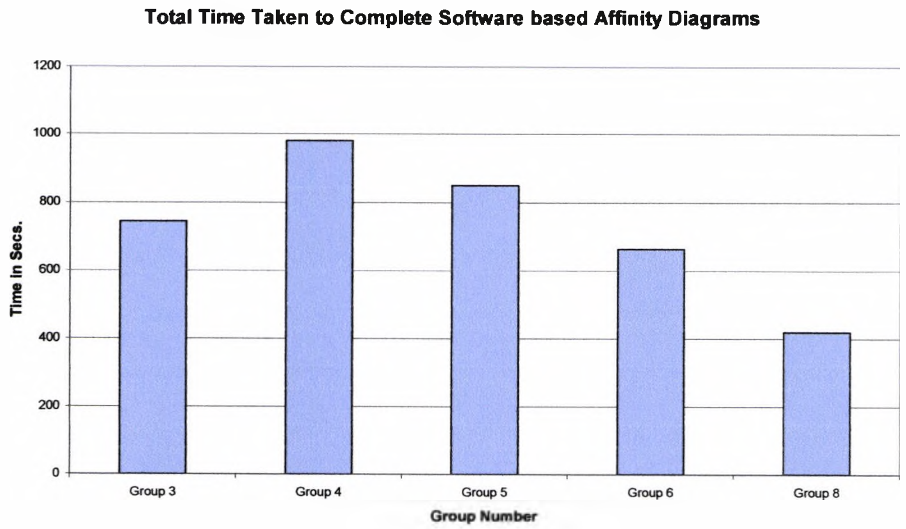


Figure 7.22: Total time taken to construct the software affinity diagrams

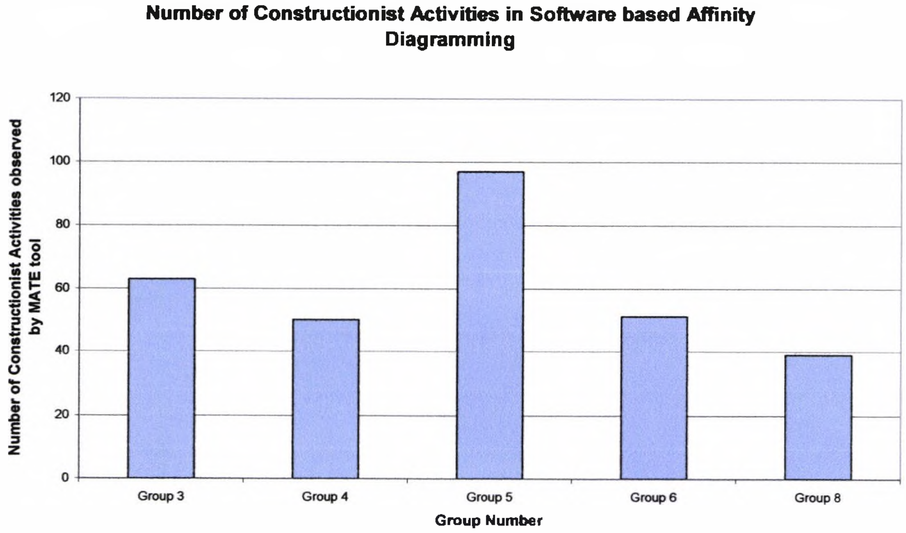


Figure 7.23: Organisational constructionist activity within the software affinity diagrams

Experts awarded Team 3 a summative total of 68% through use of the assessment criteria. Independently, the MATE tool detected 63 organisational actions (output in the graph in figure 7.24(a)) with a moderately steady pace of organisational activity over a moderate total time to complete their diagram.

Team 5 (figure 7.24(b)) were awarded 79% through assessment criteria by the expert assessors and their mark scheme. Independently, the MATE tool detected 97 organisational actions with a suddenly strong sense of constructionist activity towards the end, indicating very strong participation in a short duration of time.

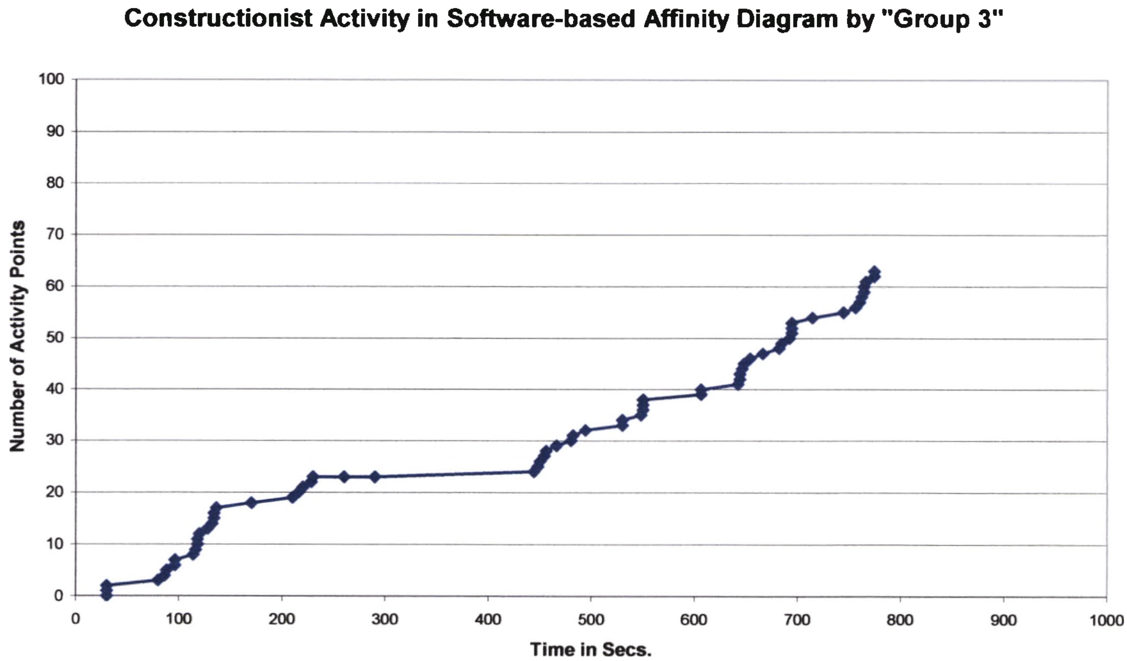
In this experiment the stimulus was obtained from the established W3C web accessibility guidelines, therefore there was only one optimal solution in categorizing them (W3C Guidelines, 2004). Based on the expert marking team 5 facilitated the most accurate affinity diagram as it is the closest to the optimal solution.

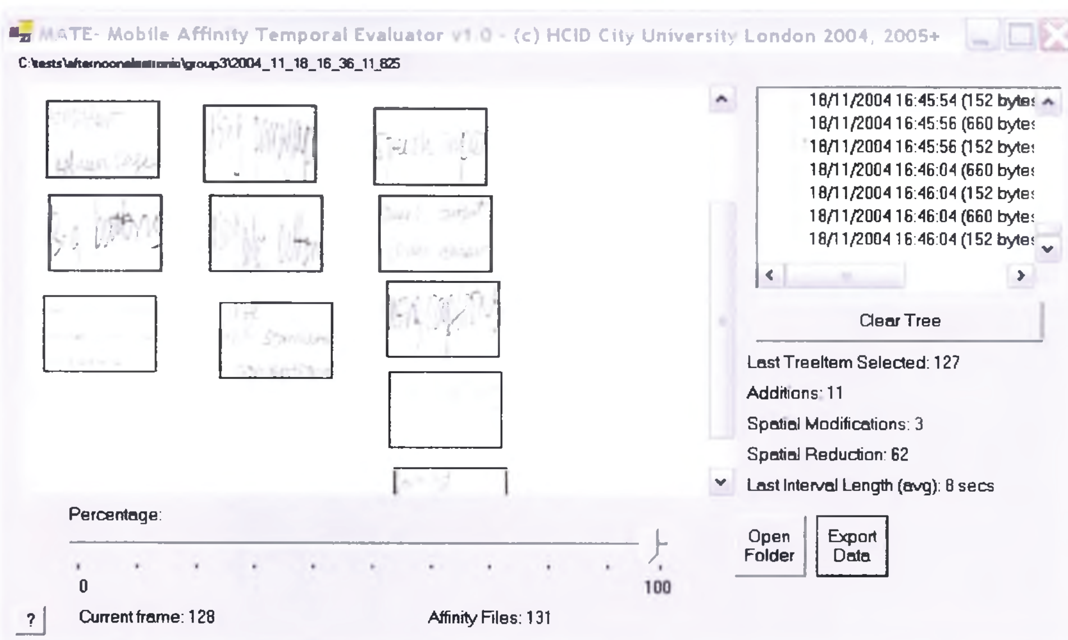
In comparison, on the lower end of the spectrum of results, the expert assessors awarded 45% through assessment criteria to team 8 (figure 7.24(c)). Independently, the MATE tool detected only 39 organisational actions with a weak dispersal of constructionist activity towards the end, indicating a lack of enthusiasm in a short duration of total time in their team. All of the other team results varied in between these 3 samples.

The use of the MATE tool for analysing the constructionist organisational activity over time determined several key points in this experimental methodology;

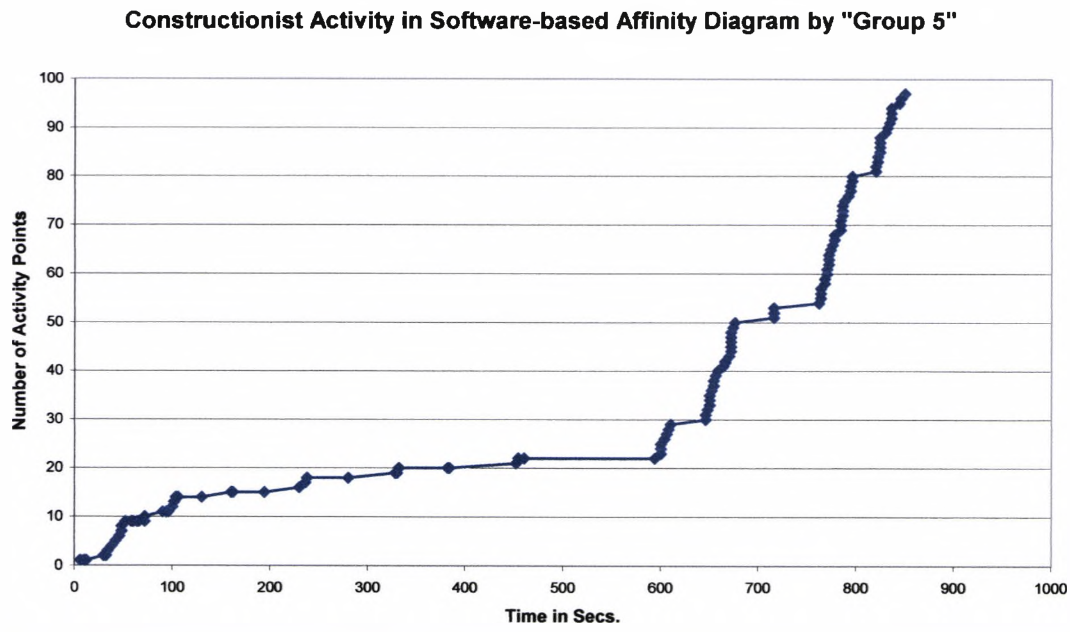
- The participant teams' constructive ability is found to be measurable in relation to their technical terminology and groupings as their awarded marks demonstrated (figure 7.24).
- Faster total times do not necessarily infer a better or lesser quality of output alone (figure 7.22).
- The organisational activity that takes place does infer, in this limited experimental context, a generalised case of the greater the activity over a longer time, the better the expert results.

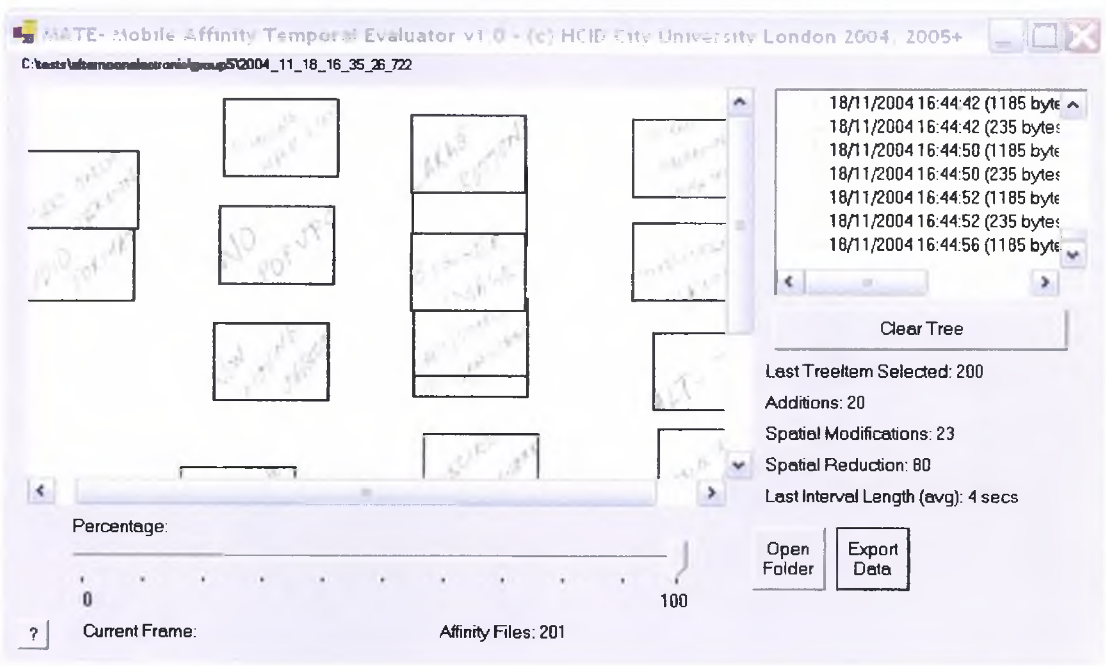
These points will be evaluated further in section 7.7.8. An example of raw data of organisational constructs from a SAW session is given in appendix E.6.1.


Constructionist Activity in Software-based Affinity Diagram by "Group 3"
Number of Activity Points
Time in Secs.
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000

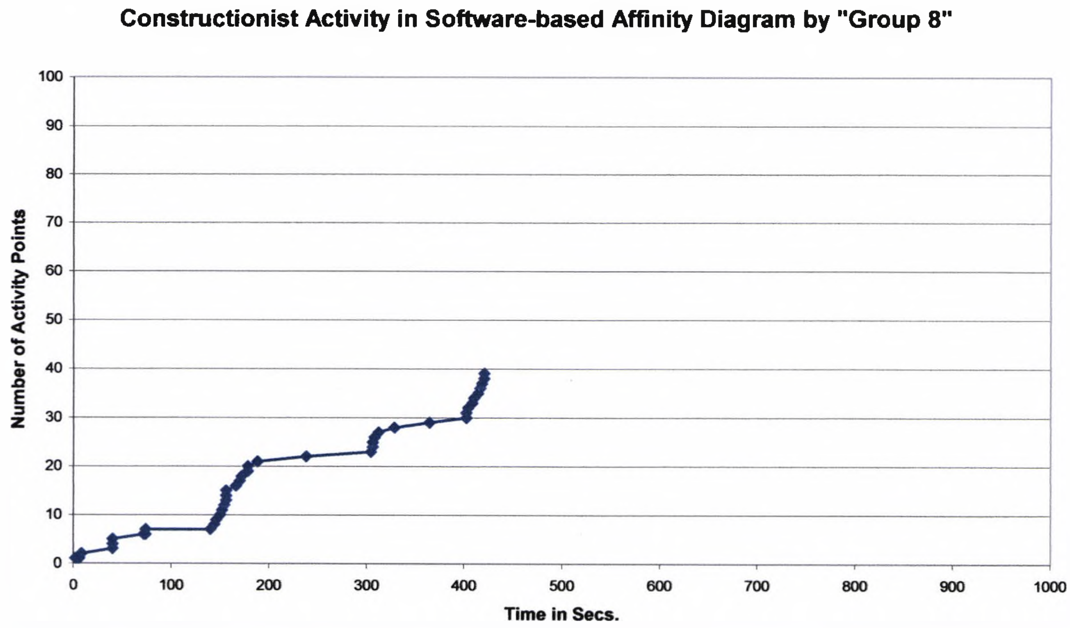

MATE- Mobile Affinity Temporal Evaluator v1.0 - (c) HCID City University London 2004, 2005+
18/11/2004 16:45:54 (152 bytes
18/11/2004 16:45:56 (660 bytes
18/11/2004 16:45:56 (152 bytes
18/11/2004 16:46:04 (660 bytes
18/11/2004 16:46:04 (152 bytes
18/11/2004 16:46:04 (660 bytes
18/11/2004 16:46:04 (152 bytes
Clear Tree
Last TreeItem Selected: 127
Additions: 11
Spatial Modifications: 3
Spatial Reduction: 62
Last Interval Length (avg): 8 secs
Percentage:
0
100
Open Folder
Export Data
Current frame: 128
Affinity Files: 131

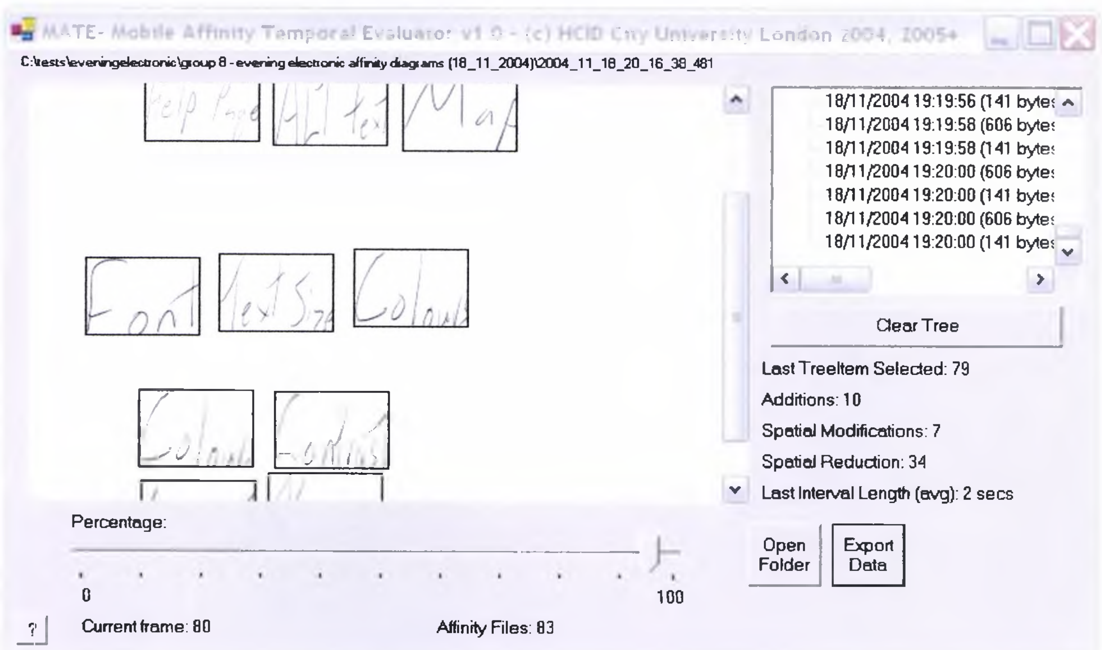
(a) Team 3


Constructionist Activity in Software-based Affinity Diagram by "Group 5"
Number of Activity Points
Time in Secs.
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
800
900
1000


18/11/2004 16:44:42 (1185 byte
18/11/2004 16:44:42 (235 byte
18/11/2004 16:44:50 (1185 byte
18/11/2004 16:44:50 (235 byte
18/11/2004 16:44:52 (1185 byte
18/11/2004 16:44:52 (235 byte
18/11/2004 16:44:56 (1185 byte
Clear Tree
Last TreeItem Selected: 200
Additions: 20
Spatial Modifications: 23
Spatial Reduction: 80
Last Interval Length (avg): 4 secs
Percentage:
0
100
Open Folder
Export Data
?
Current Frame:
Affinity Files: 201

(b) Team 5





(c) Team 8

Figure 7.24: Organisational constructionist activity in semi-dynamic constructionism, evaluated with MATE tool vs. human expert assessment marking criteria (Table 7.2)

7.8.2 HCI user evaluation of the SAW software tool

The results of the HCI post-questionnaires, CSUQ (Lewis, 1995; Appendix E.4.1) for ease of use of the tool, and QUIS (Chin et al, 1988; Slaughter et al, 1994; Appendix E.4.1) for user satisfaction, are reported in this section. Firstly, a custom designed CSUQ survey gives the results of an ease-of-use derived survey based on the original guidelines as reported by Lewis (1995). Here the scale is from 1-7 (7 being most positive, 1 being least). The results of this survey are reported in figure 7.25 and table 7.3.

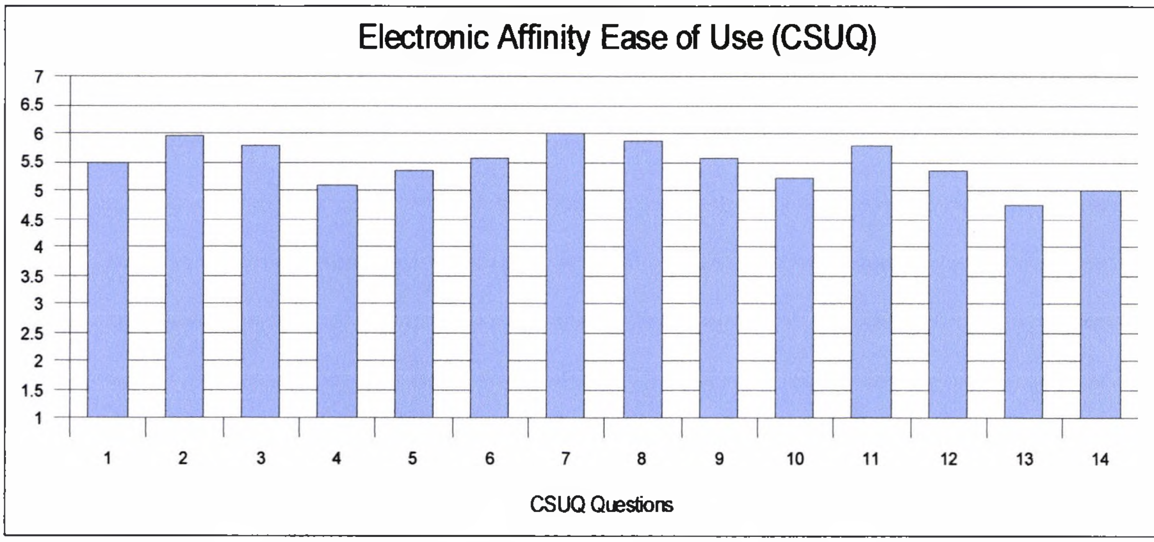


Figure 7.25: Mean CSUQ-based responses to the affinity tools

Table 7.3: CSUQ marks aggregated for each question type

CSUQ Question (ratings are from 1 to 7)	**Mean (1-7)**	**S.D.**
1. Overall I am satisfied with how easy it is to use	5.18	1.01
2. It is simple to use	5.29	1.06
3. I can complete the given task	5.24	1.22
4. I was able to complete the task quickly	4.95	1.79
5. I was able to complete the task efficiently	5.09	1.6
6. I was happy to use the software for the task	5.14	1.49
7. It was easy to learn to use	5.71	1.31
8. I became productive quickly using the software	5.05	1.43
9. Overall I am satisfied with the software	5.32	1.21
10. It was easy for our group to organise elements	5	1.9
11. It was easy for our group to make changes	4.9	1.92
12. The software brought agreement with members	4.45	1.54
13. It was easy for our group to change labels	4.77	2
14. The software has the capabilities needed for the method	4.7	1.59

The results from the CSUQ show a relatively positive confidence in the general ease of use of the technique in the mobile software, at 5.06 per person, with a standard deviation of 1.53. The QUIS ratings measure takes things further as a formal unmodified HCI questionnaire tool, measured 0 to 9 on a Likert scale, with 9 being most positive and 0 being most negative. The results of this are reported in Table 7.3 and figure 7.25. QUIS is used by HCI practitioners in industry for acquiring indicator strengths on how satisfying the software could potentially be for meeting user needs, in related future deployment scenarios, based on several key criteria and grouped by headings (table 7.4, figure 7.26).

Table 7.4: QUIS individual marks aggregated for each question type

QUIS Question (ratings are from 0 to 9)	Mean	S.D.
Overall reaction to software (1-6):	**5.96**	**1.82**
1. The software is wonderful	5.82	1.74
2. The software is easy to use	6.4	1.9
3. The software is satisfying to use	5.68	1.91
4. The software has adequate power	6	1.73
5. The software is stimulating	5.95	2.09
6. The software is flexible	5.95	1.7
Screen (7-9):	**5.41**	**1.95**
7. Reading characters on screen is easy	4.59	2.15
8. Highlighting simplifies the tasks very much	5.44	1.72
9. Organisation of options is very clear	6.24	1.61
Terminology and system information (10-15):	**5.88**	**2.07**
10. Use of terms throughout the system is consistent	6.45	1.5
11. The terminology is always related to the task	6.1	1.51
12. The position of messages on screen is consistent	6.68	1.73
13. Prompts for the input are always clear	6.35	1.95
14. The computer always informs about its progress	4.95	2.09
15. Error messages are always helpful	4.29	2.73
Learning (16-21):	**6.31**	**2.04**
16. Learning to operate the system is easy	7.1	1.33
17. Exploring new features by trial and error is easy	6.43	2.09
18. Remembering the names and use of commands is easy	6.59	1.89
19. Performing tasks is straightforward	6.64	1.89
20. Help messages on the screen are helpful	4.83	2.41
21. Supplemental reference materials are clear	5.78	2.11
System capabilities (22-25):	**6.8**	**1.7**
22. The system speed is fast enough	7.14	1.25
23. The system is reliable	6.43	1.72
24. The system tends to be quiet	7.63	1.54
25. The system is designed for all levels of users	6.05	1.9

The average QUIS based User Satisfaction score was found to be 6.09 with a standard deviation of 1.97.

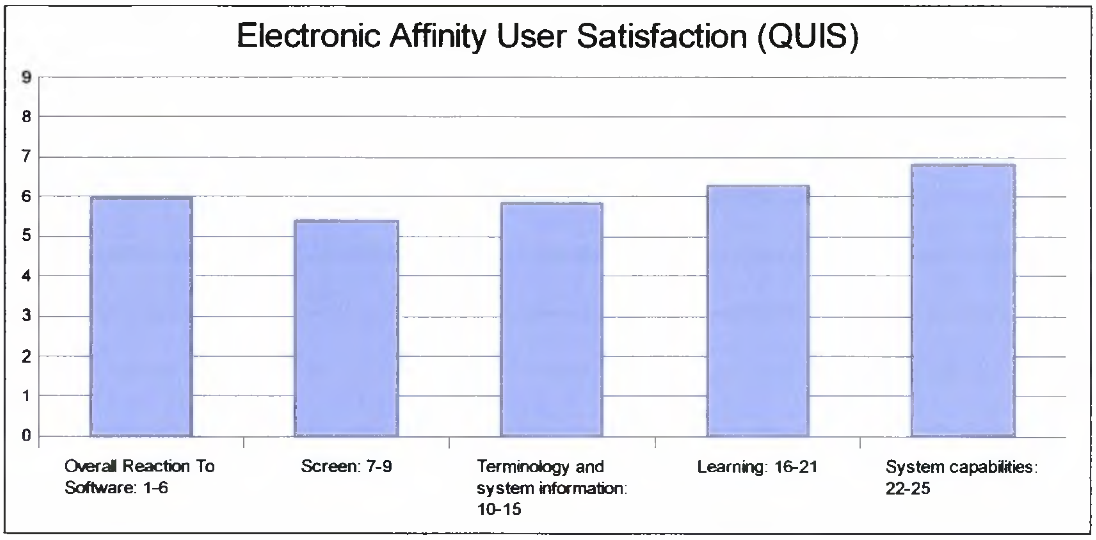


Figure 7.26: Mean QUIS responses to the affinity tools (rating 0-9)

In both of these questionnaires, the combined activity of creating cards with CATERINE and organising the cards with the SAW tool were considered favourably by the majority of users. A copy of the QUIS and custom CSUQ questions can be found in Appendix E.4.

The following statistical methodology was created to determine if a model exists to support a relationship between the standard HCI defined QUIS responses (user satisfaction), and the SAW tool based semi-dynamic constructionism.

7.9 Discussion of HCI Practitioners Benefits

In retrospect, the following points outline the key contributions of this user-centred designed and tested software methodology –

- It is portable and mobile, not requiring large equipment e.g. boards and can share output data views with others via the internet.
- The MATE tool gives extensive data for HCI practitioners to review the semi-dynamic nature of organisational constructionism within affinity diagramming.
- The board in SAW can be resized near unlimited to give large "virtual" space even though field of view is not as large as whiteboard.
- As the algorithm design for card storage and manipulation is based on linked lists, the SAW tool enables virtually memory-finite (humanly unlimited) number of cards to be used.

- All decisions are tracked and can be rolled back anytime in MATE, e.g. to compare what people think of group clusters at different temporal instances and allow practitioners to further interview and elicit the decision making factors of participants, which other than video observation has not been reported before (in addition, video observation is of a relatively low quality and it is not usually easy to read the small paper cards recorded on video).

- The software model maintains integrity as a shareable Ink-based GIF file format for cards which are therefore shareable across the internet with other users, as opposed to the paper method which is cumbersome and time consuming to collate and analyse.

- Non-editable outputs of final affinity diagrams in SAW can be shown to anyone conveniently e.g. as jpg images, whilst CATERINE features website generation to post the GIF based cards online immediately. This makes affinity diagrams easy to archive and retrieve in the same state that they were created in, as compared to the loose and obtrusive maintenance of paper based outputs.

- For novel users learning the software, the number of user actions had to be kept minimal. Thus a similar model of actions from the paper based approach is mimicked in software – user draws cards, then places on board and groups them. They then add labels and add more cards if they wish.

- SAW features the cloning cards for multiple group instances – something that paper cannot replicate quickly and easily (without drawing it out again/photocopying).

- The software has state of the art features e.g. handwriting recognition of labels, and high resolution ink manipulation for close simulacra of pen-based methods.

There are also several noted disadvantages for HCI practitioners using this software as an affinity diagramming method –

- It is obviously expensive for this equipment when compared to paper and pens; however the trade-off strength is in digitally recording and facilitating the technique in terms of time for practitioners to review and share large quantities of affinity data, which over time is worth man-hours.

- Though it has been designed to have an intuitively small learning curve, there is still a learning curve over paper and pens.

7.10 Conclusions

In investigating semi-dynamic constructionism, a tool (MATE – Mobile Affinity Temporal Evaluator) designed for automating the data analysis of the theory has been used in an empirical study with 40 postgraduates in a comparative test. The contributions are as follows; Positive results have been acquired through comparing data with expert formal assessment criteria, to demonstrate the strength and recognition of the new methodology as a viable alternative for simulating affinity diagramming with mobile technology as on-site knowledge elicitation. Results from analysing experimental data have shown that semi-dynamic constructionism can give weighted measures in mobile affinity diagramming.

In comparison to its paper based techniques, mobile software based affinity diagramming, in the apparatus form of a mobile TabletPC, has been demonstrated to enable decision making processes in affinity diagramming to be observed. This is achieved through the analysis of users' organisational construction activity of arranging atomic knowledge artefacts (cards created in a creativity tool named CATERINE, and arranged in an organisational tool named SAW), and as such gives an additional and automated measure for HCI practitioners to refer to the qualitative status of affinity diagramming over time. Comparing output data of both paper and software forms of affinity diagramming, with expert formal assessment guidelines, demonstrate the strength and applicability in using this mobile solution the existing methodology.

This research has illustrated an alternative technique using mobile software. This alternative has been empirically tested to simulate the actions of affinity diagramming, and takes into consideration the capability of the user(s) involved over the temporal view of the organisational activities in affinity diagramming. In addition to this, the technique of affinity diagramming in HCI KE now benefits from the modelling of Semi-Dynamic Constructionism theory, further grounding the domain with new variables for exploration in future HCI studies. This therefore stands as a contribution to the field of mobile HCI, pedagogical HCI and HCI in general.

Chapter 8: Dynamic Constructionism with Mobile Low-Fidelity Paper Prototyping

8.1 Introduction

This chapter aims to conclude the exploration of Chapter 5's framework of constructionist modelling in Mobile HCI KE methods. To achieve this goal, this chapter presents Dynamic Constructionism as applied to Mobile Low Fidelity Prototyping. In chapter 5, the framework of constructionist metrics reported the design of an events pattern framework for artefact driven activity (Table 5.1). This activity is strongest in dynamic constructionism whereby collaborative teams work on the construction of creative artefacts in non-linear temporal spaces. The visually and interactively rich nature of the low fidelity prototyping technique provides a basis for exploring dynamic constructionism and the full events pattern framework.

Low-fidelity prototyping is a widely used Knowledge Elicitation technique in HCI. However, empirical assessment methods for low-fidelity prototyping have remained relatively static even with the development and use of software prototyping design tools. In this chapter, we describe how the devised framework of constructionist metrics gives us a new view to modelling collections of design artefacts as measurable constructs within low-fidelity prototypes.

This provides a novel approach to acquiring further cognitive user metrics within software based low-fidelity prototyping in the HCI domain. Two mobile software tools developed for the TabletPC platform are described, PROTEUS and PROTEUS EVALUATOR, which use our theoretical framework to aid our understanding of prototype designs during their temporal construction. Results of using the tools with two scenario experiments are reported, each conducted with 40 HCI Postgraduate students. This was done in order to demonstrate the effectiveness of dynamic constructionist metrics (see chapter 5) as applied to practical low-fidelity Prototyping in mobile HCI Knowledge Elicitation.

8.2 Problem Domain

The practice of Low-Fidelity Prototyping as a HCI methodology uses simple materials and equipment to create a paper-based simulation of views to an interface or system with the aim of exploring early user requirements and visualizing layout (Snyder, 2003), accessibility and potential aesthetic approval of design ideas through early user testing. In particular, usability problems can be quickly identified (Catani & Beers, 1998; Virzi et al., 1996) and empirical testing with direct user involvement aids in the user centred design process in fitting requirements (Beyer & Holzblatt, 1998; Grady, 2000; Hackos & Reddish, 1998).

Though there are more complex techniques such as vertical and high-definition/Rapid Application Design (RAD e.g. in HTML, Visual Basic and Delphi languages) prototype designs, as Vizri et al (1998) reported in their study, low fidelity approaches reveal substantially the same set of usability problems as high fidelity conditions.

Over the years, strategies and uses of low-fidelity prototyping methods (Hardgrave & Wilson, 1994) have grown to become a key asset in the HCI toolkit. Some of these include the Wizard of Oz technique which simulates an intelligent system responding to various inputs and processes by use of humans acting on the output (Maulsby et al, 1993). With traditional paper and pen based low fidelity approaches, it is common to denote features of a user interface with visual artefacts metaphorically described on pieces of paper, e.g. menu bars with triangles on either end, or rectangular buttons for actions. If it is being constructed with movable separate pieces of paper these artefacts allow members of a prototyping team to easily reach a consensus on the effectiveness of position, size and purpose. It is also common to label features and visual artefacts, with annotation descriptions of their purposes and links to other artefacts.

There are numerous painting and drawing software programs such as Windows Paint, Macromedia Flash, Adobe Photoshop, Microsoft Visio and the GIMP which can be utilised as convenient tools for general software low-fidelity prototyping of user interface designs. Recently, several groups have notably contributed HCI-orientated prototyping tools, including the GUIR team at Berkeley (Walker et al., 2002), which has produced Denim and Silk that facilitate prototyping of early stage web site design, allowing low fidelity prototype views to be "run" connectively with hyperlink navigation to other prototype views. Also their Suede system (Klemmer et al., 2000) is a powerful speech based Wizard of Oz Prototyping tool based on speech dictation interfaces. Finally, Topiary (Li et al, 2004) allows storyboarding to be viewed on PDAs to conduct prototyping location enhanced applications, depicting spatial location elements.

In my thesis a crucial issue was to be able to capture and analyse the process of construction of design artefacts. As explained in chapter 5 my analysis is centred around constructionist measures. The problem and weakness of all of the existing computer based low-fidelity prototyping tools is that they fail to enable HCI practitioners, researchers and academics to gain a deeper insight and qualitative metrics (for example, metrics that help to generate figure 8.11) in the construction of a paper prototype. Furthermore these tools are rarely, if ever, constructed using User Centred Design (UCD) methodologies. This implied that I had to develop my own tools. In section 8.3 I describe the UCD based construction of PROTEUS to address this weakness.

This is achieved in the following research in two ways. Firstly by enabling the technique to be used mobile and on-site, to best create an environment that would put the user at ease (Snyder, 2003) and therefore gain a more naturally representative dataset of results[2]. Secondly and more importantly, it enables the use of the framework of constructionist HCI modelling (see chapter 5) on low-fidelity prototype design artefacts to infer qualitative reasoning on the prototyping ability of the user. By acquiring this constructionist information we can enhance the HCI methodology with new measures in an environment that is typically descriptive in functional knowledge elicitation, but lacking in empirical data.

8.3 Case Study A – The Design of PROTEUS

This section describes the investigation, development and evaluation of the PROTEUS software tool, which is subsequently used to prove the hypothesis of using dynamic constructionism effectively in HCI KE in Case Study B (Section 8.4).

8.3.1 Participants

The intention of developing a tool for HCI practitioners in user-centred design meant they (the practitioners themselves) would be the expert domain to conduct knowledge elicitation exercises with. Several participatory design (PD) sessions with 4 HCI researchers/practitioners were conducted for the development of PROTEUS. The 4 users (1 male, 3 female) are members of the Centre for HCI Design, City University London as of 2004. They all have had a minimum of 5 years experience with computing and the internet, and a minimum of 2 years experience in HCI. They have all been involved with teaching related computer science and HCI material at some point in their

[2] Citing the use of Situated Cognition Theory and Kelly's Personal Construct Theory as reported in Chapter 4, whereby quality of knowledge learnt from varies in their context of environment.

academic careers. These participants had been also utilised in the design and evaluation of SAW therefore they had an awareness of the motivation to create mobile tools for HCI use, but there was no bias as these methods and tools are distinctly different and the analysis of data collected did not involved comparison of the tools..

8.3.2 Design Procedure

A collaborative affinity diagramming session (chapter 7) with the 4 participants was conducted, with each of the participants creating their own list of features on cards before merging them together (appendix F.1.1). This was done to elicit first level requirements and subsequently provide a request for common features "wish list" (table 8.1) for a mobile based digital paper prototyping tool. The affinity diagramming session then merged into a focus group to elicit combined reasoning for any additional features requested. More advanced features that were considered beyond the scope of this research were at that point rejected (examples include video conferencing integration, and online chat with other users). The focus group prioritized features that were most necessary to them. At this point, mobility and constructionism was not brought into the focus group debate.

Table 8.1 Features "wish-list" for a digital paper prototyping tool

Feature requested	Reasons
Natural inking	Mouse-based drawing is not as comfortable as using a pen, hence you can't really ask users to use PCs for prototyping
Scalable screen/zooming	Being digital should allow a prototype to be viewed at different levels to add refinements if so chosen
Colours and pen types	Designs should be able to be highlighted and colour coded if a user wishes to make a point of importance. Also editing an existing prototype design to change its colour and pen properties would be a useful advantage over paper method.
Importing existing drawings	What you draw should be reusable e.g. making digital copies would be very useful and timesaving. In existing paper prototyping it is time consuming to redraw existing elements
Movable drawings	What you draw should be easily manipulated to satisfaction.
Scalable drawings	What you draw can have an impact in understanding if a user can scale items to give a sense of proportions
Shareable drawings	Existing paper prototypes are notoriously unstable by concept for sharing with others to review.
User centered UI	The main software alternative, DENIM, has an unusual and non-intuitive user interface for first time prototypers.

The focus group acknowledged that standard paper and software approaches are great for eliciting basic informal requirements, and are easy and cheap to conduct. However there are some very interesting abilities that digital methods (like DENIM) have been proven to aid HCI research in the theory of prototyping designs (Walker et al., 2002; Sefelin et al., 2003). DENIM's abilities include automating the hyperlinking of prototype objects, such that designs can be "run" and simulate the correct linkage between designs.

In addition it has various ink-simulation capabilities to enable natural user actions that simulate paper and pen designs. The tradeoff in convenience of paper vs. preparing users with digital tools was discussed as a major need to be tested (see section 8.4 experimental methods and section 8.5 results).

At this point, the focus group was prompted towards the topic of applying mobility in HCI methods and the usefulness of on-site design and usability testing. This was done to elicit their understanding of what they may gain from applying mobile computing methods to their discipline.

The first point raised was that they knew of no such tools that would aid them with this. Chapter 2 already demonstrated this weakness in the HCI discipline, but this focus group response enhanced the validity of that reasoning. At this point, the four practitioners became aware of new requirements needs and facilitated further discussions amongst themselves. The key question asked was "why would we want to do a paper prototype on-site at a client's location?". Several responses facilitated the debate further. Table 8.2 summarises the findings from this debate.

Following this, a brief discussion on the theory of Constructionism was given. Direct user observation technique (see Chapter 3) is the most widely used method to acquire a historical recording of the creation of a design construct (Shneiderman, 1998). However, reviewing the creation of design constructs from recordings is not only time consuming with individuals but in large groups it can be a lot of man-hours of work, similar to transcribing interviews.

The notion of temporal analysis capturing key design artefacts being created was then described, as per requirements of constructionist metrics framework in chapter 5. Seeing activity decisions with modifications and removing of potentially interesting and valuable design assets as they occurred in a temporal view that can be reviewed at anytime is similar to direct observation note-taking.

Table 8.2 Understanding mobility for low fidelity prototyping

Point raised	Discussion
At a company on-site, low fidelity prototyping can sometimes look childish to higher management, and its size on paper is often impractical (Snyder, 2003).	A mobile tool that can be brought into corporate environments will bring about a sense of professionalism rather than walking around with A3 pages and bits hanging off.
Sharing paper results of a prototype with a few people is not always the best way to win marketing or acquire enough confidence in a design before building, in academia or in business.	A digital format that maintains low-fidelity views but is also shareable e.g. over the internet, means a much larger audience can be a part of the prototyping critique.
In a classroom scenario the HCI students may not take low-fidelity prototyping seriously as an effective user-centred method and many do not see its value in HCI. This is evident in their lack of use of the technique in their own project work in past experience.	Perhaps a mobile tool brought into a classroom can raise enthusiasm for the use of the methodology and encourage them to explore its usefulness further.
Designs with existing prototyping software tools have not really been mobile-compatible, and are bound to be useful only in lab based experiments on desktop machines.	DENIM's TabletPC support features are growing. Not many of the other software tools available are centred on the methodology; they are more taken from the artistic and diagrammatic perspectives
Some HCI scenarios of interaction are not best evaluated by simulation in a lab with hired participants, but actually in the actual physical environments where an understanding for the context of use is more applicable, as in the theory of Situated Cognition (Choi & Hannafin, 1995).	CAKE (Mohamedally et al, 2003b) and Mobile Scenario Presenter tool (Maiden et al., 2004) demonstrates that the use of mobile user-centred tools in the context of environment will elicit accurate user data that would not have been acquired through simulation in a laboratory.

However, the suggestion that this feature could automatically generate spreadsheet data made the participants more aware of its significance in acquiring new information on user design confidence. The dynamic constructionism model viewed as artefacts in a construct would reveal user knowledge and cognitive abilities that are not otherwise easily and conveniently acquired. It was explained that a second software tool would be constructed later in the development cycle solely for this purpose.

The practitioners were then introduced to the concept of TabletPC (Microsoft Corp, 2002) as a mobile device for potential use as a platform for the tool. None of the practitioners had used a TabletPC before, but all had used PDAs before. TabletPC-based pen gestures were demonstrated, as was state of the art onscreen handwriting recognition as a potential data entry interface to the tool. PDAs were debated as an alternative platform for a while, but the limited size of the screens and lack of pressure sensitivity in stylus use, meant that prototype designs would not be comfortably designed.

Once becoming accustomed to the user capabilities of mobility and pen input on the TabletPC screen, the focus group was asked to individually design low fidelity paper prototypes of potential user interface designs to the paper prototyping tool (figure 8.1, figure 8.2; appendix F.1.2). This user-centred design gave expert HCI views to organization and layout of key functions. This was then used to compare potential user interface options, navigation consistency and investigate potential routes for minimizing user actions in creating a synthesis design of the end user interface from several expert designs.

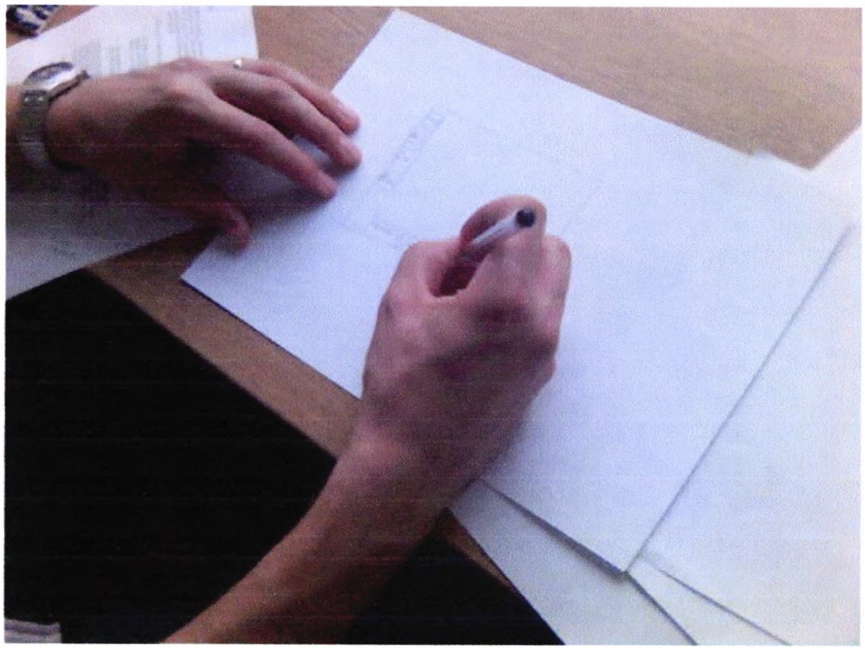


Figure 8.1: Expert prototyping design session of the PROTEUS tool

A follow-up focus group session aided in optimising button sizes for the TabletPC pen, as well as removing and minimizing less useful and potentially obstructive features. With consensus of the four HCI experts, a common style guide scheme for the user interface properties was created based on their suggestions.

Figure 8.2: expert designed low fidelity paper prototype of the PROTEUS user interface

8.3.3 Apparatus Construction (technical)

Using digital inking methods with the TabletPC meant it was possible to acquire visually rich and high quality pen emulation fidelity, with strong metaphorical mimicking of the existing interactions of paper and pen prototyping, especially with the TabletPC device in slate mode. As a hybrid mobile device between PDA and PC, a TabletPC's inking facilities feature pressure sensitivity in onscreen pen motion, pen gestures for user metaphor based event firing and real-time recognition of handwriting on visual user interface components.

In addition, it provides the user with novel advantages in being able to maintain portability for on-site uses in a digital form. The synthesis of the methodologies and inclusion of the constructionism framework leads into the title of the PROTEUS software tool (**PROT**otyping **E**nvironment for **U**ser-interface **S**tudies), with a second software tool, PROTEUS EVALUATOR, to assist in the analyzing of artefacts over time in forming constructs within PROTEUS based low fidelity designs. Both PROTEUS and PROTEUS EVALUATOR are built with the Microsoft TabletPC Software Development Kit (SDK) Version 1.7 using the Microsoft Visual Studio.Net 2003 professional development environment.

The interaction model mimics the physically tangible model of paper based prototyping as close as possible all of which were based on the functional needs of the HCI practitioners as explained in section 8.3.2, table 8.1; e.g. pen sensitive drawing/selecting/erasing (pen down with depth for drawing), auto-selecting connected elements (pen double click motion), picking up and moving visual elements (pen drag motion on selected elements), and quick erasing (pen eraser button).

These digital pen actions have the added advantage of providing a resource of data for digitally logging all motions and actions, and record-keeping of the artefact formation in progress, as well as being fast and convenient for using a pen in a one-handed mobile or stationed environment. It also enables PROTEUS EVALUATOR to calculate in software arbitrary Mediation Point delays between artefacts, originally set at a default of 10 seconds. Thus after 10 seconds of inactive use, further artefacts, mediations or refinements are considered to be a new construct.

PROTEUS version 1.0 (figure 8.3) simulates the actions of a low-fidelity paper prototype being constructed with the addition of all user events being recorded, including every pen stroke and user interface choice via SDK GUID calls[3]. Using this data it constructs temporal roll-back views of the prototypes creation so that every action of manipulation of the virtual paper prototype can be evaluated at a later date to elicit potential weaknesses or strengths at prior stages of the prototype design process.

[3] GUID – A programmatic term used to define a "Globally Unique IDentifier": a pseudo-random number used in software applications. Each generated GUID is "mathematically guaranteed" to be unique. This is based on the simple principle that the total number of unique keys (or) is so large that the possibility of the same number being generated twice is virtually zero. Referenced from http://en.wikipedia.org/wiki/GUID

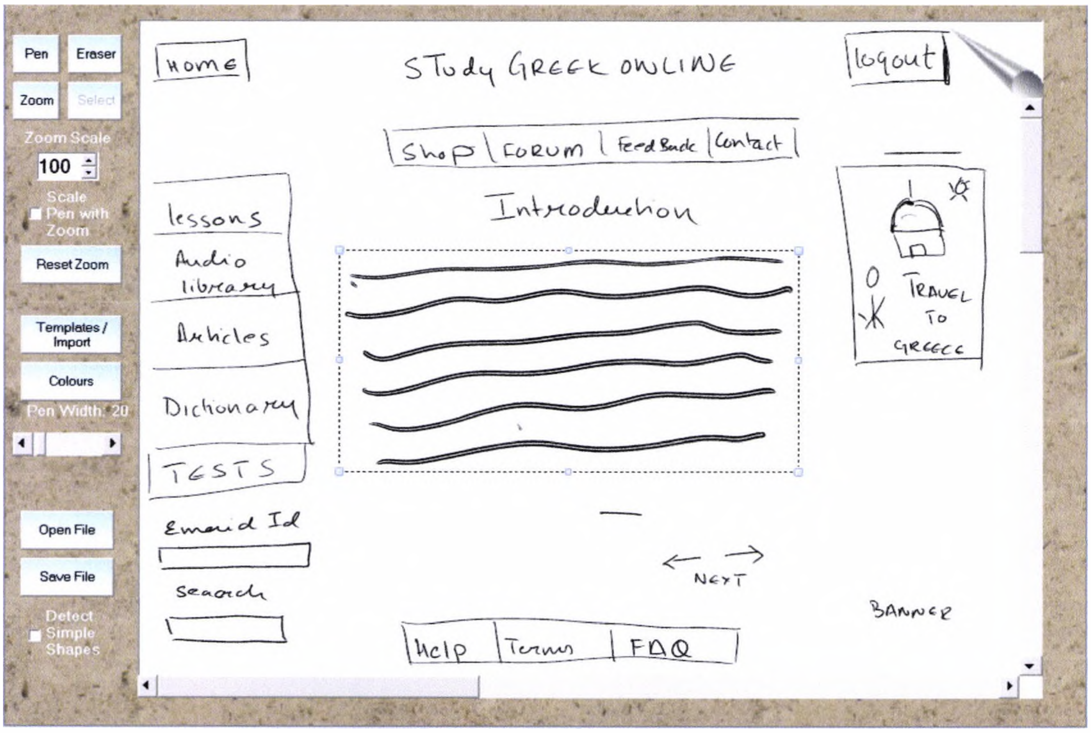


Figure 8.3: PROTEUS with a low fidelity prototype of a website design scenario

The time indexed ink-encoded GIF file output (serialized from the TabletPC SDK) can be shared with others and imported into existing designs as prototype element templates. This is in addition to applying now standard ink manipulation and interaction modifiers such as selection, scaling and moving of ink strokes and collections of strokes, applying transparency, and colouring to highlight and distinguish artefacts, and page zooming for refining ink details.

As Tabletised ink is zoomed in or scaled by the user for refinements, the TabletPC SDK has modifiers for the `DefaultDrawingAttributes` context set with `FitToCurve`, `Transparency`, and `AntiAliased` options used. This enables the redrawing of ink strokes to give a highly accurate and comparable appearance of near resolution independence upon digital inking, without visible pixilation effects (figure 8.4).

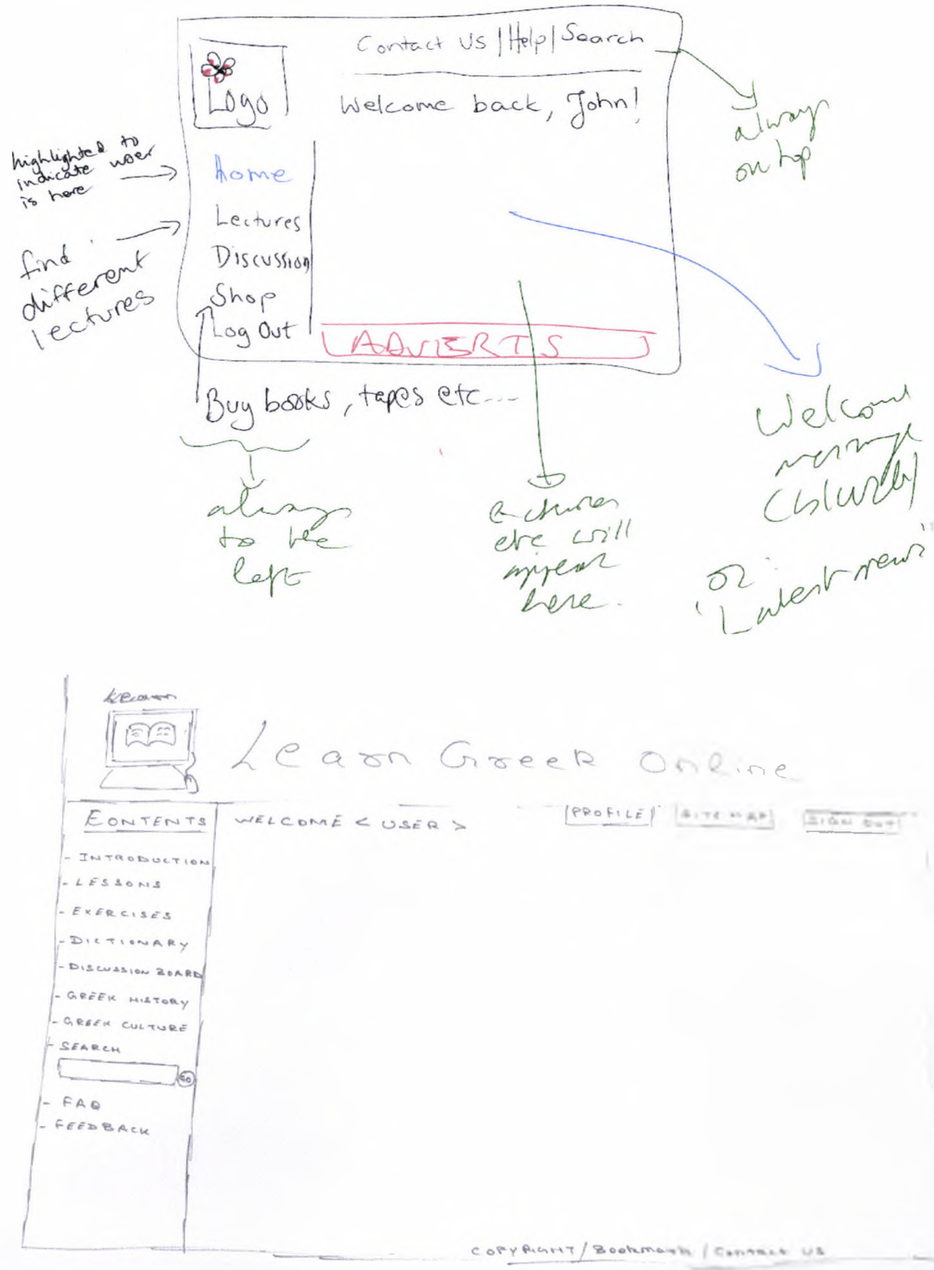


Figure 8.4: The output fidelity of PROTEUS (top) is comparative to the inking quality of normal paper and pen methods (bottom).

Ink-encoded GIFs retain their added ink stroke editable information (in the SDK as an InkCollector object type), and will also include their time stamps of creation. This is done via API calls to the `GUID(10, 11, 12, 10, 0, 0, 0, 0, 0, 0, 0)` [4]. What is important to know is that the GIFs maintain this data persistence for later re-editing and enabling others to manipulate and expand on existing prototype designs.

This in combination with the constructionist mediation points recorded allows a practitioner to get a deeper sense of how active and enthusiastic a user was when

[4] This information at the time was not freely available and it was determined to be an unpublished API call that the original development team did not explore. Subsequent revision to technical documentation at Microsoft.Net TabletPC development later incorporated it and published it widely to the development community.

designing and at what points in the design did they spend longer times or less activity on. The GIFs can also be read by any graphical image editor and web-browser supporting the standard GIF file format in non-data persisted form. This makes them very useful for sharing low-fidelity prototypes quickly with other PROTEUS users electronically as well as regular web-browser users.

All activity onscreen is tracked and can be rolled back to prior times. This enables design histories to be compared with other user design sketches in addition to comparing what users activities occurred within the decision making of a group of artefacts at different temporal instances (demonstrated by the PROTEUS EVALUATOR tool). This allows the practitioner to review the mediation point stages such as those leading to mediation and refinement facilitation (figure 8.5).

This interactive reviewing method allows a practitioner to enquire further direct observation details in post interviews and focus groups with participants, without extra equipment. It does so by allowing them to visually refer to any point of the original design timeline with the history of actions re-playable. Examples of this include erasing off parts to an artefact or moving artefacts around.

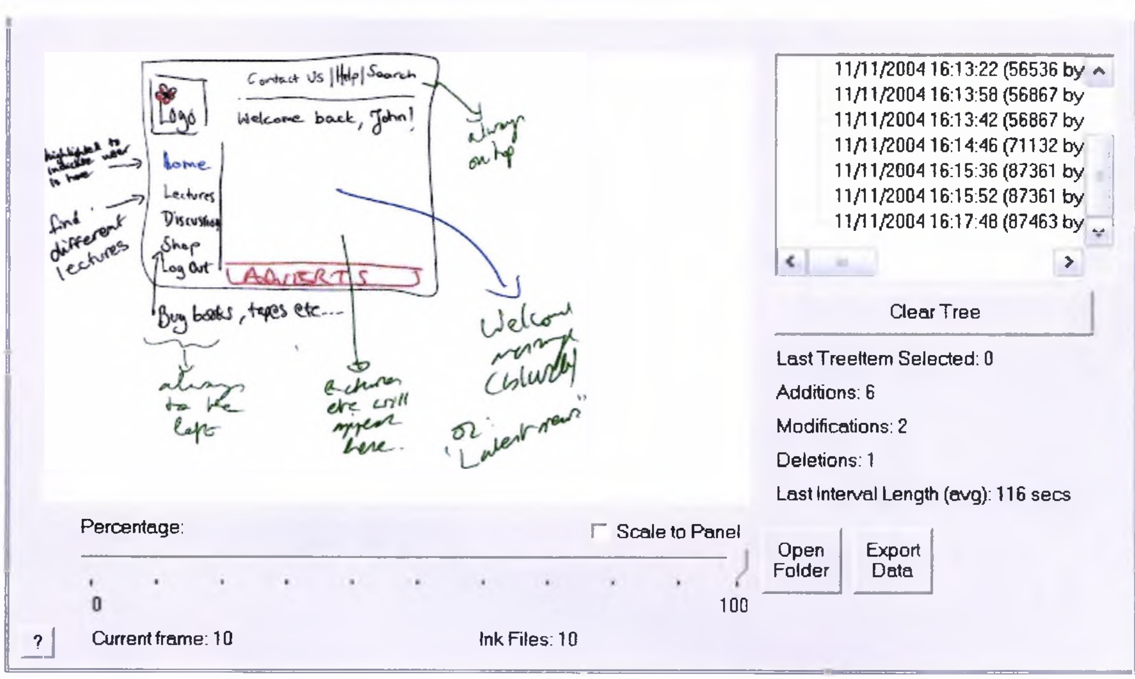


Figure 8.5: PROTEUS EVALUATOR Tool analyses prototype artefacts over time

8.4 Case Study B – Evaluating with PROTEUS

This section describes the investigation process for devising and conducting the evaluation of the dynamic constructionism part to the metrics framework in chapter 5 with the software tools devised in section 8.3.

8.4.1 Participants

In order to better understand the application of constructionist assessment in prototyping, the scenario testing of the tools and the theoretical framework were undertaken with 40 postgraduate MSc participants recruited from an HCI module, taught at City University London's School of Informatics. By use of an existing academic marking scheme, a qualitative comparison of paper prototypes creation gives us a view of the end result confidence in design. In comparison, PROTEUS would be used to create software designs, with PROTEUS EVALUATOR being able to use the constructionist framework to give temporal qualitative data on the confidence in design. This enables a comparison to be made between the constructionist framework results and with an existing expert HCI marking methodology.

An introduction to the experimental method and a consent form was given and accepted by all of the participants. A Pre-test questionnaire was then given to acquire the participant's demographic details and an understanding of their use of mobile technologies. The results of this questionnaire were reported in Chapter 7, section 7.7.1. To recap, the results showed 82% of the participant population was aged 18 – 29, with the rest being older. The male to female ratio was found to be 3:2. It was found that 86% of the participants had not used HCI specific software tools before. More specifically, 57% (approximately half) of the participants had not used a freehand software sketching tool before. The proportion of mobile devices used against number of users was reported in Chapter 7, figure 7.12.

Working in small groups each, the main experimental method was separated into two with half the class assigned to facilitating the software based method and the other half facilitating the existing paper-based prototyping method for comparison.

8.4.2 Apparatus

The software participants were invited to utilise the PROTEUS tool. They utilised 4 TabletPCs (1GHz+, each with 512Mb RAM running Windows TabletPC 2005). As the demographics data in figure 7.12 shows, very few of the participants had used a TabletPC mobile device before, although various devices as phones, PDAs and media players were quite prominently used. This data was useful to know as it means a general presumption that the participants were somewhat gadget-savvy and therefore should potentially be able to become accustomed to a new mobile device with relative ease.

A brief introduction to its facilities was given, and the TabletPC pen in particular was demonstrated to the participants, to make clear how it was to be used. Large A1 sheets of paper and a selection of felt tip pens were utilized for the paper-based prototyping participants.

The experiment was held in a large auditorium lecture hall. The purpose of the experiment was to examine real-world prototyping with HCI people as participants using the potential of mobile software. Whilst an auditorium based evaluation is not a perfect solution for mobility, it was considered to be a feasible alternative given the costs of arranging for industry testing.

To further address this problem, the student participants were invited to move about and collaborate in their groups by sharing the tabletPCs, to simulate as best as possible the aspects of mobile freedom.

8.4.3 Experiment Procedure

The participants were given instructions on the experiment they were about to take part in. For the first half of the experiment session, half of the class was using the TabletPC software and the other half was using the paper methods. The task given to them was to design an interface to an online language learning website (figures 8.4 and 8.6). This task was considered to be limiting in creativity given that the participants were already conceptually familiar with the scenario as it has been already used in other class activities. After that task was completed, the software participants swapped apparatus with the paper method participants (figure 8.7), and all of the participants had the task of designing a novel interface of a train ticket machine (figure 8.8). This task was considered to be more creative given that the participants were not familiar with the scenario as it has not been used in class before.. This way, all participants took part in two scenarios (one creative and one limiting in creativity) and used both the software and the paper method.

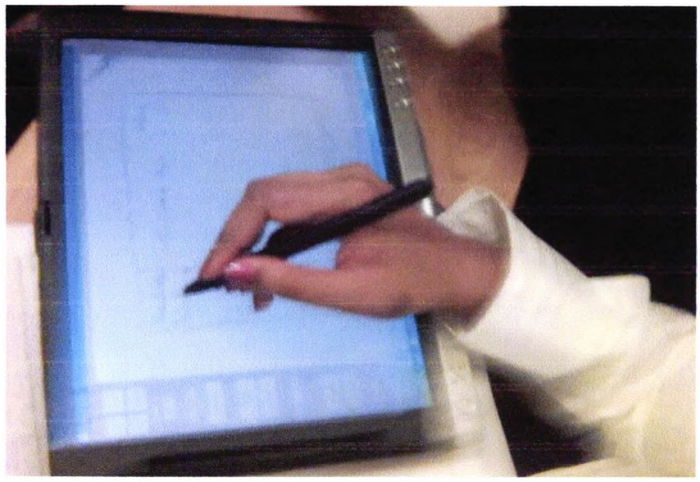


Figure 8.6: PROTEUS interaction being figured out by the participants

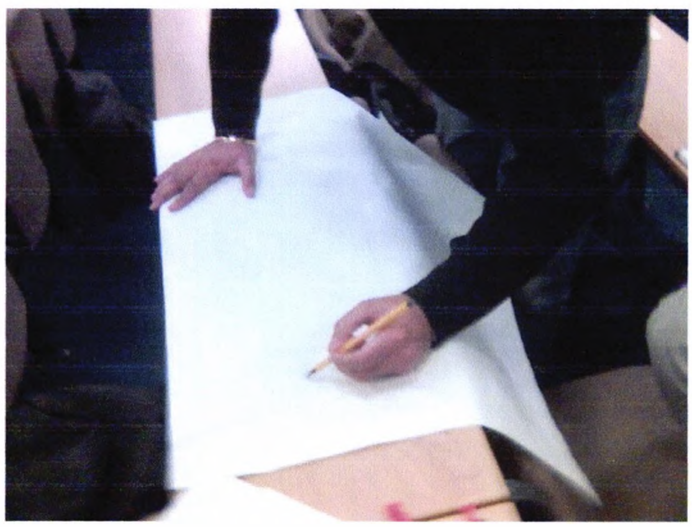


Figure 8.7: Paper based prototype being drawn by hand on an A1 sheet

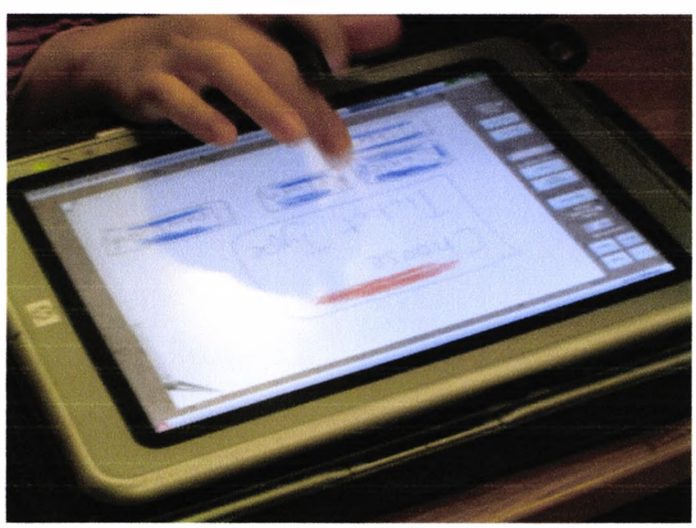


Figure 8.8: the ticket machine scenario being conducted on PROTEUS

Each group was given 20 minutes to complete each task. Upon completion of their prototypes, the different groups were shown the others solutions to demonstrate the variety of prototyping ideas that groups can be made using low fidelity prototyping in practice. Appendix F.2.1 has examples of the paper outputs created. Appendix F.2.2 has examples of Proteus EVALUATOR with example sketches.

8.4.4 Analysis Method

For HCI lecturers, practitioners and researchers, the methodologies for evaluating practical paper and software forms of low fidelity prototyping are fairly similar in acquiring key user requirements (Walker et al., 2002; Sefelin et al., 2003), eliciting more of the conceptual basis and creativity of ideas than precision in style. Table 8.3 shows our department's expert assessment criteria as used to evaluate paper prototype courseworks from an HCI MSc class. shows the Centre for HCI Design's own expert assessment criteria as devised and validated through years of use by lecturers in the department, These expert criteria can only represent the understanding of a final view to a prototype. What is of interest to HCI practitioners and educators however, is the significance of changes made to the prototype during its creation. For example, why certain artefacts which were created separately, were then moved and clustered together, or why certain artefacts were erased and replaced with alternatives. This level of enquiry has been relatively unexplored in low fidelity prototyping, and thus makes constructionism theory useful to low fidelity prototyping.

Expert marking evaluations of the prototypes were conducted with two HCI practitioners marking the software views, and a different two HCI practitioners marking the paper views, such that bias of software against paper expert comparisons could be avoided. All four HCI practitioners are academics or researchers at the Centre for HCI Design, City University London, with several years of experience in the HCI field.

Table 8.3. HCID department's Low Fidelity Prototyping Expert Assessment Criteria

Low-Fidelity Prototyping Expert Assessment Criteria
1. Use of colours and variety of pens to distinguish elements
2. Demonstrating a sense of proportions and scale
3. Use of simple shapes to denote complex objects
4. Representation consistency in reuse of shapes and colours
5. Use of contextual language, annotation and terminologies
6. Ease of 3rd party understanding of the users' representations
7. Aesthetics awareness and use of layout, usability design
8. Ideas and innovation presented to the domain proposed
9. Context of design and accessibility to domain proposed
10. Overall quality of effort

8.5 Scenario Results

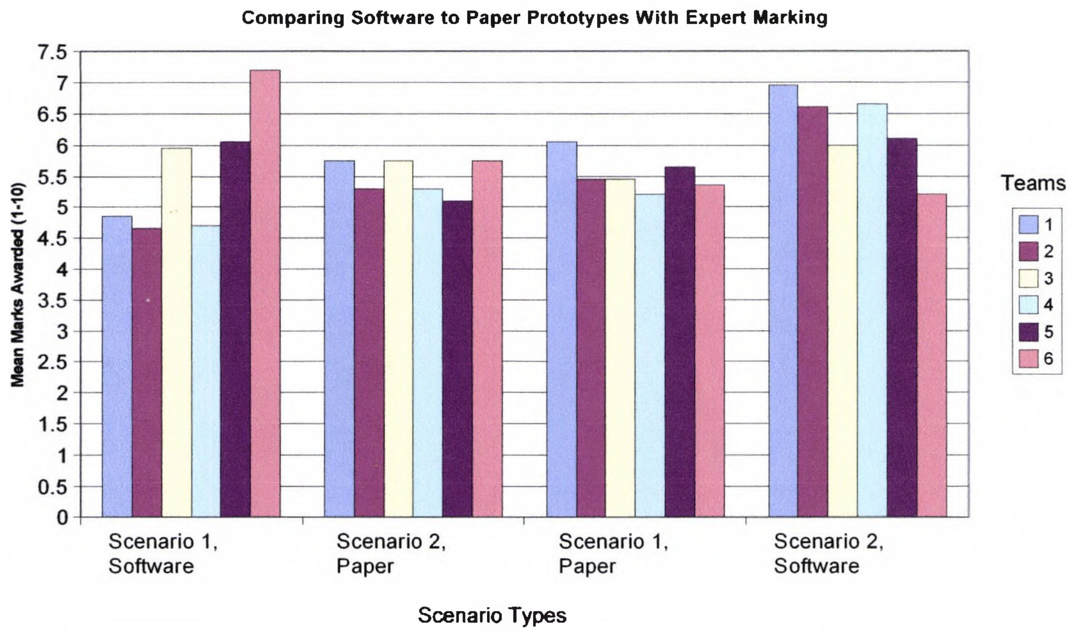


Figure 8.9: Individual team based comparison of PROTEUS vs. Paper based prototypes output on expert marking

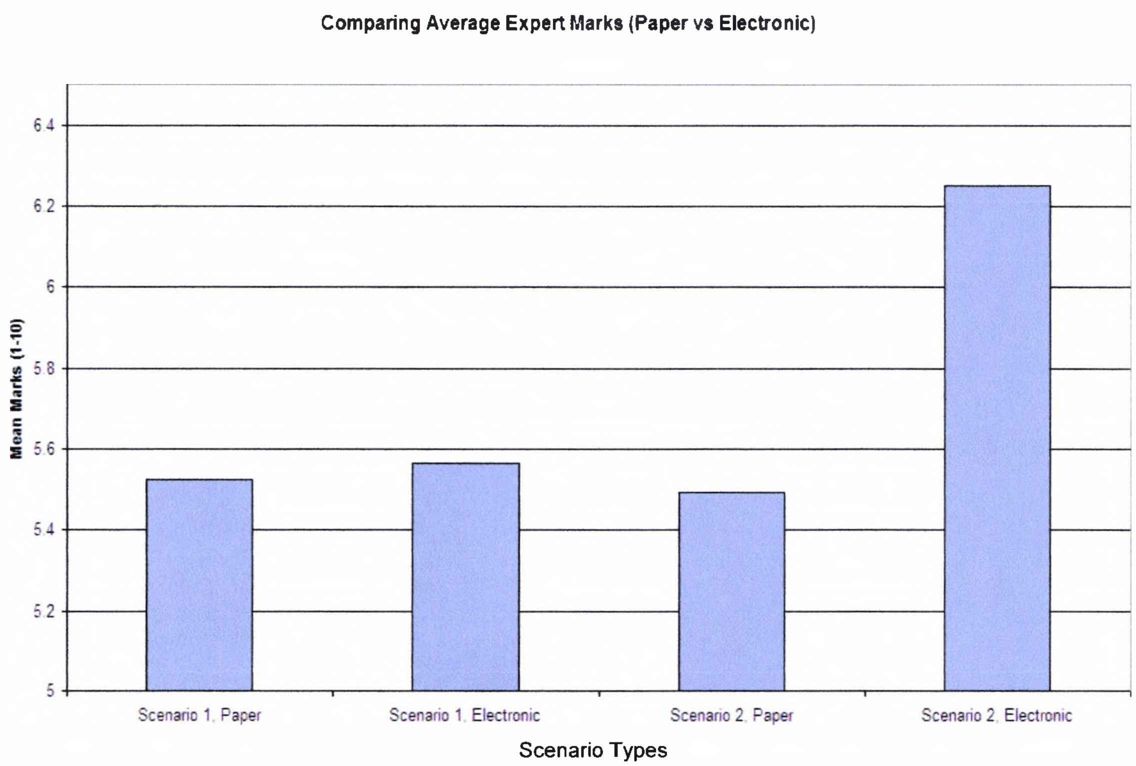


Figure 8.10: Aggregated results of PROTEUS vs. Paper based prototypes output on expert marking (Scenario 1: Website Design, Scenario 2: Train Ticket Machine)

No significant difference was found between the expert quality marks of paper version prototypes to the expert quality marks of software version prototypes ($t(11) = 1.68, p > 0.05$) indicating that using the TabletPC software was not a negative influence

No significant difference was found between the expert quality marks of paper version prototypes to the expert quality marks of software version prototypes ($t(11) = 1.68, p > 0.05$) indicating that using the TabletPC software was not a negative influence on the practical methodology of low fidelity prototyping (figure 8.9). However, a second *t*-test of Scenario 2's outputs alone (software vs. paper) demonstrates a significant difference ($t(5) = 3.13, p < 0.013$) with the software method producing better quality of output than the paper method. This might show that the effectiveness of using such digital tools is potentially dependent on the scenario of use.

Aggregated marks for the second scenario (ticket machine interface) were higher (Fig 8.10), with inferences to using more innovative ideas for a new type of ticket machine interface in comparison to the language website (scenario 1). One reason for this case might have been that the variety of pen tool options in the software enabled the participants to assert greater creativity than the first scenario. As already stated in section 8.4.3 the two scenarios were intentionally chosen so that there was one with limiting in creativity and one with high creativity. The higher aggregated marks for the second scenario reveals in these tests there is new potential insight into creativity levels with constructionism.

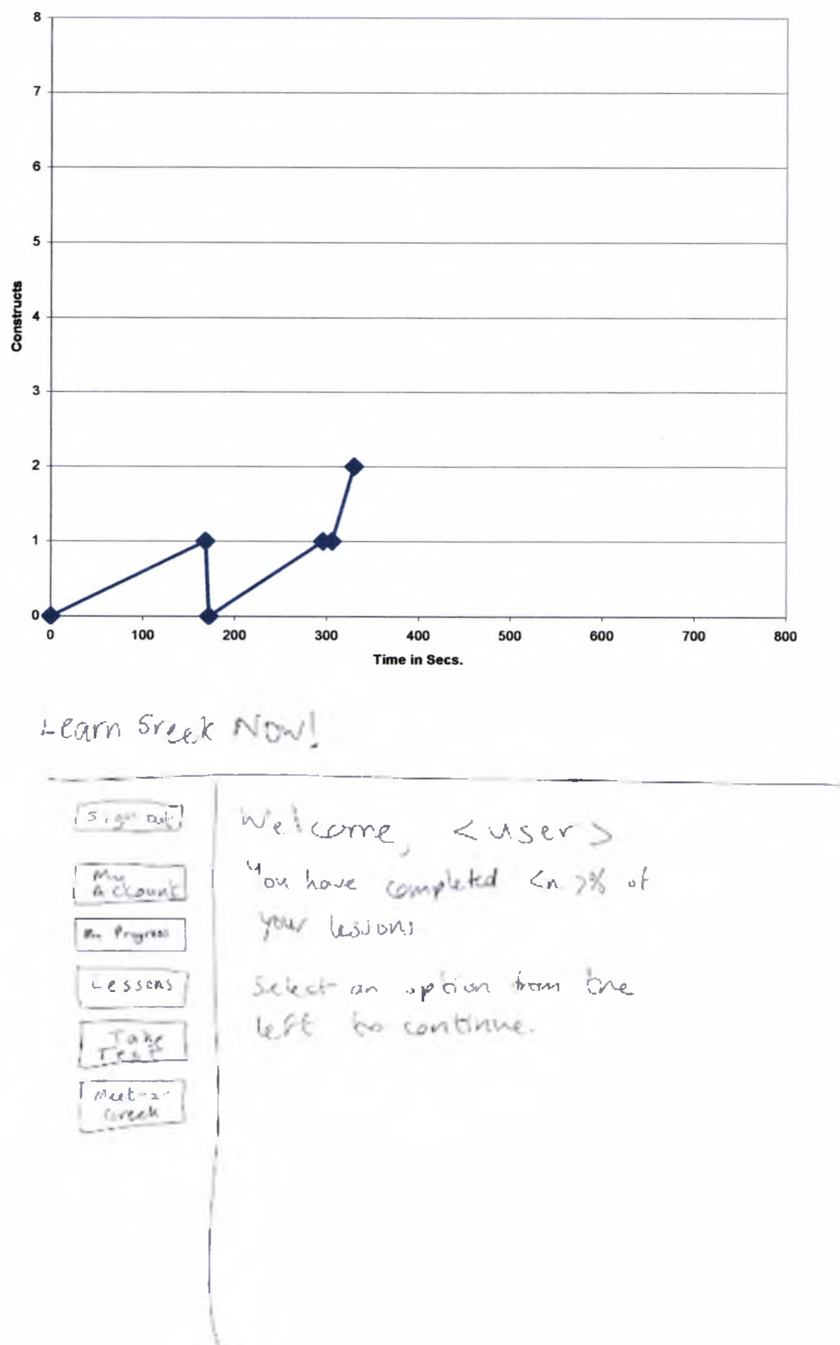
8.6 Empirical Testing of Dynamic Constructionism in Software-Based Prototyping

To evaluate the constructionist data, the PROTEUS EVALUATOR tool generates Excel compatible spreadsheets directly from the time encoding of events that occurred within the creation of the ink-encoded GIF files from the software sessions. This allows us to compare software generated results of the software prototypes in terms of artefact-driven constructs vs. the independent expert assessor evaluations.

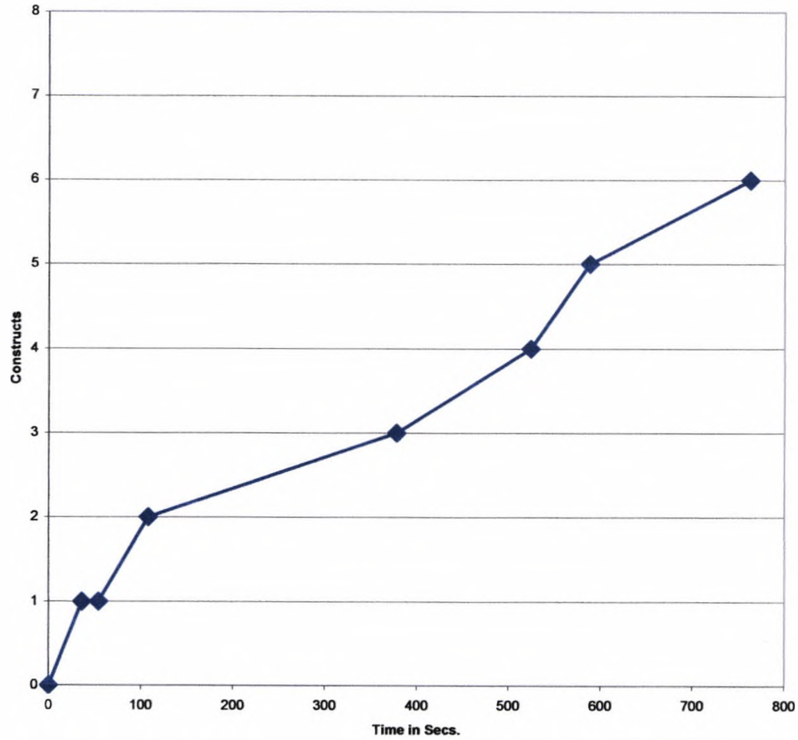
8.6.1 Measuring Constructionism in Paper Prototyping with PROTEUS EVALUATOR

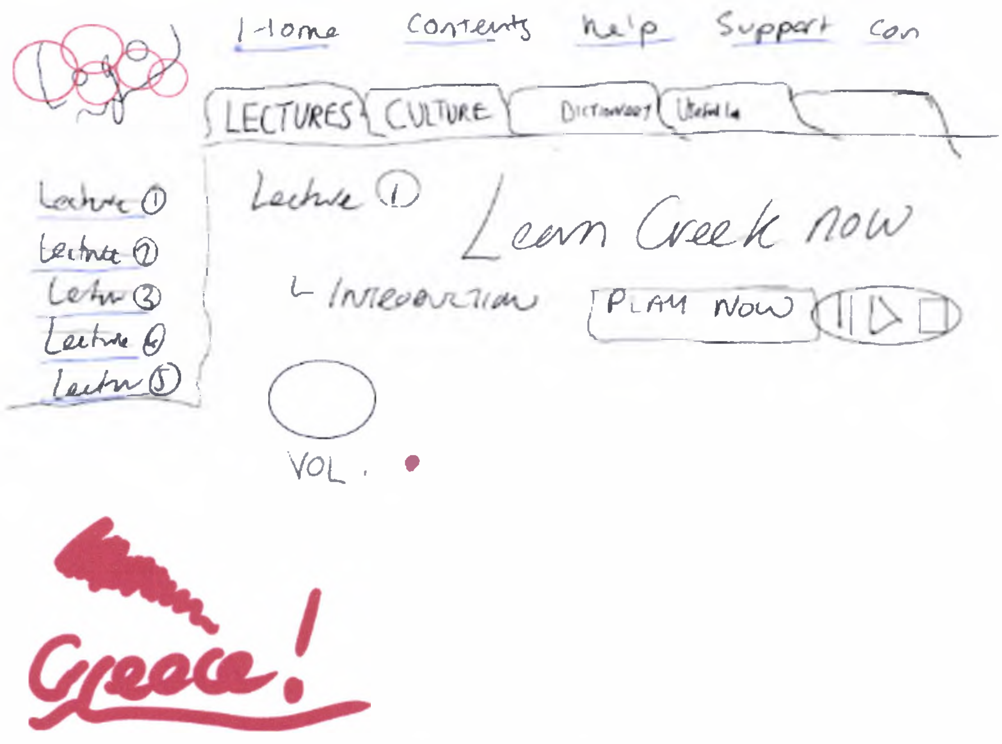
Figure 8.11 shows some of the automated results of Artefact Driven Constructs Assessment vs. Expert HCI Marking. The expert marks were awarded out of 100% based on the Assessment Criteria defined in Table 8.3. In figure 8.11(a) Scenario 1, Team 2; the expert assessors awarded the team 46% based on the expert marking scheme. The Proteus EVALUATOR software detected 5 mediation points, over a short time period, with little mediation/ refinement time in between. Reflecting on their capability and output quality, there was not much confidence in constructing or decision making (mediation points) occurring in their design.

Figure 8.11(b) in comparison again shows Scenario 1, this time with Team 5. The experts awarded them 61%. Proteus EVALUATOR detected 7 mediation points in their design, with long periods of generative activity indicating some thoughtful team consensus eliciting a better paper prototype of the website. An example of the excel data constructs identified in a Proteus sketch via Proteus EVALUATOR is given in appendix F.3.1.

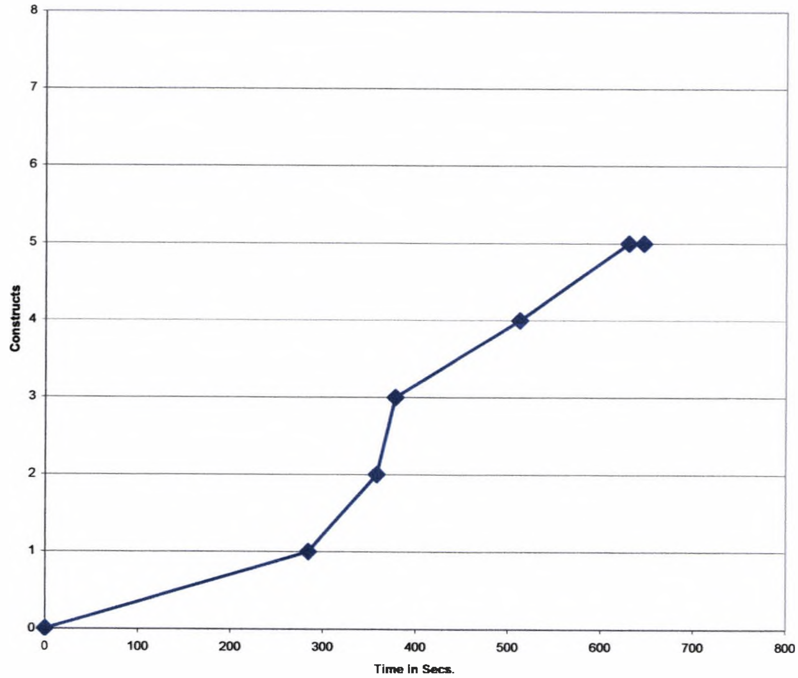


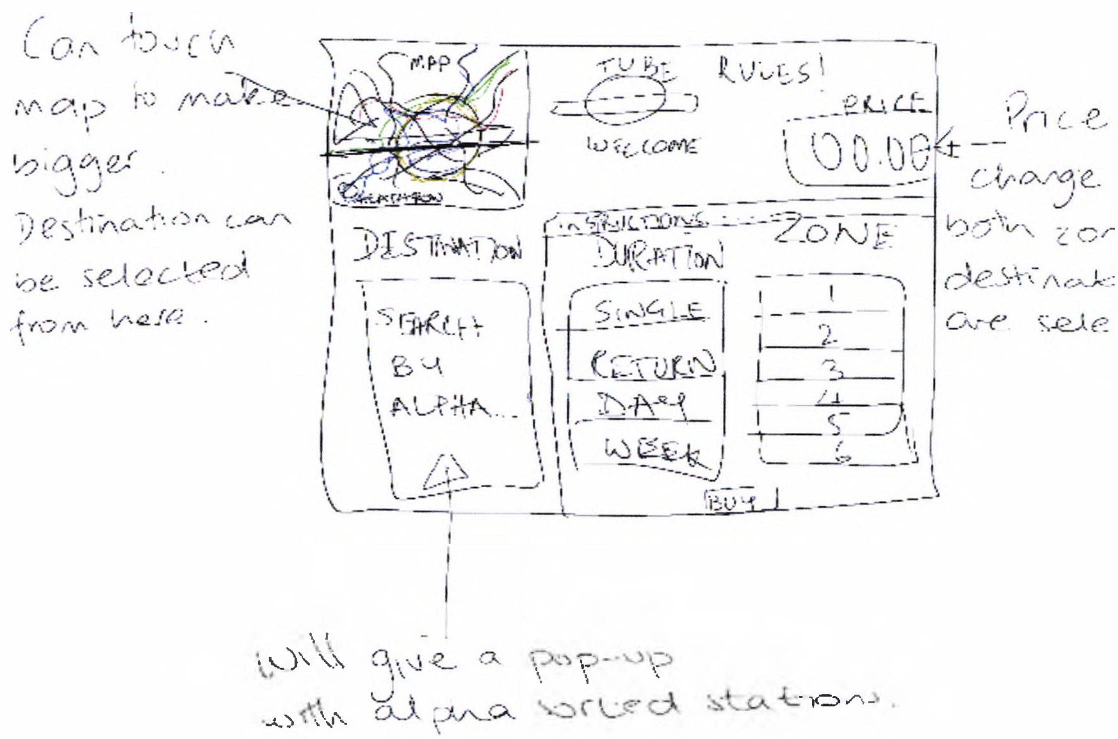
(a) Scenario 1, Team 2



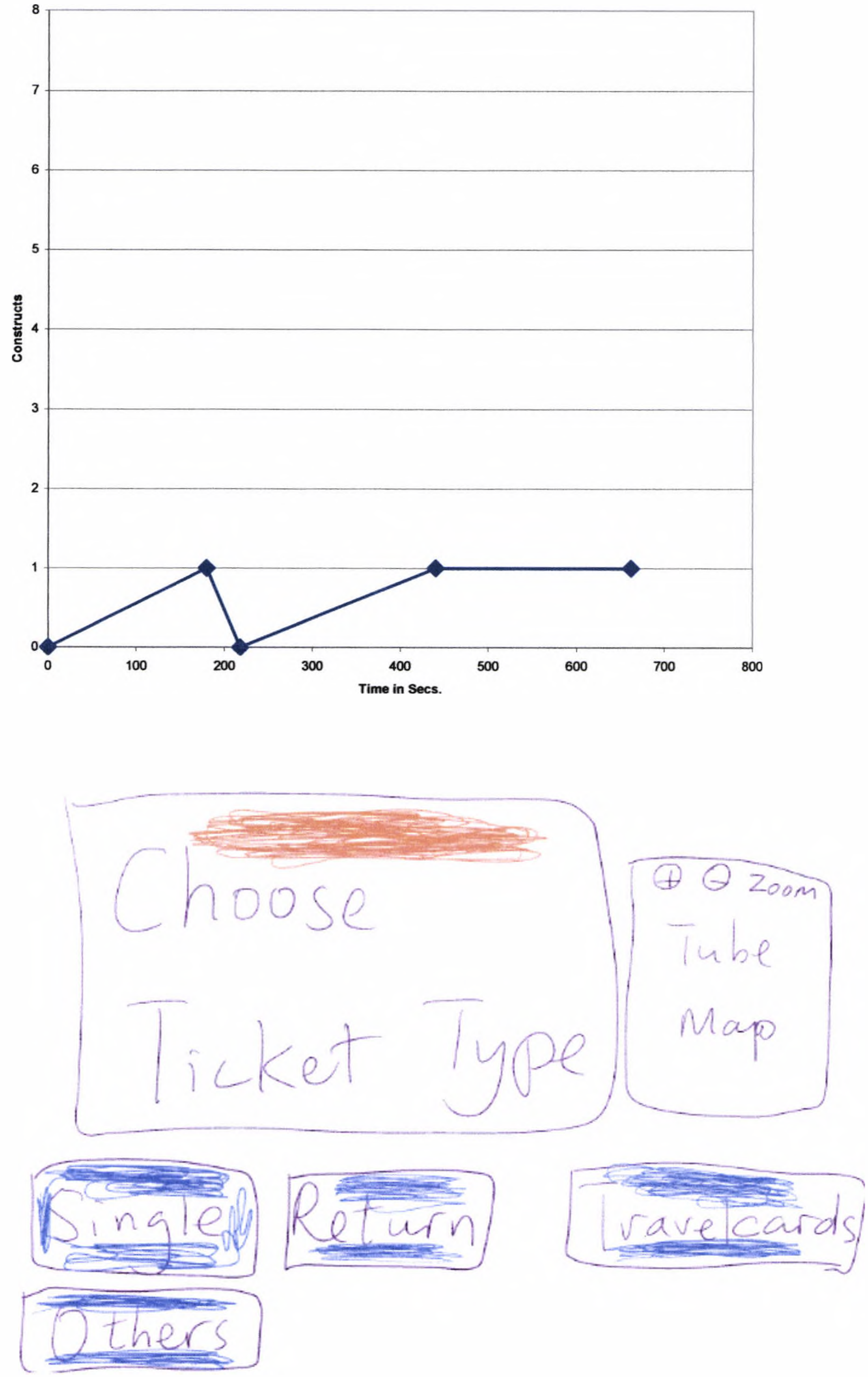


(b) Scenario 1, Team 5





(c) Scenario 2, Team 1



(d) Scenario 2, Team 5

Figure 8.11: Several examples of Artefact Constructs in Dynamic Constructionism, evaluated with PROTEUS EVALUATOR vs. Human Expert Marking Scheme (Table 8.3)

Scenario 2 is showed in figure 8.11(c) with Team 1. Here the expert assessors awarded the team 70% based on the expert marking criteria. The Proteus EVALUATOR detected 6 mediation points, with little mediation time in between rapid generative activity, possibly indicating confidence in design which is reflected in their expert assessment mark.

In comparison, team 5 in scenario 2 was awarded 52% under the expert assessment mark scheme. Only 4 mediation points detected with Proteus EVALUATOR, which indicates little generative activity but long mediation, potentially an indecisive team characteristic.

The use of the PROTEUS EVALUATOR tool analysing the constructions of artefacts within the users PROTEUS based prototype designs determined several key points in the scenario tests;

- Confident groups (lots of generative activity in short space of time) spent less time in refinement stages(post-generative activities with smaller number of manipulations);
- Low values of mediation points infer faster design cycles;
- Low values of generative activities obviously imply either non-enthusiasm or inability to construct confident and positive design artefacts;
- The average interval time between mediation points involving modifications has been found to be considerably shorter than additions and deletions, we suspect due to mediation (reflecting on choices made) and refinement (assessing possible outcomes) giving a clearer idea of what to manipulate;
- Successive generative activities indicate sources of innovation e.g. ideas fuelling the building of new ideas;

8.6.2 Users Evaluation of the Tool

After the scenario testing, a full scale post questionnaire for measuring the Quality of User Interface Satisfaction (QUIS) (Chin et al, 1988; Slaughter et al, 1994; appendix E.4.2) was conducted with the 40 student participants. This QUIS acquired ratings 0 to 9 on a variety of categories, as shown in table 8.4. Subsequently, an ease-of-use post questionnaire was conducted with additional questions to indicate personal preferences between software and paper methods (appendix F.4.1).

In both of QUIS and ease of use questionnaire types, the PROTEUS tool was considered favourably above average in all questionnaire categories (table 8.4). The QUIS based User Satisfaction per person from 0 to 9 (mean results of QUIS total per person) was found to be 6.13 with a standard deviation of 1.11.

Table 8.4: QUIS individual marks aggregated for each question type

QUIS Question (ratings are from 0 to 9)	Mean	S.D.
Overall reaction to software (1-6):	**6.01**	**1.87**
1. The software is wonderful	6.05	1.58
2. The software is easy to use	5.98	1.94
3. The software is satisfying to use	5.49	1.88
4. The software has adequate power	5.68	1.89
5. The software is stimulating	5.76	2.2
6. The software is flexible	6.13	1.68
Screen (7-9):	**6.05**	**1.99**
7. Reading characters on screen is easy	6.15	1.88
8. Highlighting simplifies the tasks very much	5.85	1.93
9. Organisation of options is very clear	5.67	2.17
Terminology and system information (10-15):	**5.87**	**2.29**
10. Use of terms throughout the system is consistent	6.48	1.72
11. The terminology is always related to the task	6.32	1.47
12. The position of messages on screen is consistent	6.27	1.98
13. Prompts for the input are always clear	6	2.03
14. The computer always informs about its progress	4.68	2.2
15. Error messages are always helpful	4.64	2.34
Learning (16-21):	**6.44**	**2.06**
16. Learning to operate the system is easy	6.33	1.91
17. Exploring new features by trial and error is easy	6.89	1.66
18. Remembering the names and use of commands is easy	6.75	1.68
19. Performing tasks is straightforward	6.8	1.65
20. Help messages on the screen are helpful	5.47	2.11
21. Supplemental reference materials are clear	5.07	2.11
System capabilities (22-25):	**6.91**	**2.11**
22. The system speed is fast enough	6.63	1.89
23. The system is reliable	6.56	1.83
24. The system tends to be quiet	8.03	1.1
25. The system is designed for all levels of users	6.45	2.29

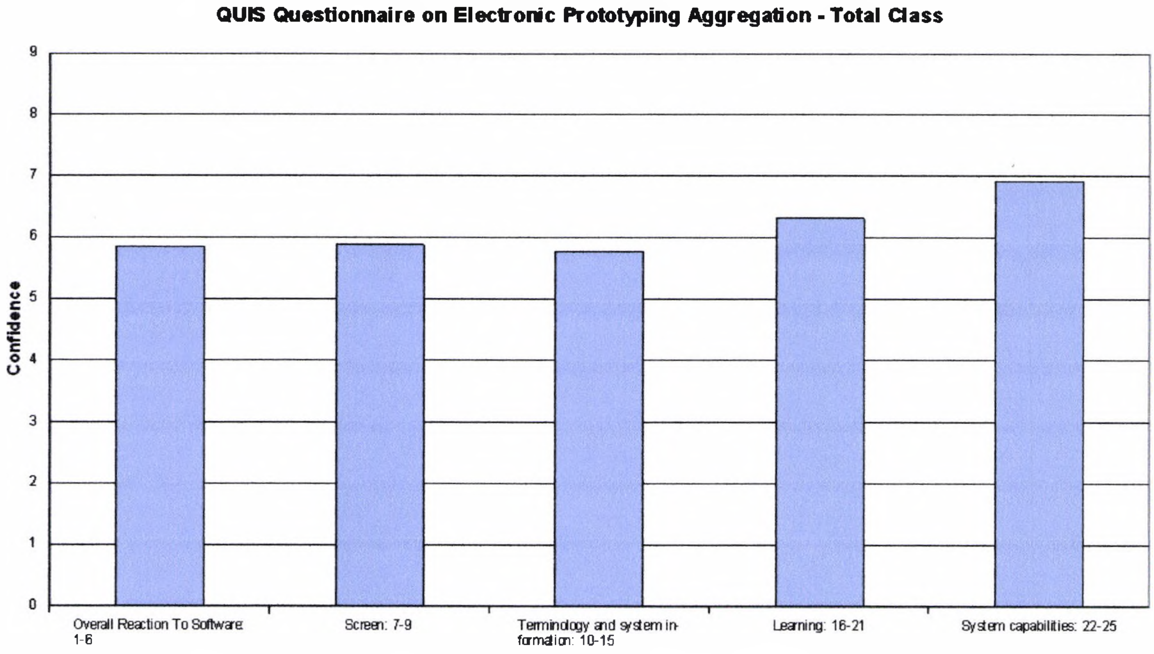


Figure 8.12: QUIS results on User Interface Satisfaction

The ease of use questionnaire (appendix F.4.1) demonstrated that 82% of the users found that the tool was comparable, if not better than the existing paper practice. Similarly, 69% of users felt that the tool gave them new capabilities in the sense that they only expected these features within a mouse-desktop paint/diagrammatic program and not within the natural feel of a pen-based direct inking tool. In addition, 89% of participants felt that the tools and software options provided covered the interaction level sufficiently to facilitate productive low-fidelity prototyping in the HCI context.

Only 43% of users said that they used the zoom facility to add finer details. In addition, only 42% of users used the templates feature but this can be logically attributed to lack of exposure to using the system enough to build up templates. Open ended questions revealed that the speed and quality of digital inking were its most positive advantages, and that using a tabletPC stylus pen was close to mimicking normal pens, but disorientating to users who had not used such technologies before.

8.7 Conclusions

In investigating dynamic constructionism, a tool for automating the data analysis of the theory has been designed and used in an empirical study with 40+ postgraduates in two scenario tests. In both scenarios, positive results have been acquired that suggest that dynamic constructionism can give weighted measures in mobile knowledge elicitation.

In comparison to paper based techniques, mobile knowledge elicitation has enabled software evaluating otherwise complex user confidence and capability issues from observing the construction of artefacts in prototyping, as an additional measure to existing low fidelity evaluation. Our contributions are as follows;

1. We have constructed a specific HCI software solution, PROTEUS, which enables the major functional requirements of low fidelity prototyping to be captured via a mobile device, in the form of a TabletPC; this enables on-site elicitation and digital recording and sharing of prototypes.
2. We have developed a second tool, PROTEUS EVALUATOR, to assist in analysing design artefacts and dynamic constructionist data in the timeline of PROTEUS designs. This has led to the exploration of using the artefact-driven constructionist theory to create a working model of artefact driven assessment metrics. This forms a research opportunity for mapping potential cognitive decision making characteristics within the temporal creation of user knowledge elicitation.
3. Finally we have conducted scenario tests of using our theoretical framework with PROTEUS, and compared data with expert formal assessment guidelines, to demonstrate the strength and advantages over the existing methodology.

For HCI practitioners and educators, existing paper based prototyping methods are obviously quick, cheap and practical if the space and materials are available. Low fidelity ideas are captured efficiently this way. However, their outputs are not effectively recorded on paper in a consistent and shareable form and intermediate decisions made are not easily recorded on paper. This research succeeds in overcoming each of these issues. In addition, this research has illustrated that prior art has been succeeded by an empirically tested methodology that assists with taking into consideration the capability of the user(s) involved over the temporal view of a design construct, via Constructionism modelling for design prototyping, which stands as a contribution to the field of mobile HCI, pedagogical HCI and HCI in general.

Chapter 9: Discussions & Conclusions

9.1 Introduction

This chapter discusses the synthesis of new knowledge and contributions made within this thesis, in light of its two significant research domains; the fields of mobile HCI cyberscience, and of Constructionism applied to HCI methods. Several substantive findings are discussed from each of the chapters in resolution of the research questions R1 to R5 initially set out in section 1.3 of this thesis. This chapter is made up of the following sections:

Section 9.2 revisits chapters 2 and 3 to discuss the literature evaluation of Mobile HCI content (Mohamedally et al., 2003b, 2004c), leading to the exploration of mobile HCI tools for HCI practitioners (Mohamedally et al., 2003b, 2004b, 2004d, 2005a, 2005b, 2006a), i.e. MIKE tools. This leads to a discussion on contributions made by this thesis to the science of HCI Knowledge Elicitation technology.

Section 9.3 presents a discussion on chapters 4 and 5, through which a review of methodologies within pedagogical epistemology came to focus on Constructionism, its links to mobility and how this can apply to the field of HCI Knowledge Elicitation. A discussion on chapter 5's framework for Constructionism in HCI (Mohamedally et al., 2005d, 2006b) follows with contributions made by this thesis to the science of HCI Knowledge Elicitation methodology.

Section 9.4 explores the contributions made to HCI Cyberscience, by synthesis of new HCI KE technology and methodology. This is achieved firstly by exploring how MIKE tools can be a viable alternative to current-day methods with its own unique benefits. Secondly, it explores how existing HCI methods can be enhanced, in the form of empirical testing of chapter 5's framework for Constructionism in HCI. This discusses the findings made within the case studies from chapters 6, 7 & 8, leading to deducing three principles (inert, semi-dynamic and dynamic constructionism) to apply in future HCI research involving Constructionism.

Section 9.5 discusses limitations of the research developed in this thesis. **Section 9.6** reports on future research directions and finally **Section 9.7** concludes this thesis with closing remarks.

9.2 Improving the state of the art: Mobile Cyberscience in HCI KE with MIKE tools

Chapter 2 explored the state of the art in Mobile HCI research. It was investigated through literature review followed up by an expert-based card sorting experiment, conducted with HCI researchers and lecturers from City University London. It was found through this literature review that there was significant research being conducted in using existing HCI methods for mobile systems and mobility theories. However HCI as a field itself was not shown at the time of writing to be pursued as a significant research direction within the Mobile HCI community, i.e. to improve the HCI methodologies or technologies employed by HCI researchers and practitioners. This led to the general theme of this thesis, to contribute to the scientific instrumentation of HCI methodologies and technologies through the use of mobile tools, e.g. mobile HCI cyberscience.

Though several key research topics were identified in the literature review, it is noted that the list is not exhaustive. Mobile HCI in healthcare and in military uses is acknowledged in the peer-reviewed proceedings but was not considered to be top level categories by HCI practitioners who took part in the expert card sorting. However it was important to this thesis to disseminate an understanding of mobile computing in a wide variety of HCI contexts, such that potential capabilities and limitations in other disciplines of mobility could be observed. The themes from the state of the art research form generic taxonomy headings for future mobile HCI research to expand upon.

Chapter 3 took the cyberscience of HCI into consideration for exploring Mobile HCI as its theme. The current day techniques of HCI practitioners were explored (R1), in particular knowledge elicitation in HCI methods were selected for scientific exploration. Their psychology-rooted models have changed little over the decades and these measures remain professional and expert standards to the HCI community. Traditionally, measures of performance related metrics of productivity, efficiency, and accuracy are key attributes in using knowledge elicitation methods in HCI (Preece et al., 2002). This review was followed up subsequently by examining existing tools for HCI practitioners, both web based and desktop based (R2). The research landscape for mobile computing tools for HCI practitioners emphasised that it was currently elusive.

Current HCI KE methods invoke low technology mechanisms as tools to assist in these measures of user performance as reported in chapter 3, and as such, Computer Science has room for further exploration in facilitating improvements to existing techniques. Reported examples of this in summary include HCI practitioners transcribing interviews and diaries, collecting and analysing large surveys, and improving the capture and use of observational techniques.

Several mobile tool designs (Appendix B, Mohamedally et al., 2004d, 2005b, 2005c) were thus presented to model the practices of current knowledge elicitation theory by HCI practitioners with the assistance of electronic tools (R3). These mobile designs report several potential advantages for enhancing and augmenting the abilities of HCI practitioners and served as a starting point for more in-depth research in subsequent chapters.

Recent exploration of HCI tools research as reported in Chapter 3 has adopted the use of the web (Scholtz & Laskowski, 1998). Combining mobility with the infrastructure of web application design has given rise to the concept of cyberscience management, in particular, Virtual Research Environments (VRE) for scientists. This field of computing explores managing experimentation via the web. Chapter 3 and appendix B.3 refers to collaborative work undertaken for a first-published HCI based VRE (Mohamedally et al., 2005a, 2006a). This enables practitioners to facilitate the acquisition and management of HCI data using mobile devices and web browsers including the MIKE tools described in this thesis.

Mobility as a function of HCI researchers and practitioners is not a widely and rigorously explored topic as evident by the sincere lack of mobile computing tools for HCI practitioners, denoted in chapter 3's tools review. This also implies that the conducting of HCI research and user testing outside of the HCI laboratory and into the real-world scenarios of use have not yet reached their full or even partial potential.

This thesis presented a precursor to further the cyberscience of this area, by contributing subsequently in later chapters, through several case studies, tool implementations and experiments. These case studies were based on testing scenarios that HCI educators would use mobility factors within real-world classroom teaching, and as such stand as a contribution to the science of applying mobile technologies in HCI pedagogy. A second key contribution to the technological advances made with the development of these tools is the temporal mechanisms for recording events such that these HCI techniques (namely affinity diagramming and paper prototyping) can be reviewed historically.

9.3 Augmenting HCI theory with Constructionism

By facilitating the concept that an "idea" can be considered a node in the formulation of a logical construct and that temporal and spatial variables can affect the measuring of user-centred constructs, this enabled the design of a three-layer framework that could demonstrate constructionism in the form of measurable artefacts for HCI KE methods. Within this framework, the knowledge created by the users facilitating constructionist activity during HCI knowledge elicitation activity was shown to describe the chaining effect as presented in prior works by others within Activity Theory (Leont'ev, 1978; Vygotsky, 1978), thereby validating its connection to the original learning theories.

The separation of the framework into three layers was a design choice to consider three unique aspects of HCI knowledge elicitation techniques; where KE participants work by themselves, work in groups with restricted rules, and finally working in groups with unrestricted rules. This is not exhaustive of the potential for more layers of constructionism in HCI, but fulfils the requirements of the research questions (R1-R5) for this thesis and provides a potential area for future research directions.

The first layer, Inert Constructionism in HCI infers no interactivity between users and limited interaction in their task (Chapter 6: Linear Card Sorting), with knowledge starting from initially set (known) domains. This leads to all KE constructs being created by the learned experiences of the individual without outside influences (hence the terming Inert). The second, Semi-Dynamic Constructionism in HCI infers interactivity between users, but again limited interactions with their task to only KE creation (Chapter 7: Affinity Diagramming). Finally the third, Dynamic Constructionism infers interactivity between users and with their task, including its destruction as well as creation (Chapter 8: Paper Prototyping). These are illustrated in table 9.1.

Table 9.1 Chapter 5's Three key techniques with variations of Constructionist Metrics; Inert, Semi-Dynamic and Dyamic.

Linear Card Sorting	Inert Knowledge	Individual Based	Static Data Analysis	Textual Representation
Affinity Diagramming	Semi-Dynamic Knowledge	Group Based	Temporal Data Analysis	Textual in Visual Representation
Low-Fidelity Paper Prototyping	Dynamic Knowledge	Group Based	Temporal Data Analysis	Graphical Representation

Focusing on the "Activity" aspect of Constructionism, it was noted that actions and operations over time (Leont'ev, 1978) played an unspecified role in measuring Constructionism in people (Papert, 1991; Resnick, 1996). To identify the relationship of activity in HCI KE as relative to activity in Constructionism, Activity Theory (Vygotsky, 1978; Luria, 1981; Ryder, 1998) was brought in to describe the units of collaborating ideas tangibly as artefacts.

Specifically of importance to the theory is the understanding that Constructionism does not take place without an objective or end goal, thus in modelling within HCI methods, only certain finite experimental methods are applicable. For example, Diaries, Video Observation and Surveying users have no finite end point to their protocol as they can theoretically go on for extensive periods of time; also there is no tangible sharing of knowledge either in the user themselves, or with others.

Linear Card Sorting was designed such that a finite state of Card Sorting can be completed, as theoretically, a non-expert card sorter can execute card sorting indefinitely by continuous shuffling. As Card Sorting is an individual user KE method, it was selected to be the first experimental model of implementing Constructionism in KE, which is Inert Constructionism.

Affinity Diagramming was selected to be a Constructionist methodology as it enables collaborative Constructionism with a finite end point, for example the group members have to reach a final consensus on the final affinity diagram. The nature of Affinity Diagramming however does not enable the destruction of knowledge, rather it continues to use and reuse what has been created. This is not entirely in agreement with Papert (1991) and Resnick (1996) as their work exploring Constructionism in Logo, by their definitions, enables the user to remove existing constructs and restart. For this purpose, this particular type of Constructionism was named Semi-Dynamic Constructionism.

Finally, Low-Fidelity Paper prototyping was selected as a third KE method to explore Constructionism. Low-Fidelity Paper Prototyping as conducted with groups of users reaches a viably finite end state before it is deemed that the prototype in question is of a higher fidelity (Rudd et al, 1996; Snyder, 2003). Its collaborative nature allows for the destruction of knowledge artefacts and thus emulates the principles of Constructionism as outlined by Papert (1991) and Resnick (1996). For this purpose, it was termed Dynamic Constructionism in HCI.

Bannon and Bødker (1991) made significant inroads in applying uniqueness to artefacts such that it could apply to design. In addition, Beguin & Rabdarel (2000) reported on the use of mediation to explain artefacts within the cycle of a construct as a combined result of generative activity, mediation and refinement stages over time. This, as termed a Temporal Iterative Construct (TIC) state in section 5.3, became the reinforcing metric in this framework of Constructionism for HCI (figure 9.1) (Mohamedally et al., 2005d, 2006b).

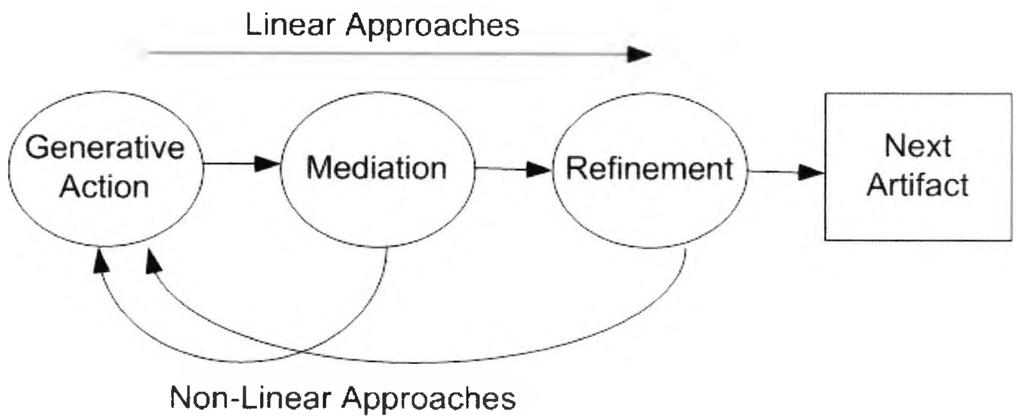


Figure.9.1 Chapter 5's framework identifies TIC states as metrics within constructionism

These Constructionism rules and variables build up the foundation to apply the framework of constructionism to several HCI methods as case studies.

9.4 Mobile HCI KE Case Studies

The selection of the three HCI KE techniques (Card Sorting, Affinity Diagramming, and Paper Prototyping) chosen to explore constructionism were based on several factors; personal interest in these techniques, having existing desktop software tools to compare functionality against and improve upon, and their potential for mimicking their tangible nature of dealing with paper-based artefacts, in mobile software, thus leading to the ability to measure three distinct layers of constructionism (Inert, Semi-Dynamic and Dynamic). Before presenting the application of Constructionism in mobile HCI, R4 is resolved by the software development and user studies which compared outputs from these mobile HCI KE methods with their current-day paper based alternatives.

9.4.1 Mobile HCI KE vs. Paper Based HCI KE

In reviewing the process of Card Sorting, tools such as IBM's EZ Sort (2002) and WebCat (Scholtz & Laskowski, 1998) demonstrated functionality limitations and strong learning curves. In creating a new method for eliciting first impressions in category elicitation via a Linear Card Sorting method (Mohamedally et al, 2003b, 2004b), a novel approach to removing user complexity to card sorting facilitated a previously unexplored domain of card sorting categorisation, such that individual participants could carry out the card sorting process on a mobile device. In scenario testing and iterative user centred design of the CAKE tool in chapter 6, results from the experiments determined that this was not a significant difference in eliciting card sort data from software and paper based participants alike.

Chapter 7 reported the user centred design and development of a novel mobile HCI tool, the SAW environment for affinity diagramming (Mohamedally et al., 2005b, 2005c). SAW is designed to simulate the methodology of affinity diagramming as close as possible, from digital ink representations in post it notes creation to virtual whiteboard manipulation of post-it note arrangements. Chapter 7 reported that this approach was considered critically important from the user centred design perspective by HCI educators to express the functionality requirements in conducting existing affinity diagrams, making it suitable as a teaching platform as well as a practitioner platform. In empirical testing as reported in chapter 7, the SAW environment is determined to be not significantly different in eliciting affinity diagram data digitally output from mobile participants, as compared to paper based participants.

Similarly, chapter 8's user centred design and development of the Proteus environment (Mohamedally et al., 2005c, 2005d) for low-fidelity prototyping via tabletPCs was facilitated by the need to improve upon the interface tools design and user metaphors of existing tools such as Denim (Lin et al, 2000; Walker et al., 2002) whilst keeping mobility and data sharing in mind. It is noted that the Denim tool has also been redesigned to be tabletPC compatible for mobile scenarios of use, post development timeline of Proteus. However, the known limitations of Denim are that still lacks the user centred design interface suited for HCI practitioners to deploy to participants for prototyping considerations alone (Denim is primarily a storyboarding tool). In focus of Proteus' advantages as described in this thesis is the user centred design for new participant users, temporal review capabilities and the constructionism analysis core that Proteus provides. As reported in chapter 8, Proteus in empirical comparison with paper based methods also did not show a significant difference in the quality of expertly assessed HCI data output.

9.4.2 Synthesis of Constructionism with Mobile HCI KE

The final research question (R5) of this thesis deals with the expansion of HCI theory, using Constructionism with mobile HCI KE. From a broader view of how chapter 5's framework of constructionism can apply to HCI theory, observing the three layers devised (Inert, Semi-Dynamic and Dynamic) leads to the application of three grounding models that can be applied in other HCI techniques if they fit the model requirements.

Inert Constructionism was facilitated via the CAKE tool reported in Chapter 6. The formulation of Inert Constructionism is described in chapter 5 and discussed in section 9.3. The CAKE tool demonstrated in chapter 6's research methodology that diverse inert constructs can be created electronically through the use of mobile tools. This form of constructionism did not elicit specifically measurable iterations of constructionism, as it referred directly to a static manipulation view of constructing artefacts of new knowledge. The knowledge artefacts formed here were constrained by user actions and retained a closed domain of knowledge from the individual participants.

By experimental design, using closed card sort theory to explore constructionism at this stage demonstrated that Inert Constructionism can be shown in an HCI technique that involves set knowledge transformed into concrete thinking (Piaget, 1952; Papert,

1991) as self-constructed knowledge. This is shown as the final cluster categories formed in Chapter 6's experimental methods, as inertly constructed artefacts in HCI knowledge. Figure 9.2 illustrates this process as a deduction of the work from chapter 6, such that in Inert Constructionism, a set initial domain of knowledge (X) transforms through Inert Constructionism modelling (individual based KE, limited user tasks) to a concrete domain of knowledge (Y):

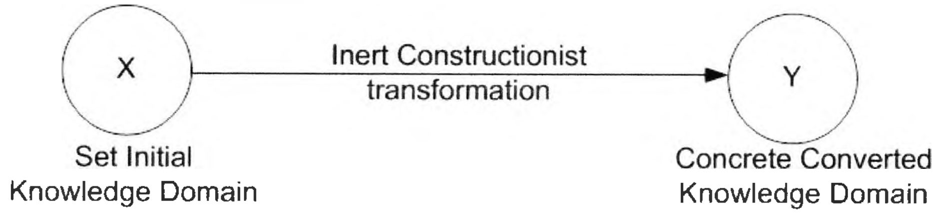


Figure 9.2: Inert Constructionism as applied to HCI, a static form of Constructionism

Temporal manipulation was examined empirically in Semi-Dynamic and Dynamic Constructionism, reported in chapters 7 & 8 respectively. Semi-Dynamic Constructionism was examined in Section 7.8 through the empirical testing of the SAW environment (Section 7.5) together with the MATE tool (Section 7.6). The results of this showed that the temporal aspect of reviewing the construction of affinity artefacts and manipulating them until they are concrete reveals insights into the semi-dynamic constructionist capability of HCI participants. These are reported in section 7.8.1.

Figure 9.3 describes the application of semi-dynamically constructed artefacts in HCI as deduced from chapter 7. Interpreted or constructed knowledge domains (X') transform via the rules of Semi-Dynamic Constructionism (collaborative interactivity between users, limited tasks). These either become concrete converted knowledge (Y) or are modified significantly enough through a TIC state (section 5.3) to be reconsidered as X', and therefore are recycled before transforming to Y.

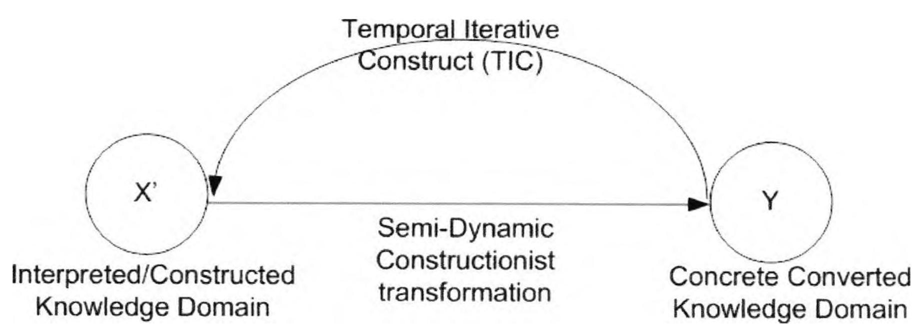


Figure 9.3: Semi-Dynamic Constructionism as applied to HCI, a temporal but restrained form of Constructionism

Finally, Dynamic Constructionism was examined in Section 8.6 through the empirical testing of the PROTEUS tool with aid of the PROTEUS Evaluator tool (Section 8.3). The results of this showed that the temporal aspect of reviewing the construction of paper prototype artefacts, selectively manipulating them and destroying them until they are concrete reveals insights into the Dynamic Constructionist potential of HCI participants. These are reported in section 8.6.1.

Figure 9.4 describes the application of dynamically constructed artefacts in HCI as deduced from chapter 8. Interpreted or constructed knowledge domains (X') transform via the rules of Dynamic Constructionism (collaborative interactivity between users, unlimited flexibility in tasks). These again either become concrete converted knowledge (Y) or are modified significantly enough through a TIC state (section 5.3) to be reconsidered as X', and therefore are recycled before transforming to Y. However there is also the possibility to concretely destroy the knowledge created and start from scratch (Y').

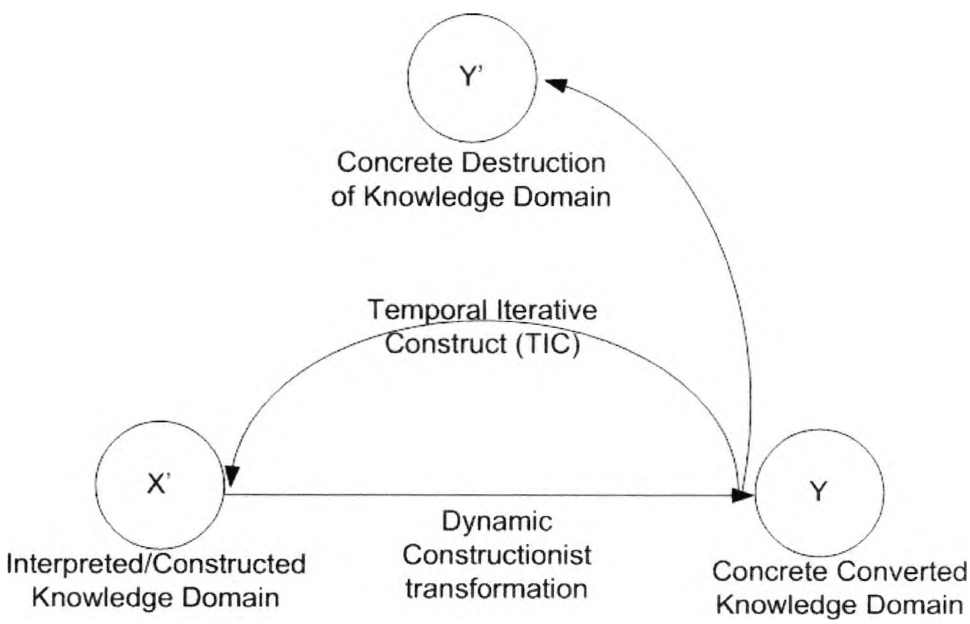


Figure 9.4: Dynamic Constructionism as applied to HCI, a temporal and unrestrained form of Constructionism

These three applications of constructionism within mobile HCI KE form models that can be explored in future related HCI research.

9.5 Limitations of the Case Studies

Comparing the environment actions of participants with their artefact-driven constructionism would be an effective follow-up to the work presented in this thesis. This however takes the direction of constructionism in HCI to social and distributed constructionism, which is outside the scope of this thesis. In connection to this, it would have been useful to elicit and compare visual and audible reactions as synchronised with the progress of artefact driven constructionism in HCI. The case studies from caper 6, 7 and 8 were conducted using undergraduate and postgraduate class sessions to validate a feasible scenario of mobility i.e. class driven pedagogical scenario.

Recording the user observations in the environment of the entire classes running the experiments in parallel for each case study would not have been feasible in practice. It would have been hypothetically obtrusive to the experiment with visible disruption, including the practical need for human presence in management of recording equipment, therefore is was not considered to play a part of this thesis's experimental design. For this reason the VIVID tool (Mohamedally et al., 2005c; appendix B.2.2) was created, post-case study analysis, such that future research in comparing the participants' visual and audible environment with constructionism would be possible. VIVID has been utilised in several HCI undergraduate studies to high degrees of successful knowledge elicitation as a user observation tool.

A significant number of participants were utilised in the three case studies; 60 in card sorting, 40 in affinity diagramming and 40 in paper prototyping. However, the given nature of affinity diagramming and paper prototyping with groups of users means that though there is significance in number of contributors to the knowledge domains, the total number of outputs for deducing conclusions from data would have been increased with a greater number of participants. Nevertheless, given the resources and time allocated for this research, the number of participants was considered acceptable for applying this thesis's framework of Constructionism to HCI.

Identification of usability errors and enhancements suggested in the UCD of the three main MIKE tools, CAKE, SAW and PROTEUS were based on the academic scope of six HCI educators and researchers at the Centre for HCI design, City University London. It is unknown if different usability scopes would have been shown if HCI professionals from HCI industry were employed to test with based on their experience in industry applications of HCI theory. However, all of the HCI educators and researchers at the Centre for HCI design have been professionally trained in their field and are regarded as experts in the domain of HCI.

Open card sorting, whereby cards are created by the participants as opposed to the closed card sorting methods described in chapter 6, was not considered appropriate for the experimental design. This would have inferred semi-dynamic constructionism as already demonstrated through examining Affinity Diagramming in chapter 7, i.e. starting with an interpreted knowledge domain rather than a given set knowledge domain (X' in figure 9.3, vs. X in figure 9.2). By definition reported in chapter 5's framework of constructionism, Inert Constructionism refers to the individual self-modelling iterations of knowledge based on a given context, which was the constructionism layer to be tested in this thesis. With further time and resources available, an empirical comparison of individual based semi-dynamic constructionism vs. group based semi-dynamic constructionism would be interesting i.e. open card sorting vs. affinity diagramming. However, this would not be of significance in this thesis outside of reporting further insights in semi-dynamic constructions which this thesis already contributes an application of this layer of constructionism in HCI. The same argument applies to individual dynamic constructionism vs. group dynamic constructionism in paper prototyping.

9.6 Future Research Directions

The framework of Constructionism applied to MIKE tools in HCI provides an empirically tested perspective of the given research questions R1 to R5. There are several noted directions for future research to extend the work presented in this thesis and the following areas have been identified.

9.6.1 Extending the scope of the case study experiments

Several scopes fore future research identified through the case study experiments include;

- Use of participants with different demographic characteristics would reveal interesting levels of relationships in constructionism, e.g. older generation users.
- More scenarios, inside HCI education requirements and outside in real-world HCI applications would be of use to determining constructionist effects on a variety of knowledge domains, this may infer unexplored patterns in certain domains of participants and field applications.

- Increased emphasis on capturing sensory data of the environment, e.g. with the use of the VIVID tool for recording screen, audio and user activity would elicit factors that would be of use to social and distributed models of constructionism beyond the scope of artefact driven constructionism as described by this thesis.
- The experiments from chapters 6, 7 & 8 were conducted in a real-world environment of mobile use, i.e. a classroom environment, which gives significance in grounding the mobility use of MIKE tools; a key contribution to this thesis. However it would be of scientific interest to devise tests to compare artefact driven constructionism measures in controlled lab environments, compared with the real-world environment, and determine if Choi & Hannafin's Situated Cognition (1995) applies stress variables in HCI that can be measured in HCI KE experiments. This has significance for HCI in terms of selecting whether to deploy a KE session in a HCI lab setting or on-site; a topic that has potential for scientific exploration. As a recommendation for further science to this cause, scenarios should be considered where mobility maybe critical to the success of positive HCI, not just to its advantage.
- The temporal recording mechanisms in SAW (affinity diagramming) and PROTEUS (paper prototyping) have significance to HCI practitioners in enabling historical review of the existence of a KE dataset. This is of importance as elements that have been manipulated and even destroyed can be reviewed for further enquiry by the practitioner, enabling the re-evaluation of entire timelines of KE artefact constructions. Whilst this is not novel in its theory, it is novel in practicality and empirical testing for the tools that currently exist in the HCI tools domain.

9.6.2 Further research directions

The study results reported in section 7.8.3 did not reveal a statistical relationship with the quality of user satisfaction in accomplishing the technique via a mobile tool whereas the study results reported in section 8.6.3 described a positive correlation. For future research in improving the selection of HCI KE techniques, this may be valuable data to be investigated further as to whether limiting human activity in a HCI method affects their satisfaction and sense of freedom when using the technique.

For practitioners, the evolution of mobile and embedded technologies will provide substantial frameworks for applying future MIKE based tools in HCI, and as such grow the domain of mobile cyberscience use in HCI industry. Improvements in natural speech and handwriting recognition embedded in ubiquitous forms of computing will enable human activity to elicit qualitative knowledge for HCI with on-site participants. Mohamedally et al. (2006a) (appendix B.3.2) provides an insight into the potential of network connected mobile devices that are as convenient as mobile phones and still are capable of capturing and managing HCI data with other practitioners. The application of Constructionism in this thesis context furthers the grounding of HCI theories in measuring human capability, which will hopefully become useful measures for practitioners to apply in their fieldwork.

Exploring constructionism in the application of HCI KE has been defined from three detailed theoretical, practical and empirical case studies in this thesis. There are other KE methods in HCI (Burge, 2001) that work well in team-based activities with tangible entities, such as wizard of oz role playing. These may be useful to tangible knowledge artefacts and their construction, be it inert, semi-dynamic or dynamic. Further pedagogical and psychological explorations into constructionism relationships with human intentions in various scenarios should follow up the work started in table 5.1. This could provide a potential for constructionism guidelines, of which the complexity has implications to empirical epistemological pedagogy modelling. Advancing technologies that simulate the ease of paper based mechanisms with digital data capture and manipulation will be of interest to HCI from the mobile computing science community.

9.7 Conclusions and Closing Remarks

This thesis has provided a deep investigation into the development and potential for mobile computing technologies to become a significant domain of science as tools for HCI practitioners, researchers and educators. This emerging field has been termed Mobile Cyberscience or m-Science for HCI, and the technologies developed termed MIKE tools.

Significant research in the domain of electronic tools for HCI has been augmented with several peer-reviewed publications and software productions, the MIKE tools suite, through this thesis. A framework for applying artefact driven constructionism has been designed, theoretically grounded and empirically tested in three case studies of HCI KE methods.

This Framework of Constructionism for HCI has offered and explored three models to apply constructionism as a potential measure for inclusion in HCI theory, namely Inert, Semi-Dynamic and Dynamic Constructionism. The findings of applying these models in HCI KE in this thesis's case studies highlight that there is data of value to HCI within the scope of observing how a person learns and interprets knowledge through digitally simulated tangible artefacts.

The findings from these case studies highlight that the MIKE tools suite created for mobile HCI KE do not detract the quality of HCI output from the current day paper based methodologies that they simulate. Rather it suppositions the field with empirically designed and tested alternatives, of scientific value should the need for on-site digital KE tools be wanted. Beyond constructionism, other advantages over existing paper based methods are also noted, e.g. in reporting digitally the temporal and spatial decision making processes that occur in constructing HCI artefacts of knowledge from HCI participants. Thus HCI practitioners, researchers and educators are augmented with new capabilities in their field.

References

3G News and Information (2002). Retrieved June, 6, 2003, from http://www.3g.co.uk

802.11b & 802.11g (1999). WiFi Standards, Retrieved June, 6, 2003 from http://www.ieee.org

Abascal, J, Cagigas, D., Garay, N., & Gardeazabal, L (2002). Mobile Interface for a Smart Wheelchair. ACM Mobile HCI Conference 2002. Pisa, Italy.

Ackermann, E (1996). Perspective-taking and object construction: two keys to learning, in: Y Kafai & M Resnick (Eds), Constructionism in Practice: Designing, Thinking and Learning in a Digital World (pp25-35). Mahwah, NJ: Lawrence Erlbaum Associates

Ackermann, E (1999). Pretense, models and machines, in: J Bliss, P Light and RSaljo (Eds), Learning Sites: Social and Technological Contexts for Learning (pp144-154). Elsevier

Ahead Corp (2004). Nero 6, Nero Recode (MPEG-4) and NeroVision Player. Retrieved on March 14th 2004, from http://www.ahead.com

Al-Malki, D.(2004). The development of VNC environments for secure networks, MPhil thesis. School of Engineering, City University London. UK.

American Psychological Association (1986). Standards for Educational and Psychological Testing, Revised Edition Amer Psychological Assn;

Ames, M., Brush, A.J.B, & Davis, J. (2004). Comparing Synchronous Remote and Local Usability Studies for an Expert Interface. GHC ACM Women in Computing Conference, Illonois, 2004.

Aneki World Facts (2003). Retrieved June, 6, 2003, from http://www.aneki.com/phones.html

AT&T Laboratories Cambridge (2000). VNC - Virtual Network Computing. Retrieved on 27th May 2003., http://www.uk.research.att.com/archive/vnc/index.html

ATI Technologies Corp. (2004). Retrieved on March 14th 2004., from http://www.ati.com

Ausubel, D.P. (1968). Educational Psychology - A cognitive view. Holt Rinehart and Winston, New York.

Backstrom, C. & Nilsson, C. (2002). Mixed Mode Handling surveying: a comparison of paper questionnaires and web questionnaires.Dept. of Information Technology and Media, Mid-Sweden University.

Baddeley, A. D. (1966). Short-term memory for word sequences as a function of acoustic, semantic, and formal similarity. Quarterly Journal of Experimental Psychology, 362-365.

Bannon L. & Bødker S. (1991). Beyond the interface: Encountering artefacts in use. In: J.Carroll (ed.): Designing Interaction: Psychology at the Human-Computer Interface. Cambridge: Cambridge University Press 1991, pp. 227-253.

Beyer, H. & Holtzblatt, K. (1998). Contextual design: defining customer-centered systems, Morgan Kaufmann Publishers.

Bedny G.Z. (2000). Activity theory: history, research and application. Theoretical Issues in Ergonomic Science 2000. Vol.1 No. 2. P168-206

Beguin, P. & Rabardel, P. (2000). Designing for Instrument Mediated Activity. Scandinavian Journal of Information Systems, 2000, 12: 173-190

Bertelsen, O.W (1998). Elements of a theory of Design Artefacts. PhD Thesis.

Bluetooth official membership site (1998). Retrieved June, 6, 2003, from http://www.bluetooth.org

Booch, G., Jacobson, I., Rumbaugh, J. (1998). Unified Modeling Language User Guide (Object Technology). Addison Wesley

Bradley, N. A. & Dunlop, M.D (2002). Understanding Contextual Interactions to Design Navigational Context-Aware Applications. ACM Mobile HCI Conference 2002. Pisa, Italy.

Brewster, S.A., Leplatre, G. & Crease, M.G. (1998). Using Non-Speech Sounds in

Mobile Computing Devices. ACM Mobile HCI Workshop 1998. Glasgow, UK.

Brown, B.A.T., O'Hara K., & Sellen A.(1999). A Diary Study of Information Capture at Work. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Brown, J.S. (1999). Learning, working & playing in the digital age. Paper presented at the 1999 Conference on Higher Education of the American Association for Higher Education, March 1999, Washington, USA.

Brown, P.J., Bovey, J.D. & Chen, X. (1997). Context-aware applications: from the laboratory to the market place. IEEE Personal Communications, Vol. 4, No. 5 (1997). 58-64

Brown, W., Malveau, R., McCormick, H.W. & Mowbray, T.J (1998). AntiPatterns: Refactoring Software, Architectures, and Projects in Crisis. Wiley Press.

Bruijin, O.D., Spence, R., Chong, M.Y.(2001). RSVP Browser: Web Browsing on Small Screen Devices. ACM Mobile HCI Workshop 2001. Lille, France.

Bruner, J. (1960). The process of education. Harvard University Press, Cambridge Massachusetts.

Bruner, J. (1966). Toward a Theory of Instruction. Cambridge, MA: Harvard University Press.

Bruseberg, A. & McDonagh-Philp, D. (2001). New product development by eliciting user experience and aspirations, International Journal of Human-Computer Studies, 55(4), 435-452.

Brusilovsky, P., & Rizzo, R (2002). Map-Based Access to Multiple Educational On-Line Resources from Mobile Wireless Devices. ACM Mobile HCI Conference 2002. Pisa, Italy.

Buisson, M.. & Jestin, Y.(2001). Design issues in distributed interaction supporting tools: mobile devices in an ATC working position. ACM Mobile HCI Workshop 2001. Lille, France.

Burge, J.E. (2001). Knowledge Elicitation Tool Classification. PhD Thesis, Worcester Polytechnic Institute.

Burton, A. M., Shadbolt, N. R., Rugg, G., & Hedgecock, A. P.(1990) The Efficacy of Knowledge Elicitation Techniques: a Comparison Across Domains and Levels of Expertise, Knowledge Acquisition, (1990).Vol. 2: 167-178.

Carboni, D., Sanna, S., Giroux, S., & Paddeu, G. (2002). Interactions Model and Code Generation for J2ME Applications. ACM Mobile HCI Conference 2002. Pisa, Italy.

Catani, M.B. & Biers, D.W. (1998). Usability evaluation and prototype fidelity: users and usability professionals. Proceedings of the Human factors and Ergonomics. Society 42nd Annual Meeting. P 1331-5.

Carroll, J. (1995). Scenario-Based Design. John Wiley and Sons, Inc.

Chang, C.Y. & Sheu, J.P. (2002). Design and implementatin of Ad Hoc classroom and eSchoolbag systems for ubiquitous learning. IEEE WMTE 2002.

Chesta, C (2002). Globalization of Voice-Enabled Internet Access Solutions. ACM Mobile HCI Conference 2002. Pisa, Italy.

Cheverst, K., Mitchell, K., & Davies,.N. (2001). Investigating Context-aware Information Push vs. Information Pull to Tourists. ACM Mobile HCI Workshop 2001. Lille, France.

Chin, J.P., Diehl, V.A., & Norman, K.L. (1988). Development of an Instrument Measuring User Satisfaction of the Human-Computer Interface. ACM CHI'88 Proceedings, 213-218 (1988)

Chincholle, D., Goldstein, M., Nyberg, M., & Eriksson, M. (2002). Lost or Found? A Usability Evaluation of a Mobile Navigation and Location-Based Service. ACM Mobile HCI Conference 2002. Pisa, Italy.

Chittaro, L., & Camaggio, A (2002). Visualizing Bar Charts on WAP Phones. HCI Lab, Dept. of Math and Computer Science. ACM Mobile HCI Conference 2002. Pisa, Italy.

Chittaro, L., & Cin, P.D.(2001). Evaluating Interface Design Choices on WAP Phones: Single choice List Selection and Navigation among Cards. ACM Mobile HCI Workshop 2001. Lille, France.

Choi, J.I & Hannafin M. (1995). Situated Cognition and Learning Environments: Roles, Structures, and Implications for Design. ETR&D, Vol. 43, No. 2, 1995, pgs. 3-69, ISSN 1042-1629.

Clarke, D.J. & Philips, J. (2001). Learning on the Go. Retrieved on 6th January 2003. http://www.techtv.com/callforelp/howto/jump/0,24331,3347882,00.html

Cognition and Technology Group: Vanderbilt (1992). The Jasper Series as an example of anchored instruction: Theory, program description and assessment data. Educational Psychologist, 27, (3), 291-315.

Colbert, M (2002). A Diary Study of Rendezvousing: Groups Size, Time Pressure and Connectivity. ACM Mobile HCI Conference 2002. Pisa, Italy.

Cooke, N. J. (1994). Varieties of knowledge elicitation techniques, International Journal of Human-Computer Studies, Vol. 41:801-849.

Cordingley E.S. (1989). Knowledge elicitation techniques for knowledge-based systems. In Diaper D. (Ed.), Knowledge elicitation: Principles, techniques and applications. Chichester,England: Ellis Horwood.

Costa-Montenegro, E., Gonz´alez-Casta˜no, F.J., Garc´ýa-Reinoso, J., Vales-Alonso, J., & Anido-Rif´on, L. (2002). Pushing Web Pages into Personal Digital Assistants: Need, Tools and Solutions. ACM Mobile HCI Conference 2002. Pisa, Italy.

Cotton, J. (1995). The theory of learning: an introduction. UCL press.

Coxon, A. P. M. (1999). Sorting Data: Collection and Analysis. Thousand Oaks: Sage.

Csikszentmihalyi, M. & Larson, R. (1987). Validity and reliability of the experience sampling method. Journal of Nervous and Mental Disease,175, pp526–536.

Csikszentmihalyi, M. Larson, R. & Prescott, S. (1977). The ecology of adolescent activity and experience. Journal of Youth and Adolescence, 6, pp181–294.

Cuban, L. (1986). Teachers and Machines: the Classroom Use of Technology Since 1920. Teacher College Press, New York.

Curzon, L.B. (1990). Teaching in Further Education. Cassell. London.

Czerwinski, S., Zhao, B., Hodes, T., Joseph, A.,& Katz, R. (1999). An Architecture for a Secure Service Discovery Service. In Proceedings of MobiCom '99, Seattle, WA, August 1999.

Davies. N, Mitchell. K, Cheverst. K, & Blair. G (1998). Developing a Context Sensitive Tourist Guide. ACM Mobile HCI Workshop 1998. Glasgow, UK.

De Groot, B., & Van Welie, M.(2002). Leveraging the Context of Use in Mobile Service Design. ACM Mobile HCI Conference 2002. Pisa, Italy.

De Vet, J., & Buil, V.(1999). A personal digital assistant as an advanced remote control for audio/video equipment. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Delbecq A.L. (1975). Group Techniques for Program Planning: A Guide to Nominal Group and Delphi Processes, Scott, Foresman and Company.

Deshe, O., & Van Laar, D. (1999). Applying Perceptual Layers to Colour Code Information in Hand-Held Computing Devices. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Devrs Team. (2003). Devkit Advance for Gameboy Advance. Retrieved on 10th March 2003, http://devkitadv.sourceforge.net/

Divx Organisation (2002). Divx Codec http://www.divx.org

Dix, A. Finlay, J., & Beale, R. (1992). Analysis of user behaviour as time series. Proceedings of HCI'92: People and Computers VII, Eds. A. Monk, D. Diaper and M. Harrison. Cambridge University Press. 429-444.

Doherty, G.J., Rist, T., & Wilson, M.D.(2001). Information Representations for Shared Communication Spaces. ACM Mobile HCI Workshop 2001. Lille, France.

Dong, J., Martin, S. & Waldo, P. (2001). A User Input and Analysis Tool for Information Architecture. IBM EZSort (USort and EZCalc) Tool published on IBM's Ease of Use Archives (no longer publicly accessible)

Dourish, P. & van der Hoek, A. (2002). Émigré: Metalevel Architecture and Migratory Work. ACM Mobile HCI Conference 2002. Pisa, Italy.

Drucker, P.F. (1999). Knowledge-Worker Productivity - The Biggest Challenge.

California Management Review 41(2). 79-94.

Dubois, E., Gray & P., Nigay, L (2002). ASUR++: A Design for Mobile Mixed Systems. ACM Mobile HCI Conference 2002. Pisa, Italy.

Dubois, E., Nigay, L., Troccaz, J., Chavanon, O., Carrat, L. (1999). Classification Space for Augmented Surgery, an Augmented Reality Case Study. In Conf. Proc. of Interact'99 (1999). 353-359

DVD actual data rate from the MPEG association Retrieved June, 6, 2003, from http://www.mpeg.org/MPEG/DVD/Book_A/Specs.html

Ebbinghaus, H. (1885). Memory: A contribution to Experimental Psychology. Translated by Ruger, H.A. and Bussenius, C.E. (1913). Columbia University, New York.

Ebling. R. & Satyanarayanan (1998). On the importance of Translucence for Mobile Computing. ACM Mobile HCI Workshop 1998. Glasgow, UK.

Eldridge, M., Lamming, M., Flynn, M., Jones, C. & Pendlebury, D.(1999). Research methods used to support development of SATCHEL. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Engeström, Y. (1987). Learning by expanding: an activity-theoretical approach to developmental research. Orienta-Konsultit, Helsinki.

Engeström, Y. (1990). Learning, Working and Imagining: Twelve Studies in Activity Theory. Orienta-Konsultit, Helsinki.

Engeström, Y., Brown, K., Engeström, R. & Koistinen, K. (1991). Organizational forgetting: An Activity Theoretical perspective. In Middleton, D. and Edwards, D. (eds) Collective Remembering, pp. 139–168. SAGE Publications.

Engeström, Y., Miettinen, R. & Punamäki, R.L. (eds) (1999). Perspectives on Activity Theory. Cambridge University Press, Cambridge.

Engeström, Y (2000) Activity Theory and the social construction of knowledge: a story of four umpires. Organization: The Interdisciplinary Journal of Organization, Theory and Society 2000, volume 7 number 2. pp. 301-310

ETSI Telecommunications Standards. Retrieved June, 6, 2003, from http://www.etsi.org

Eysenck, M.W. (2000). Principles of cognitive psychology. Psychology Press Ltd. UK

Fallman, D. (2002). An Interface with Weight: Taking Interaction by Tilt beyond Disembodied Metaphors. ACM Mobile HCI Conference 2002. Pisa, Italy.

Fishkin, KP, Gujar, AU, Harrison, BL, Moran, TP & Want, R (2000). Embodied user interfaces for really direct manipulation. Communications of the ACM, 43(9), 74-80

Fitton, D. (2003). Retrieved on 17th January 2004, from http://www.comp.lancs.ac.uk/computing/users/fittond/

Flavell, J.H. (1963). The developmental psychology of Jean Piaget. Van Nostrand Reinhold, New York.

Fontana, F., Fuiello, A., Gobbi, M., Murino, V, Rocchesso, D, Sartor, L. & Panuccio, A (2002). A Cross-Modal Electronic Travel Aid Device. ACM Mobile HCI Conference 2002. Pisa, Italy.

Furnas, G.W., Landauer, T.K., Gomez, L.M., & Dumais, S.T. (1987). The vocabulary problem in human-system communication. Communications of the ACM 30. November Issue, p 964-971.

Gaffney, G.(2004). Classified Card Sorting Tool. Retrieved on December 11th from

http://www.infodesign.com.au/usabilityresources/classified/default.asp

Gagne, R. (1974). Learning Hierarchies. Contemporary Issues in Educational Psychology. Allyn & Bacon.

Gagne, R. (1987). Instructional Technology Foundations. Hillsdale, NJ: Lawrence Erlbaum Assoc.

Gagne, R., Briggs, L. & Wager, W. (1992). Principles of Instructional Design (4th Ed.). Fort Worth, TX: HBJ College Publishers.

Gaines, B.R. (1987a). An overview of knowledge acquisition and transfer. International Journal of Man-Machine Studies 26(4), 453-472.

Gaines, B.R. & Shaw, M.L.G. (1993). Knowledge acquisition tools based on personal construct psychology. The Knowledge Engineering Review, 8(1).

Gaines, B.R. & Shaw, M.L.G. (1980). New directions in the analysis and interactive elicitation of personal construct systems. International Journal of Man-Machine Studies 13(1), 81-116

Gamma, E., Helm, R., Johnson, R., & Vlissides, J. (1994). Design Patterns: Elements of Reusable Object Orientated Software. Addison Wesley Press.

Gerardin, O. (2003). PalmVNC 2.0. Retrieved on 12th February 2004., from http://palmvnc2.free.fr/

Ghosh , D.(2000). Mobile IP. Dept of Computer Science, University of Illinois, Chicago USA. ACM Interactions.

Gierkink, T & Ruggles, R. (1997). "Leveraging Knowledge for Business Value: Creating Living Knowledge Representations through the Power of Communities." Ernst and Young Centre for Business Innovation Working Paper. Retrieved on 19th February 2003. http://www.businessinnovation.ey.com/mko/html/levera.html

Gilbert, T.F. (1962). Mathetics: The Technology of Education. Journal of Methetics, 1(1), 70-73.

Goldstein, M., Book, R., Alsi, G. & Tessa, S. (1998). Ubiquitous Input for Wearable Computing: Qwerty Keyboard without A Board. ACM Mobile HCI Workshop 1998. Glasgow, UK.

Goldstein, M. & Chincholle D.(1999). The Finger Joint Gesture Wearable Keypad. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Goldstein, M., Oqvist, G., Bayat-M, M., Ljungstrand, P. & Bjork, S.(2001). Enhancing the Reading Experience: Using Adaptive and Sonified RSVP for Reading on Small Displays. ACM Mobile HCI Workshop 2001. Lille, France.

Gomes, P., Tostao, S., Goncalves, D. & Jorge, J.(2001).Web clipping: compression heuristics for displaying text on a pda. ACM Mobile HCI Workshop 2001. Lille, France.

Gonzalez-Castano, F.J., Anido-Rifon, L. & Costa-Montenegro, E.(2002). A New Transcoding Technique for PDA Browsers, Based on Content Hierarchy. ACM Mobile HCI Conference 2002. Pisa, Italy.

GPRS and GSM Specification - The Website of the GSM Association. Retrieved June, 6, 2003, from http://www.gsmworld.com

Grady, H.M. (2000). Approaches to prototyping: website design – a case study in usability testing using paper prototypes. Proceedings of IEEE Professional Communication Society. International Professional Communication Conference.

Grand, M.,(2000). Patterns in Java, Volume 2, Wiley Publishing. UK.

Greenberg, S. (1998). Prototyping for design and evaluation. Retrieved on November 30, 2004 at http://pages.cpsc.ucalgary.ca/~saul/681/1998/prototyping/survey.html

Hackos, J.T. & Reddish, J.C. (1998). User and task analysis for Interface Design. Wiley Publishers NYC.

Hall, R.R. (2001). Prototyping for usability of new technology, International Journal of Human-Computer Studies, 55, 4, 485-502.

Hardgrave, B.C. & Wilson, R.L., (1994). An Investigation of Guidelines for Selecting a Prototyping Strategy, Journal of Systems Management, 45 (4), April 1994, 28-35.

Harel, I & Papert, S. (1991) Constructionism. Ablex Publishing.

Harris, S (2005). Investigating Interaction Breakdown: A Systemic-Structural Activity Approach to the Analysis of HCI Field Data. Proceedings of HCI International 2005. Las Vegas.

HAVi Consortium. Retrieved June, 6, 2003, from http://www.havi.org

Hein, G. (1992). Constructivist Learning Theory. Developing Museum Exhibitions for Lifelong Learning. London. The Stationery Office.

Hermann, F., & Heidmann, F (2002). User Requirement Analysis and Interface Conception for a Mobile, Location-Based Fair Guide. ACM Mobile HCI Conference 2002. Pisa, Italy.

Hibino, S., & Mockus, A (2002). handiMessenger: Awareness-Enhanced Universal Communication for Mobile Users. ACM Mobile HCI Conference 2002. Pisa, Italy.

Hjelmeroos, H., Ketola, P., & Raiha, KJ.(1999). Coping with consistence under multiple design constraints: The case of the Nokia 9000 WWW Browser. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Holland, S. & Morse, D.R. (2001). Audio GPS: Spatial audio in a minimal attention interface. ACM Mobile HCI Workshop 2001. Lille, France.

Holland, S., Morse, D.R., & Gedenryd (2002). Direct Combination: A new user interaction principle for mobile and ubiquitous HCI. ACM Mobile HCI Conference 2002. Pisa, Italy.

Huang, E.M., Terry, M., Mynatt, E., Lyons, K., & Chen, A.(2002). Distributing Event Information By Simulating Word-of-Mouth Exchanges. ACM Mobile HCI Conference 2002. Pisa, Italy.

Hudson, W. (2004). Put the "card" back into card sorting: Computer-aided paper sorting (Caps). UK UPA Event, Retrieved on March 22th 2005 at http://www.syntagm.co.uk/design/cardsort.shtml

Huttenrauch, H., Norman, M (2001). PocketCERO - mobile interfaces for service robots. ACM Mobile HCI Workshop 2001. Lille, France.

Iacucci, G.(2001). Bridging Observation and Design in Concept Development for Mobile Services. ACM Mobile HCI Workshop 2001. Lille, France.

IBM EZ Sort (2002). Retrieved on 14th March 2004, from http://www-3.ibm.com/ibm/easy/eou_ext.nsf/Publish/410

IBM. (2004). IBM ViaVoice SDK for Windows & Linux (JavaSpeech). Retrieved on 5th March 2004., http://www.ibm.com/viavoice

IMSISOFT (2004). IMSISOFT FormTool 2004. Retrieved on 29th February 2004, from http://www.imsisoft.com/all_products.asp

Ishii, H., & Ullmer, B (1997). Tangible bits: towards seamless interfaces between people, bits and atoms. CHI 97

ISO (1999), ISO 13407: Human-centred design processes for interactive systems, International Standards Organisation.

ISO/IEC Standard MPEG-4 v1.0,(1998). ISO/IEC JTC1/SC29/WG11. International Standards Organisation

Izadi, S., Fraser, M., Benford, S., Flintham, M., Greenhalgh,C., Rodden, T. & Schadelbach, H.(2001).Citywide: supporting interactive digital experiences across physical space. ACM Mobile HCI Workshop 2001. Lille, France.

Java main website. Retrieved June, 6, 2003, from - http://www.javasoft.com

Jini - The community resource for Jini technology (2001). Retrieved June, 6, 2003, from http://www.jini.org/

Jonassen, D. (1994). Thinking technology. Educational Technology, 34(4).

Jones, M., Buchanan, G. & Thimbleby, H (2002). Sorting Out Searching on Small Screen Devices. ACM Mobile HCI Conference 2002. Pisa, Italy.

Jordan, P.W., Peacock L.A., Chmielewski, D. & Jenson, S.(2001). Disorganisation and how to support it - reflections on the design of wireless information devices. ACM Mobile HCI Workshop 2001. Lille, France.

Kaikkonen, A. & Roto, V (2002). XHTML in Mobile Application Development. ACM Mobile HCI Conference 2002. Pisa, Italy

Karlsson, P. & Djarbi, F.(2001). Analogue styled user interfaces: an exemplified set of principles intended to improve aesthetic qualities in use. ACM Mobile HCI Workshop 2001. Lille, France.

Kawakita, J.(1975) .KJ Method: a Scientific Approach to Problem Solving. Kawakita Research Institute, Japan 1975.

Kelly, G. (1955). The Psychology of Personal Constructs, W.W.Norton, New York. (1955).

Khronos Working Group Retrieved June, 6, 2003, from http://www.khronos.org

Kidd, A. (1987), "Knowledge Acquisition: An Introductory Framework", In Kidd, A., Knowledge Acquisition for Expert Systems: A Practical Handbook, London: Plenum, 1-15.

Kjeldskov, J. (2002). "Just-in-Place" Information for Mobile Device Interfaces. ACM Mobile HCI Conference 2002. Pisa, Italy.

Klemmer, S.R., Sinha, A.K., Chen, J., Landay, J.A., Aboobaker, N., & Wang, A. (2000). "SUEDE: A Wizard of Oz Prototyping Tool for Speech User Interfaces." In CHI Letters, The 13th Annual ACM Symposium on User Interface Software and Technology: UIST 2000. 2(2).p1-10

Kohno, M. & Rekimoto, J. (2002). New Generation of IP-Phone Enabled Mobile Devices. ACM Mobile HCI Conference 2002. Pisa, Italy.

Koppinen, A.(1999). Design Challenges of an In-Car Communications System UI. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Koschman, T., (1996). "Paradigm shifts and instructional technology: An introduction," in CSCL: Theory and Practice, T. Koschman, Ed. Mahway, NJ: Lawrence Erlbaum Associates, 1996, pp. 1-23.

Kuniavksy, M (2003). Observing the User Experience.Morgan Kaufmann Publishers.

Kurniawan, S. & Zaphiris, P (2003). Web Health Information Architecture for Older Adults. In B. Shneiderman, J. Lazar, M. Ivory (Eds.) IT and Online Society, Special Issue on Web Navigation, 1 (3), 2003, 42-63, Stanford University, USA

Lakoff, G. & Johnson, M. (1980). Metaphors We Live By. Chicago University Press

Lamberts, H. (2002). Case Study: A PDA Example of User Centered Design. ACM Mobile HCI Conference 2002. Pisa, Italy.

Landa, L. (1974). Algorithmization in Learning and Instruction. Educational Technology Publications. Englewood Cliffs, NJ

Landay, J.A., & Myers, B. A. (1996). Interactive Sketching for the Early Stages of User Interface Design. Proceedings of ACM CHI'96 Conference on Human Factors in Computing Systems.

Lassaline, M.E. & Murphy, G.L. (1998). Alignment and category learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 24, 144-160.

Leont'ev, A.N. (1978). Activity, Consciousness and Personality. Prentice Hall, Englewood Cliffs, NJ.

Lewis, J. R. (1995). IBM Computer Usability Satisfaction Questionnaires: Psychometric Evaluation and Instructions for Use. International Journal of Human-Computer Interaction, 7:1, 57-78.(1995)

Li, J.Y., Hong, I. & Landay, J.A. (2004). Topiary: A Tool for Prototyping Location-Enhanced Applications, To Appear in Symposium on User Interface Software and Technology - UIST'2004, Santa Fe, New Mexico

Lin, J., Laddaga, R. & Naito, H. (2002). Personal Location Agent for Communication Entities. ACM Mobile HCI Conference 2002. Pisa, Italy.

Lin, J., Newman, M.W., Hong, J.I., & Landay, J.A. (2000) DENIM: Finding a Tighter Fit Between Tools and Practice for Web Site Design. In CHI Letters: Human Factors in Computing Systems, CHI 2000, 2000. 2(1): pp. 510-517.

Lindsay, P.H., & Norman, D.A.(1977). Human Information Processing, an introduction to psychology. Thomson Learning.

Linstone H.A., & Turoff M. (1975). The Delphi Method: Techniques and Applications, Addision Wesley Publishing Company, Inc.

Lorhol, G., Hiipakkal, J. & Marila, J. (2002). Structured Menu Presentation Using Spatial Sound Separation. ACM Mobile HCI Conference 2002. Pisa, Italy.

Lowen, T.D., O'Hare, G.M.P. & O'Hare, P.T. (2002). Mobile Agents point theWAY: Context Sensitive Service Delivery through Mobile Lightweight Agents. In: Proc. of First International Joint Conference on Autonomous Agents and Multi-Agent Systems, Bologna, Italy

Luchini, K., Quintana, C. & Soloway, E. (2002). ArtemisExpress: A Case Study in Designing Handheld Interfaces for an Online Digital Library. ACM Mobile HCI Conference 2002. Pisa, Italy.

Lund, A.M. (1997). Another approach to cost justifying usability. Interactions, 4, (3), 48-56.

Luria, A. R. (1981). Language and Cognition, New York: Wiley & Sons

Macaulay, L.A. (1996), Requirements engineering, Springer Verlag Series on Applied Computing.

MacKenzie, S.(2001). KSPC (Keystrokes per Character). as a Characteristic of Text Entry Techniques. ACM Mobile HCI Conference 2002. Pisa, Italy.

Macromedia Corp. (2004). Macromedia Dreamweaver. Retrieved on 29th February 2004, from http://www.macromedia.com/dreamweaver

Maiden, N.A.M. Mistry, P, & Sutcliffe, A.G.(1995). How people categorise requirements for reuse: a natural approach. Proc. of the 2nd IEEE Symposium on Requirements Engineering (1995), 148-155.

Maiden, N.A.M., & Rugg, G. (1996). "ACRE: A Framework for Acquisition of Requirements", Software Eng., No.3 Vol 11, pp 183 - 192.

Maiden, N.A.M., N. Seyff, & P. Grünbacher.(2004). The Mobile Scenario Presenter: Integrating Contextual Inquiry and Structured Walkthroughs. in Proc. 2nd Int. Workshop on Distributed and Mobile Collaboration (DMC 2004), within 13th IEEE Int. Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises (WETICE-2004). 2004: IEEE CS.

Mander, R. & Smith, B. (2002), Web usability for dummies, New York: Hungry Minds.

Manis, J & Meltzer, B. (1972). Symbolic Interaction: A Reader in Social Psychology, 2nd edition, Boston; Allyn and Bacon, Inc.

Manis, J. & Meltzer, B. (1978). Symbolic Interaction (Third Ed). Allyn & Bacon.

Mantyjarvi, J. & Seppanen, T(2002). Adapting Applications in Mobile Terminals Using Fuzzy Context Information. ACM Mobile HCI Conference 2002. Pisa, Italy

Marshall, C.C., Golovchinsky, G. & Price, M.N. (2001). Digital Libraries and mobility. Microsoft Corp. Redmond WA and FX Palo Alto, Palo Alto CA & Public Mind, Scotts Valley, CA. ACM Interactions.

Martin, S. (1999). Cluster Analysis for Web Site Organization. Internetworking 2, 3 (1999). Retrieved on 29th February 2004, from http://www.internettg.org/newsletter/dec99/cluster_analysis.html <http://www.internettg.org/newsletter/dec99/cluster_analysis.html>.

Martinez-Bejar, R., Benjamins, R., Martin, F. & Catillo, V. (1996). Deriving Formal Parameters for Comparing Knowledge Elicitation Techniques based on Mathematical Functions. In Proceedings of the Tenth Knowledge Acquisition for Knowledge Based Systems Workshop, KAW96.

Marucci, L. & Paternò , F (2002). Supporting Adaptivity to Heterogeneous Platforms through User Models. ACM Mobile HCI Conference 2002. Pisa, Italy.

Maulsby, D., Greenberg, S., & Mander, R. (1993). Prototyping an intelligent agent through Wizard of Oz. In Proceedings of SIGCHI conference on Human Factors in Computing Systems, p 277 – 284.

Mayora-Ibarra, O., Cambranes-Martínez, E., Miranda-Palma, C., Fuentes-Penna, A. & De la Paz-Arroyo, O. (2002). UML Modelling of Device-Independent Interfaces and Services for a Home Environment Application. ACM Mobile HCI Conference 2002. Pisa, Italy.

McConnell, D. (1994). Implementing computer supported cooperative learning. Kogan Page, London.

Melchior, M.(2001). Perceptually guided scrolling for reading continuous text on small screen devices. ACM Mobile HCI Workshop 2001. Lille, France.

Merrill, M.A. & Terman, L.M. (1937). Measuring Intelligence - A guide to the administration of the new revised Stanford-Binet Tests of Intelligence. Houghton Mifflin Company, New York.

Michahelles, F. & Samulowitz, M.(2001). Smart CAPs for Smart Its - Context Detection for Mobile Users. ACM Mobile HCI Workshop 2001. Lille, France.

Millward, L.J. (1995). In G.M. Breakwell, S.Hammond and C.Fife-Shaw (Eds.). Research Methods in Psychology. Sage.

Microsoft Corp. (2002). Windows Media Player and WMV standard. Retrieved on 29th February 2004, from http://www.microsoft.com/windowsmedia

Microsoft Corp. (2002). TabletPC Platform. Retrieved on 29th February 2004, from http://www.microsoft.com/tabletpc

Microsoft Corp. (2002). Windows XP Operating System. Retrieved on 29th February 2004, from http://www.microsoft.com/windowsxp

Microsoft Corp. (2003). MS Frontpage 2003. Retrieved on 29th February 2004, from http://www.microsoft.com/frontpage

Microsoft Corp. (2003). MS Speech API/SDK. Retrieved on 29th February 2004, from http://www.microsoft.com/speech <http://www.microsoft.com/windowsxp>

MIDP Specification . Retrieved June, 6, 2003, from http://java.sun.com/j2me

Miller, G.A. (1956). The magical number seven plus or minus two: some limits on our capacity for processing information. Pyschological Review 63, 81-97.

Miner, C (2001). Pushing functionality into even smaller devices. DesignLab, IBM Almaden Center USA. ACM Interactions.

Mizobuchil, S., Mori, K., Ren, X. & Michiaki, Y.(2002). An Empirical Study of the Minimum Required Size and the Minimum Number of Targets for Pen Input on the Small Display. ACM Mobile HCI Conference 2002. Pisa, Italy.

Moore, J.L., Lin, X., Schwartz, D,L., Petrosino, A, Hickey, D,T., Campbell, O. & Hmelo, C.(1994). The Relationship Between Situated Cognition and Anchored Instruction: A Response to Tripp. Educational Technology, October, 1994.

Morrison, D.,& Goldberg, B. (1996). "New actors, new connections: The role of local information infrastructures in school reform.," in CSCL: Theory and practice of an emerging paradigm, T. Koschman, Ed. Mahway, NJ: Lawrence Erlbaum Associates, pp. 125-145.

MozDev. (2004). uzCardSort Tool. Retrieved on December 11th 2004 from http://uzilla.mozdev.org/cardsort.html

Myers, B.A.(2002). Mobile Devices for Control. ACM Mobile HCI Conference 2002.

Pisa, Italy.

Navarro, P. & Shoemaker, J. (1999). "The Power of Cyberlearning: An Impirical Test," Journal of Computing in Higher Education, Vol. 11, No. 1, pp. 29-54.

Nielsen, J. (1994). Usability Engineering; Morgan Kaufman.

Nigay, L., Salambier, P., Marchand, T., Renevier, P. & Pasqualetti, L. (2002). Mobile and Collaborative Augmented Reality: A Scenario Based Design Approach. ACM Mobile HCI

Norman, D. A. (1998). The design of everyday things. London MIT Press

NVidia Corp. (2004). Retrieved on March 14th 2004, from http://www.nvidia.com

O'Hare, G. & O'Grady, M. (2002). Addressing Mobile HCI Needs through Agents. ACM Mobile HCI Conference 2002. Pisa, Italy

O'Hare, G.M.P., O'Hare, P.T. & Lowen, T.D.(2002). Far and A WAY: Context Sensitive Service Delivery through Mobile Lightweight PDA hosted Agents. In: Proc. of 15th International Florida Artificial Intelligence Conference. Pensacola, FL, USA

Olmsted, E. & Horst, D. (2003). Remote Usability Testing: Practices and Procedures. Workshop at Usability Professionals Association conference. 2003.

Olphert, C.W. & Damodaran, L. (2002), Getting what you want, or wanting what you get? - beyond user centred design, Proceedings of the Third International Conference on Design and Emotion, Loughborough, UK, 1-3 July 2002.

OpenGL Consortium .(1994). Retrieved June, 6, 2003, from http://www.opengl.org

Papert, S. (1991). Situating Constructionism. Constructionism, eds. Idit Harel and Seymour Papert. Ablex Publishing. NJ.

Paredes, M., Ortega, M., Sánchez-Villalón, P.P. & Ángel Velázquez-Iturbide1, J.(2002). A Ubiquitous Computing Environment for Language Learning. ACM Mobile HCI Conference 2002. Pisa, Italy.

Passani, L.(2002). Building Usable Wireless Applications. OpenWave Systems. ACM Mobile HCI Conference 2002. Pisa, Italy.

Pavlov, I.P. (1927). Conditioned reflexes: An investigation of the physiological activity of the cerebral cortex. London Oxford, University Press.

Perkins, C. (1997). Service Location Protocol White Paper, May 1997.

Perl (2002). Retrieved on 29th February 2004, from http://www.perl.org

Perlman, G. (2002). Web-Based User Interface Evaluation with Questionnaires. Retrieved on the 26th January 2004 at http://www.acm.org/~perlman/question.html

Petrie. H, Furner. S, & Strothotte. T (1998). Design Lifecycles and Wearable Computers for Users with Disabilities, ACM Mobile HCI Workshop 1998. Glasgow, UK.

Piaget, J. (1952). The Origins of Intelligence in Children. International University Press, New York.

Pinnacle Systems (2004). Pinnacle Systems Studio 8 for hardware MPEG decoders. Retrieved on 14th March 2004, from http://www.pinnaclesys.com

Polanyi, M. (1958). Personal Knowledge: towards a post-critical philosophy London: Routledge and Kegan Paul.

Pospischil, G., Umlauft, M., & Michlmayr, M. (2002). Designing LoL@, a Mobile Tourist Guide for UMTS. ACM Mobile HCI Conference 2002. Pisa, Italy.

Preece, J., Rogers, Y., Sharp, H., Benyon, D., Holland, S., & Carey, T. (1994). Human-Computer Interaction. Addison Wesley. UK.

Proceedings of the ACM Mobile HCI (1998-2002), ACM Press.

Python Scripting Language . Retrieved June, 6, 2003, from http://www.python.org

Resnick, M. (1995). New paradigms for computing, new paradigms for thinking. In A. A. DiSessa, C. Hoyles, R. Noss & L. D. Edwards (Eds.), Computers and exploratory learning (pp. 31-43). Berlin New York: Springer.

Resnick, M. (1996). Distributed Constructionism. Proceedings of the International Conference on the Learning Sciences. Association for the Advancement of Computing in Education. Northwestern University.

Resnick, M, Maryin, F, Berg, R, Boovoy, R, Colella, V & Kramer, K (1998). Digital manipulatives: new toys to think with. Proceedings of the ACM SIGCHI 1998 Conference on Human Factors in Computing Systems, 281-28

Rettig, G. (1994). Prototyping for tiny fingers. Communications of the ACM, 37, (4), 21-27.

RFC- Request For Comments, (1982). RFC 821 - SMTP Simple Mail Transfer Protocol definition. Retrieved on March 21st 2003., from http://www.faqs.org/rfcs/rfc821.html

Rist, T.(1999). Using mobile Communication Devices to Access Virtual Meeting Places. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

Rist, T. & Brandmeier, P.(2001). Customizing Graphics for Tiny Displays of Mobile Devices. ACM Mobile HCI Workshop 2001. Lille, France.

Rorscharch, H. (1921). Psychodiagnostics, Grune & Straton, NY (1921).

Rosch, E., & Mervis, C.B. (1975). Familiar resemblances: Studies in the internal structure of categories. Cognitive Psychology, 7, 573-605

Rosch, E., Simspon, C., & Miller, R.S. (1976). Structural bases of typicality effects. Journal of Experimental Psychology: Human Perception and Performance, 2. 491-502

Roschelle, J. & Patton, C. (2002). To unlock the learning value of wireless mobile devices, understand coupling. Keynote speech presented at IEEE WMTE 2002.

Roth, J.(2001). Patterns of Mobile Interaction. ACM Mobile HCI Workshop 2001. Lille, France.

Rudd, J., Stern, K. & Isensee, S. (1996). Low vs. high fidelity prototyping debate. Interactions 3(1), p.76-85, ACM Press.

Salber, D., Siewiorek, D.P. & Smailagic, A (2001). Supporting Mobile Workgroups on a Wireless Campus. ACM Mobile HCI Workshop 2001. Lille, France.

Salvendy, G (1997). Handbook of Human Factors and Ergonomics, 2nd Edition. Interscience Publishing.

Sazawal, V., Want, R. & Borriello, G. (2002). The Unigesture Approach One-Handed Text Entry for Small Devices. ACM Mobile HCI Conference 2002. Pisa, Italy.

Schilit B, Adams N & Want R. (1994). Context-Aware Computing Applications. In: Proceedings of the Workshop on Mobile Computing Systems and Applications. Santa Cruz, CA, U.S. 1994.

Schmidt, A., Stuhr, T. & Gellersen, H. (2001). Context-Phonebook - Extending Mobile Phone Applications with Context. ACM Mobile HCI Workshop 2001. Lille, France.

Schofield, E. & Kubin, G (2002). On Interfaces for Mobile Information Retrieval. ACM Mobile HCI Conference 2002. Pisa, Italy.

Sears A., Plaisant C. & Shneiderman B., (1992). A new era for high precision touchscreens, Advances in Human-Computer Interaction, Vol.30, Ablex, Norwood, NJ 1-33

Sefelin, R., Tscheligi, M., & Giller, V. (2003). Paper prototyping – what is it good for ? A comparison of paper and computer based low fidelity prototyping. In Proceedings of Human Factors in Computing Systems, CHI 2003.

Shaw, M.L.G. & Gaines, B.R. (1987a). An interactive knowledge elicitation technique using personal construct technology. Kidd, A., Ed. Knowledge Elicitation for Expert Systems: A Practical Handbook. pp.109-136. Plenum Press.

Shaw, M.L.G., Ed. (1981). Recent Advances in Personal Construct Technology. London: Academic Press.

Scholtz, J. & Laskowski, S. (1998). Developing usability tools and techniques for designing and testing web sites. Proc. of the 4th Conference on Human Factors & the Web.

Scholtz, J. (2001). Adaptation of Traditional Usability Testing Methods for Remote

Testing. In Proceedings of Hawaii International Conference on System Sciences. 2001.

Shneiderman, B (1983). Direct manipulation: a step beyond programming languages. IEEE Computer, 16(8), 57-69

Shneiderman, B. (1998). Designing the User Interface: Strategies for Effective Human-Computer Interaction. Addison-Wesley, Reading, MA, 1998.

Siirtola, H. & Heimonen, T.(2001). Scalable Support for Work Groups and Groupwork. ACM Mobile HCI Workshop 2001. Lille, France.

Silbershatz, A. (1994). Operating System Concepts. Fourth edition, Addison-Wesley.

Skinner, B.F. (1938). The Behavior of Organisms: An Experimental Analysis, Prentice Hall, Englewood Cliffs, New Jersey.

Slaughter, L.A., Harper, B.D. & Norman, K.L. (1994). Assessing the equivalence of the paper and on-line formats of the QUIS 5.5. In Proceedings of Mid Atlantic Human Factors Conference pp.87-91

Sleeman, D. and White, S. (1997). A toolbox for goal-driven knowledge acquisition. In Proceedings of the Nineteeth Annual Conference of the Cognitive Science Society (COGSCI'97), Stanford, CA.

Smart-Its Project, Retrieved June, 6, 2003, from http://www.smart-its.org

Snyder, C. (2003). Paper Prototyping . Morgan Kaufmann Publishers.

Snyder, C. (2004). Paper Prototyping Grows Up. STC 51st Annual Conference. Baltimore M.D.

Sokoler, T., Nelson, L. & Pedersen, E.R (2002). Low-Resolution Supplementary Tactile Cues for Navigational Assistance. ACM Mobile HCI Conference 2002. Pisa, Italy.

Sony Aibo Robotic Dog. Retrieved June, 6, 2003, from http://www.us.aibo.com/

Soronen, A. & Tuomisto,V (2002). Mobile Image Messaging - Anticipating the Outlines of the Usage Culture. ACM Mobile HCI Conference 2002. Pisa, Italy.

Spearman, C. (1904). General intelligence objectively determined and measured. American Journal of Psychology 15, 201-293.

Stager, G.S. (2001) Computationally-Rich Constructionism and At-risk Learners. 2001 World Conference on Computers in Education. Denmark.

Star, S. L. (1989). The Structure of Ill-Structured Solutions: Boundary Objects and Heterogeneous Distributed Problem Solving. In Gasser, L. & M. N. Huhns Distributed Artificial intelligence, volume II. London: Pitman Publishers. pp. 37-54.

Stelting, S.A. & Maassen, O. (2001). Applied Java Patterns. Prentice Hall Publications.

Sternberg, R.J. (1982). Handbook of Human Intelligence. Cambridge University Press, New York.

Stroustrup, B. (1997). The C++ Programming Language. Addison-Wesley Publishing.

Sun Microsystems (2004). The Java Language. Retrieved on 14th March 2004, from http://java.sun.com

T-Mobile (2004). Hotspot WIFI accounts for public use; Retrieved from http://www.t-mobile.co.uk/hotspot

Tarrini, L., Bandinelli, R.B., Miori, V. & Bertini, G (2002). Remote Control of Home Automation Systems with Mobile Devices. ACM Mobile HCI Conference 2002. Pisa, Italy.

Techsmith Corp (2005). Camtasia Tool for Screen Recording Activity. Retrieved November 14, 2005, from www.techsmith.com

Tegic Corp T9 text prediction system . Retrieved June, 6, 2003, from http://www.tegic.com

Thorndike, G.J. (1932). The Fundamentals of Learning. Teachers College Bureau of Publications. New York.

Thurstone, L.L. & Thurstone, T.G. (1963). SRA Primary Abilities. Science Research Associates, Chicago.

Tulving, E. (1968). Theoretical issues in free recall. In Dixon, T & Horton, D. Verbal Behaviour and General Behaviour Theory. Prentice Hall, New Jersey.

Tummolini, L., Lorenzon, A., Bo, G. & Vaccaro, R. (2002). iTutor: AWireless and Multimodal Support to Industrial Maintenance Activities. ACM Mobile HCI Conference 2002. Pisa, Italy.

Unified Modelling Language (n.d.). Retrieved June, 6, 2003, from http://www.uml.org

Vainio, T, Kotala1, O., Rakkolainen, I. & Kupila, H (2002). Towards Scalable User Interfaces in 3D City Information Systems. ACM Mobile HCI Conference 2002. Pisa, Italy.

Van Welie, M. & De Groot, B. (2002). Consistent Multi-device Design Using Device Categories. ACM Mobile HCI Conference 2002. Pisa, Italy.

Vanderdonckt, J., Florins, M. & Oger, F.(2001). Model based design of mobile user interfaces. ACM Mobile HCI Workshop 2001. Lille, France.

Virzi, R.A. (1989). What can you learn from a low-fidelity prototype? In Proceedings of the Human Factors and Ergonomics Society 33rd Annual Meeting (Atlanta), p224-228. Santa Monica CA.

Virzi, R.A., Sokolov, J.L. & Karis, D. (1996). Usability problem identification using both low and high fidelity prototypes. In Proceedings of CHI 1996, p236-243

Von Niman, B., Chaplin, C., Collado-Vega, A.C., Groh, L., McGlashan, S., Mellor, W., & Van Leeuwan, D. (2002). "Do as I Say! ... But Who Says What I Should Say - or Do?" On the Definition of a Standard Spoken Command Vocabulary for ICT Devices and Services (ETSI SPECIAL TASK FORCE STF182). ACM Mobile HCI Conference 2002. Pisa, Italy.

Vygotsky, L.S. (1978). Mind in Society: The Development of Higher Psychological Processes. Compiled from several sources and edited by Cole, M., John-Steiner, V. and Scribner, S. Harvard University Press, Harvard, MA.

W3C Guidelines (2004). Retrieved on 6th June 2004, from http://www.w3.org/TR/WAI-

WEBCONTENT/

Waldo, J (2001). When the network is everything. Sun Microsystems, Burlington MA USA. ACM Interactions.

Walker M., Takayama L., & Landay, J.A. (2002). High-fidelity or low-fidelity, paper or computer medium? Proc. of the Human Factors and Ergonomics Society 46th Annual Meeting: HFES2002. HFES (2002), 661- 665.

Walker, K. & Brewster, S.(1999). Extending the Auditory Display Space in Handheld Computing Devices. ACM Mobile HCI Workshop 1999. Edinburgh, UK.

WAP Forum press release. Retrieved June, 6, 2003, from http://www.wapforum.org/new/20010208270NUM.htm

WCDMA protocol. International Mobile Telecommunications 2000. Retrieved June, 6, 2003, from http://www.itu.int

Websort (2003). Websort card sorting via Macromedia Flash in a browser. Retrieved on 14th March 2004., http://www.websort.net/

Weiser, M. (1991). The computer for the 21st century. Scientific American, Sept. 1991.

Weiss, S. (2002). Handheld Usability. Wiley Publishing, U.K.

White, S. (2000). Enhancing Knowledge Acquisition with Constraint Technology. PhD Thesis, Dept. of Computer Science, University of Aberdeen.

Winder, R. (1998). Developing Java Software, Wiley Publishing. UK. p4.

Wilson, A.L. (1993). The Promise of Situated Cognition. New Directions for Adults and Continuing Education, No. 57, Spring, 1993

X10 electrical-to-computer-software hardware protocol and controller equipment . Retrieved June, 6, 2003, from www.x10.com

XML. Retrieved June, 6, 2003, from http://www.xml.org

Yang, S., Lee, H., Chung, K. & Kim, H (2002). A Content Provider-Specified Web Clipping Approach for Mobile Content Adaptation. ACM Mobile HCI Conference 2002. Pisa, Italy.

Yee K. (2003). Peephole Displays: Pen Interaction on Spatially Aware Handheld Computers CHI2003 Florida, USA.

Zaphiris, P. & Kurniawan, S.H. (2001). Using Card Sorting Technique to Define the Best Web Hierarchy for Seniors. In Proceedings of CHI 2001 Conference on Human Factors in Computing Systems, ACM Press, USA.

Zaphiris, P., Zacharia, G. & Rajasekaran, M.S. (2002). Distributed Constructionism through Participatory Design. In Ghaoui, C. (Ed) E-education Applications: Human Factors and Innovative Approaches, Idea Group Publishing, London, UK.

Appendices

Appendix A

A.1 Article Reference Citations and Summary Form (Literature Record)

By Dean Mohamedally, Panayiotis Zaphiris & Helen Petrie
Centre for HCI Design, City University London, UK.
Email: dean@mohamedally.com

(*example*)
Date read: 20/10/02
Paper number: 12

Source location: Proceedings of the First Workshop on Human Computer Interaction with Mobile Devices, British Library.

Reference (APA format): Petrie. H, Furner. S, Strothotte. T (1998). Design Lifecycles and Wearable Computers for Users with Disabilities, Proceedings of the First Workshop on Human Computer Interaction with Mobile Devices, (Glasgow, UK), Department of Computing Science, University of Glasgow

Abstract (copy and paste):

Summary of Findings, Key Citations (key parts to the paper, summarised by you):
Reflection (your thoughts on this paper, illustrate potential relationships with other papers):

Taxonomy (your own keywords to search later):
Blind users, design lifecycles and methods of device development, user testing methods.

References:
[1] Carroll, J. M., Kellogg, W.A. and Rosson, M.B. (1991). The task-artifact cycle. Carroll, J. M. (Ed.), *Designing interaction.* Cambridge: Cambridge University Press.
Etc.

(Original template used in the following research study☺
Mohamedally. D, Zaphiris. P, & Petrie. H. (2003). "Recent research in mobile computing: A review and taxonomy of HCI issues", In Proceedings of HCI International 2003, Crete, Greece.

A.2 Taxonomy by methodology categorisation

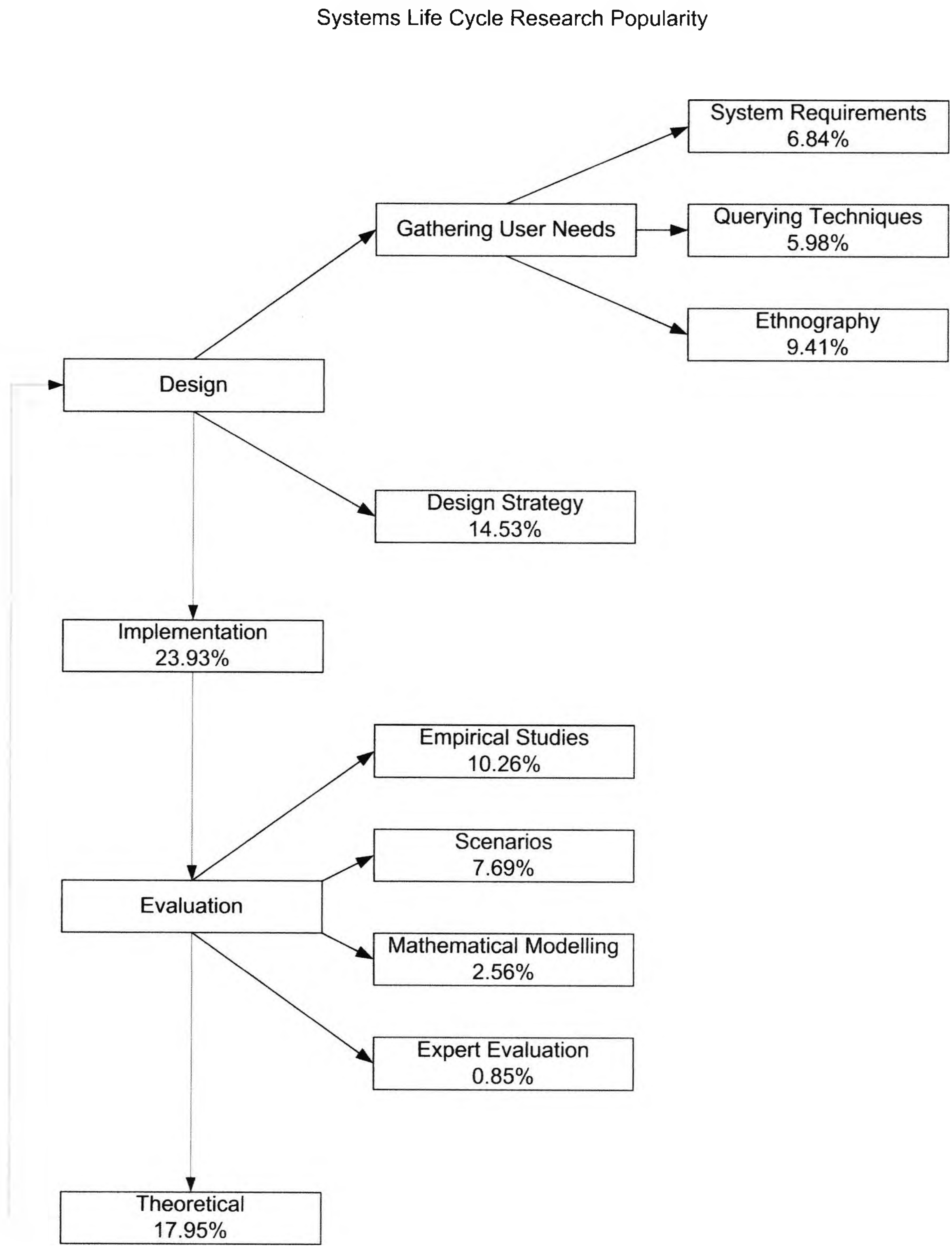


Diagram B: Taxonomy popularity by life cycle stage

Appendix B

B.1 Theoretical Mock-up MIKE Prototypes for supporting HCI Cyberscience

The following sections demonstrate theoretical exploratory case study prototypes that synthesise existing HCI based KE techniques with the current state of the art in mobile and interactive technologies.

B.1.1 ATTIC: Autonomous Transfer and Transcription of Interviews Capture

Interviews are a typical HCI KE activity. It is a direct enquiry style of knowledge elicitation which White (2000) described three forms of interviewing (Diaper, 1989). These are an unstructured interview the KE investigator asks probing questions and records the responses, a focused interview concentrates on a single aspect of problem solving and covers it in great depth; and finally a structured interview allows a KE investigator to align the questions specifically to an agenda relating to a domain.

The ATTIC prototype provides a theoretical solution to this scenario problem by use of personal digital media recorder devices or mobile phones with voice recording in combination with speech recognition technologies. In this non-functional prototype a KE investigator records the conversations digitally on a device with sufficient memory requirements to hold several interviews.

Figure B.1 demonstrates a simple prototype navigation interface to the system with recordings taken from a Samsung Yepp MP3/Voice Recorder;

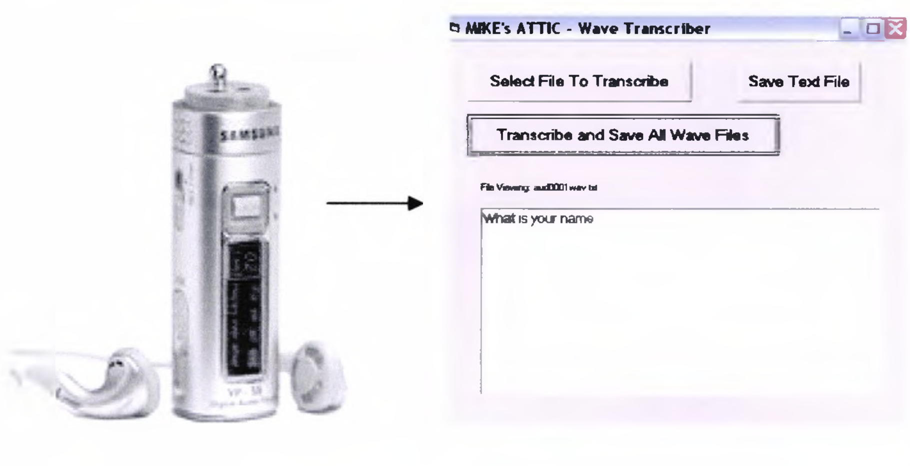


Figure B.1: MIKE's ATTIC prototype design

Several development tools are available for the construction of such a system, most notably is IBM ViaVoice SDK (software development kit) cross-platform JavaSpeech libraries (IBM, 2004), which operate on both Windows and Linux platforms, and MS Speech SDK 5.2 (SAPI) (Microsoft, 2003) which has bindings to the Visual Studio.Net platform for developers to embed in Visual Basic and Visual C++ systems on Windows platforms.

The current limitation to this system is in the effectiveness of parsing multiple voices in real-time capture without significant training. Also accented voices pose significant issues for pre-trialling participants with sppech recognition training before even taking part in a HCI KE experiment. Trial development with the IBM ViaVoice/JavaSpeech library proved to be currently ineffective with dealing with complex statements unless prior language training of each individual had been incorporated into the host library – a requirement that is unacceptable to eliciting knowledge from large numbers of random participants in interview scenarios. Private contractors and government technology may have the research capabilities for high-end recognition but the public availability of robust toolkits and its affordability is a constraint of the dimension of this prototype.

However, the trustworthiness and accuracy of AI based speech recognition capabilities is growing with each iteration of speech engine development and many products are beginning to support natural language recognition without prior training. At one point in the near future it may be possible using standard speech APIs to predict unclear words by electronic contextual analysis of the content as well as handle voice inflections (such as questioning). Also using such technology on constrained vocabulary exercises will enhance reliability, e.g. interviews with limited response options.

B.1.2 VIEW: VNC based Indirect-observational Elicitation through WiFi

Indirect observation recordings are a reliable source of HCI KE data in Software Engineering and HCI (Preece, 1994). It is an especially effective KE method as a usability testing technique.

VNC from AT&T Laboratories (AT&T, 2000) is a powerful client-server technology that goes beyond screen capture technologies and allows the real time visual representations and activities of a desktop to be captured and transmitted virtually, including all end user actions across a network to a client station. With the advent of wireless networks such as the WiFi 802.11b/g standard, it is possible to view a desktop PC's actions taking place from anywhere with a network connection by installing the VNC platform.

Al-Malki (2004) presents a method for securing SSH tunneling networks for VNC thus enabling the technology to be used as a platform for observing educational tasks. Taking this further, an existing VNC client software implementation from Gerardin (2003) enables PalmOS based PDAs to have VNC capabilities. Thus combined as the theoretical VIEW platform, this allows Gerardin (2003)'s client viewer access to remote observation over an Ad-Hoc (Peer to Peer) WiFi network, suitable for classroom scenarios. Figures B.2 and B.3 show screenshots of what observational capture looks like, courtesy of Gerardin's PalmVNC implementation.

Figure B.2 Gerardin's PalmVNC 2.0, running unscaled on a greyscale PalmOS PDA

Figure B.3 Gerardin's PalmVNC 2.0, running scaled on a colour PalmOS emulator

It is noted on these images that his technology encapsulates scaling features to dynamically resize views to the host PDA hardware's capabilities if selected.

The premise of VIEW is important as it elicits natural behavioural actions from participants when using desktop software without significant visible indications that they are under observation. By being un-tethered with wireless network capabilities and use of near real-time mobile visualisation, a KE investigator can select observation views from a location within a wireless zone. A potential research direction to explore further in VIEW would be the automated capture of all real-time networked VNC server screens to a central storage server (non-mobile based solution), in a manageable data format to an archive for later retrieval and further analysis. See section B.2.2 for more on a similar concept.

B.1.3 MOVIE: Multi-spatial Observational VIdeo Elicitation

The use of video recordings in direct and indirect observation has presented a series of difficulties to the management of large quantities of elicited video data and it's storage by HCI practitioners. MOVIE looks to resolve this issue through a number of tools and technologies. Firstly, the concept of MPEG video compression (ISO MPEG-4, 1998) is a standard across the internet for high quality video encoding to digital formats, with several derivative standards developing customized versions around the standard implementation (Microsoft Windows Media 9, 2002; DivX, 2002). Where a typical 2 hour feature film quality DVD MPEG-2 video stream equates to 4.9 Gigabytes of data storage (4900Mb), the same stream of video and audio compressed with MPEG-4 equates to approximately 700 Megabytes of storage space, with very little loss in visual accuracy and resulting in better economics for storage capacity requirements.

On another development, significant enhancements have been made to the technologies behind graphics rendering hardware and graphics processing units (GPUs) from companies like NVidia (2004) and ATI (2004). Though considered to be of primary importance in the fields of Virtual Reality and games technology, the improvements to visual rendering quality and video stream capabilities have been significant in the last decade. Hardware MPEG and H.263 video decoding facilities and advanced embedded qualitative analysis algorithms for video playback have matured to ensure a consistently smooth stream of video playback. More significantly, the GPU enhanced desktop PCs on the market now support multiple monitor facilities, enabling a low cost method for expanding the visual space for navigation and working on an extended operating system desktop view.

MIKE's MOVIE was designed as a theoretical prototype to overcome a deficiency in the way in which MPEG video playback is split across multiple monitors. Its importance to this research comes when considering that HCI practitioners have the availability of video enabled PDAs, personal video recorders and mobile phones, capable of MPEG capture. The potential for using this with the availability of extended computing display spaces (e.g. multi-monitor and widescreen configurations) give the practitioner the capability to manage multiple views of an elicited video scenario. This could be of significance in the identification of easy to miss events when reviewing several video clips linearly rather than simultaneously, as shown in a capture of several views elicited from an Affinity diagram exercise, in Figure B.4. It is of particular interest to role playing, scenarios walkthroughs and requirements activities.

Figure B.4. MOVIE replaying several Mobile MPEG-4 streams combined, each segment capable of 640x480 resolution

Once several captures of mobile video streams (upto 8 individual files) are taken from such mobile devices they are transferred to a desktop PC with a GPU graphics card installed. The current status of this prototype requires a video editing tool (Pinnacle Studio, 2004) to merge the files into one large video stream file. However, future extensions of this research would consider it a prerequisite to enable several individual video files to be selectively played on demand simultaneously, with their own individual timelines for playback management.

This thesis does not claim that the demonstrated extended desktop video solution is original, as others have created multiscreen video playback software commercially prior to this implementation being made (Ahead NeroVision, 2003). As a HCI tool it describes mobile video management and factors in multi-view scenarios analysis of human-computer interaction. It's most significant advantage is as a low cost method for practical video analysis on readily available equipment in comparison to current-day HCI laboratory video monitoring equipment.

B.2 Practical Cyberscience Prototypes as Implemented MIKE Designs

The following MIKE tools are functional prototype designs, and have been used by HCI researchers, practitioners and students within the Centre for HCI Design, City University London as of 2004.

B.2.1 MUSE: Mobile User Survey Environment

Deploying surveys on-site are readily available approaches to enquiring user centred data digitally. Upon the literature review conducted in chapter 2, it was found that there were no significant works reported on mobility solutions to this aspect of knowledge elicitation. MUSE is a Mobile User Survey Environment for PDAs. It maintains its state of the art as a mobile survey building tool, with the integration of pre-designed survey templates as well as facilities for real world construction of surveys.

Surveys can either be built on PDA devices or on desktop machines or later uploaded. The context of a MUSE survey is written with an XML description of question and answer-type pairs, with the option for either multi-scalar answers or open ended text answers. These XML templates can then be beamed (via Bluetooth or IrDA Infrared) from one PDA to another with the MUSE client so that a particular survey can be set up and distributed amongst KE experimenters.

Based on the constraints of handheld devices (Weiss, 1998), MUSE takes into consideration PDA screen formatting, modeling the paradigm of web browser style navigation. This has been shown to present a number of challenges for UI designers (Yang et al, 2002). Thus the rendering interface of the MUSE tool takes into consideration the PDA platform specifics for graphics capabilities. As successive generations of PDAs are available with higher resolutions, survey scales with MUSE will scale accordingly. Figure B.5 demonstrates this high resolution mode.

Survey response data can be saved in either XML or in CSV text locally on the PDA, or transmitted to a webserver solution for collection and analysis. Both of these file formats easily import the data into Microsoft Excel for the HCI practitioner to collate and analyse on-site survey responses.

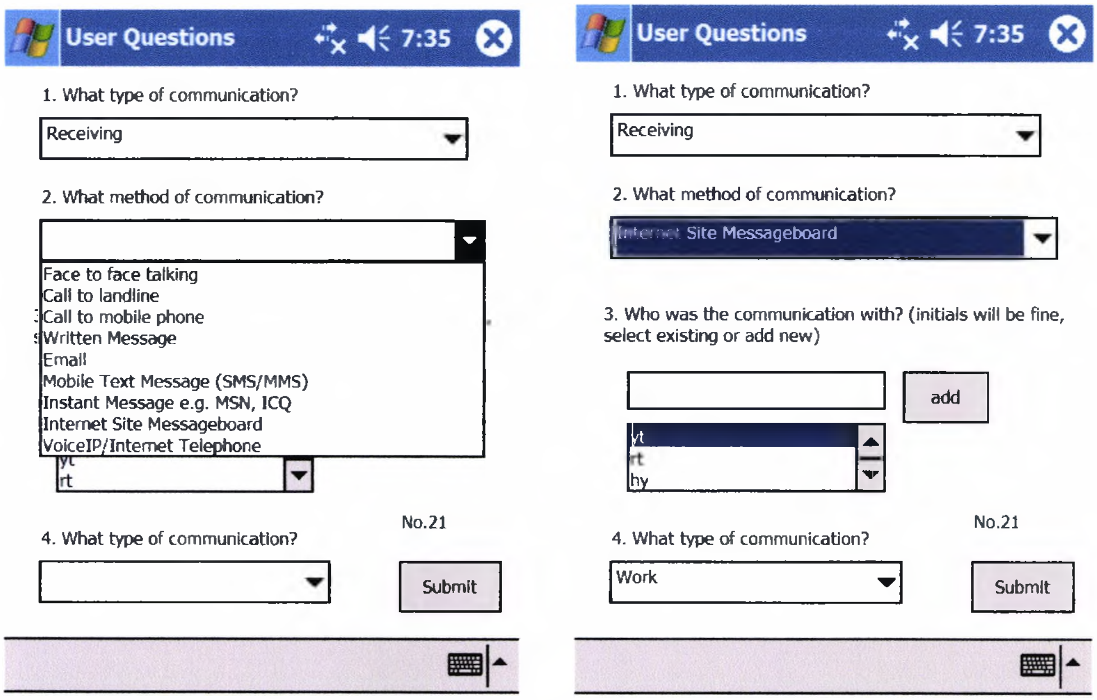


Figure B.5. MUSE screenshots of a high resolution mobile surveys on PocketPC PDAs.

B.2.2 VIVID: Virtual Interface to VIDeo

Indirect (remote) observation for user testing is a non-human interaction elicitation method on the part of the KE investigator whereby the activities of a participant are recorded and logged if necessary by software or video capture. As such, video observation of direct and indirect actions (screen and user) is a common technique for HCI practitioners for many purposes, including enquiry of usability flaws with heuristic evaluations, and accessibility optimisations for designers.

Though considered an important indirect method of eliciting the knowledge of participants, the use of video recordings in direct and indirect observation has presented a series of difficulties to the management of large quantities of such video data and it's storage by HCI practitioners. The costs of extensive video recording and storage solutions of the typical HCI laboratory are relatively high (typically £2000+), and in particular requires that stakeholder users be forced to come into a laboratory scenario. For eliciting HCI data that is set for particularly difficult scenarios to model, this poses a loss in accuracy in knowledge elicitation.

VIVID (VIrtual VIDeo) is a tabletPC based screen, video and audio capture tool (figure B.6). Indirect video observation is a common technique for HCI practitioners for many purposes, including enquiry of usability flaws with heuristic evaluations, and accessibility optimisations for designers.

Whilst there are numerous other commercial video capture tools that can record desktop observations such as Techsmith's Camtasia (Techsmith, 2005), VIVID is a free research tool that utilises the Windows Media 10 SDK to invoke the near native resolution quality screen capture codecs that are a part of Windows Media Player. These are of significantly high quality and compression of both the screen and audio via microphone (WMV/WMA formats) i.e. focus group experiments or talking aloud elicitation.

This highly compressed media format easily replaces the last decade's typical HCI usage of rooms of video tape user screen-activity observations with a lot less hard drives in comparing physical space. In addition to the screen codec, VIVID allows multiple WMV9 bitrate types to be chosen as well, such that video observation data can be streamed for expert review via mobile devices (pdas and capable phones, figures B.7 and B.8).

The development of the freeware VIVID tool places it alongside Camtasia and other commercial tools, and has been utilised as a HCI tool by several successful undergraduate and research HCI projects at the Centre for HCI Design, on a variety of scenarios.

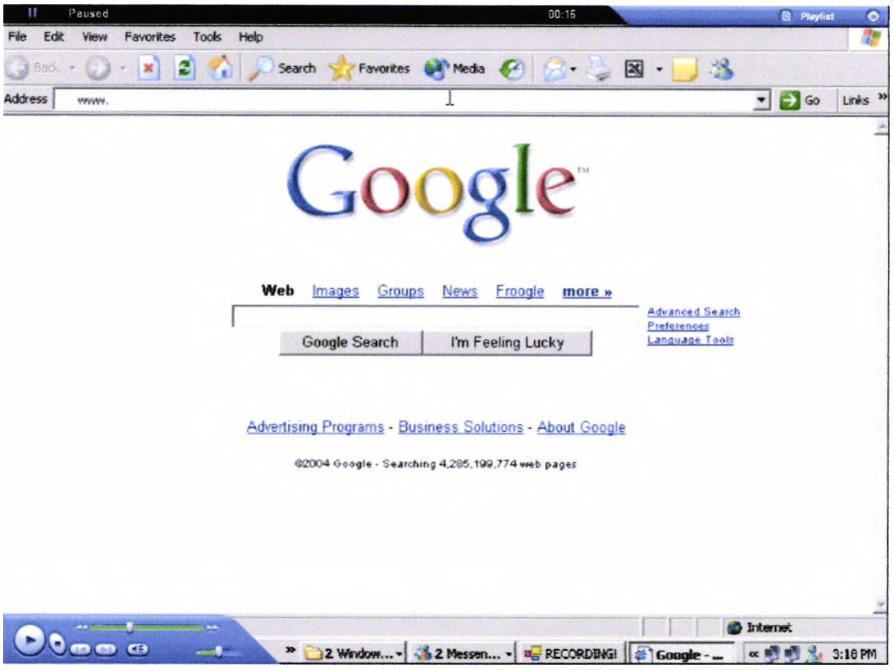
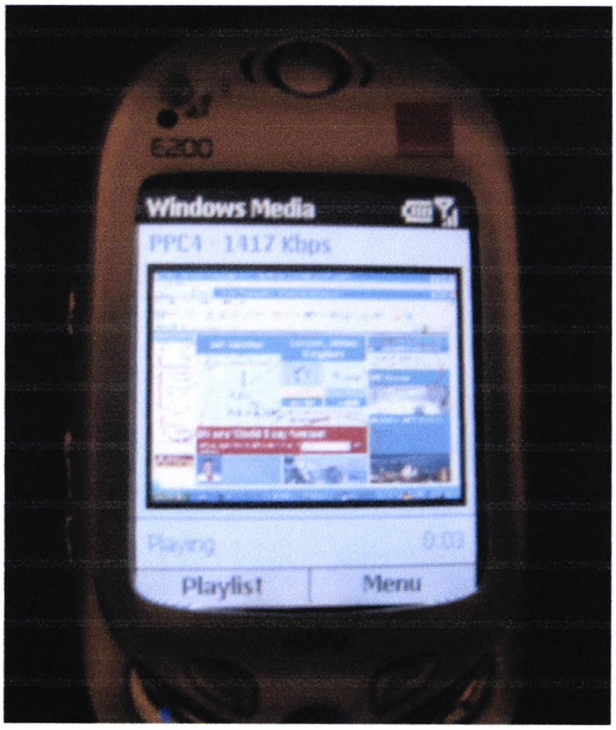


Figure B.6. VIVID screenshot of replaying a user navigating a website



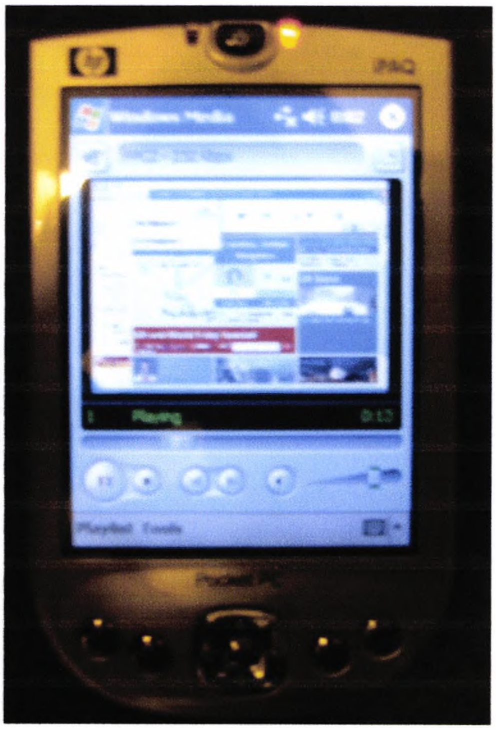


Figure B.7 and B.8. VIVID screenshot replaying a VIVID encoded clip, with audio encoding, tested on an SPV E200 Mobile phone and an HP Ipaq 4150 PocketPC

B.3 Collaboration Work on VREs supporting MIKE tools and HCI Cyberscience

In dealing with cyberscience tools for HCI, the research undertaken in this thesis has led to. work on Virtual Research Environments (VREs) for HCI. These aim to manage and enable the collaboration of the scientific artefacts in HCI data collection and analysis. CONKER and PET are two such tools developed in collaboration with the University of Brandenburg to support the MIKE tools that this thesis describes.

B.3.1 CONKER – A Collaborative Non-linear Knowledge Elicitation Repository for Mobile HCI practitioners

For further information see:

Mohamedally, D., Edlich, S., Zaphiris, P., & Petrie, H. (2005). "MIKE's CONKER - A COllaborative Non-linear Knowledge Elicitation Repository for Mobile HCI Practitioners", In Proceedings of SPIE's 17th Annual Symposium for Electronic Imaging 2005, San Jose, California, USA.

B.3.2 PET – A Participant-based Experiment Tracking tool for Mobile HCI practitioners

For further information see:

Mohamedally, D., Edlich, S., Klaus, E., & Zaphiris, P. (2006). "MIKE's PET – A Participant-based Experiment Tracking Tool for HCI Practitioners using Mobile Devices" , In Proceedings of SPIE's 18th Annual Symposium for Electronic Imaging 2006, San Jose, California, USA.

Appendix C

C.1 Expert Participatory Design Pre-Questionnaire

Mobile digital tools for Human-Computer Interaction (HCI) specialists conducting user experiments
(expert group responses)

Participant number:

1. Do you have an interest in HCI?

   YES NO

2. Are you a HCI specialist?

   YES NO

3. Have you conducted HCI user experiments before?

   YES NO

4. Are you familiar with Card Sorting?

   YES NO

5. Have you conducted a user Card Sort experiment before?

   YES NO

6. Are you familiar with Affinity Diagrams?

   YES NO

7. Have you conducted a user Affinity Diagram experiment before?

   YES NO

8. Are you familiar with Paper Prototyping?

   YES NO

9. Have you conducted a Paper Prototype with users before?

   YES NO

10. How regularly do you utilise web-browsers?

    I Don't rarely monthly weekly daily

11. How often do you play card games?

    Don't know any rarely monthly weekly very often

12. Would you kindly mark which age group you are?

    Prefer not to 18-25 26-35 36-45 46+

13. Would you kindly mark whether you are male or female?

    Prefer not to Male female

14. Have you ever used a tabletPC before?

    YES NO

15. As a HCI specialist would you kindly suggest a type of user based knowledge acquisition that you believe would most benefit you by having some kind of device/software/tool to assist your routine experimental practices?

16. In capturing user information, which media representation do you acknowledge by highest priority?

	HIGHEST FIRST
Textual (e.g. questionnaires, card sorting)	1
Graphical (e.g. paper prototyping, storyboarding)	2
Audio (e.g. observational, interviews)	3
Video (e.g. observational)	4

17. Do you have any comments to add?

C.2 Expert Participatory Design Post-Questionnaire

Mobile digital tools for Human-Computer Interaction (HCI) specialists conducting user experiments

Participant number:

1. As a HCI specialist would you kindly suggest a type of user based knowledge acquisition that you believe would most benefit you by having some kind of device/software/tool to assist your routine experimental practices?

2. Rank the importance of these methods highest first by numbering them 1-13

	HIGHEST FIRST
Questionnaires	
Focus groups	
Interviews	
Task Analysis	
Repertory Grids	
Card Sorting	
Storyboards	
Scenario decomposition	
Affinity Diagrams	
Direct Observation	
Paper Prototyping	
Indirect Observation	
Thinking out aloud	

3. Aside from the methods above, are there any critically important user knowledge acquisition methods that you use regularly in user-centered design and evaluation, and what number importance would you place it in the table?

4. From your knowledge do you believe there is a place in HCI for mobile assistant tools for conducting user based knowledge acquisition experiments, and for what reason?

5. In capturing user information, which media representation do you acknowledge by highest priority?

	HIGHEST FIRST
Textual (e.g. questionnaires, card sorting)	1
Graphical (e.g. paper prototyping, storyboarding)	2
Audio (e.g. observational, interviews)	3
Video (e.g. observational)	4

6. Do you have any comments to add?

Appendix D

D.1 User Centred Design of CAKE

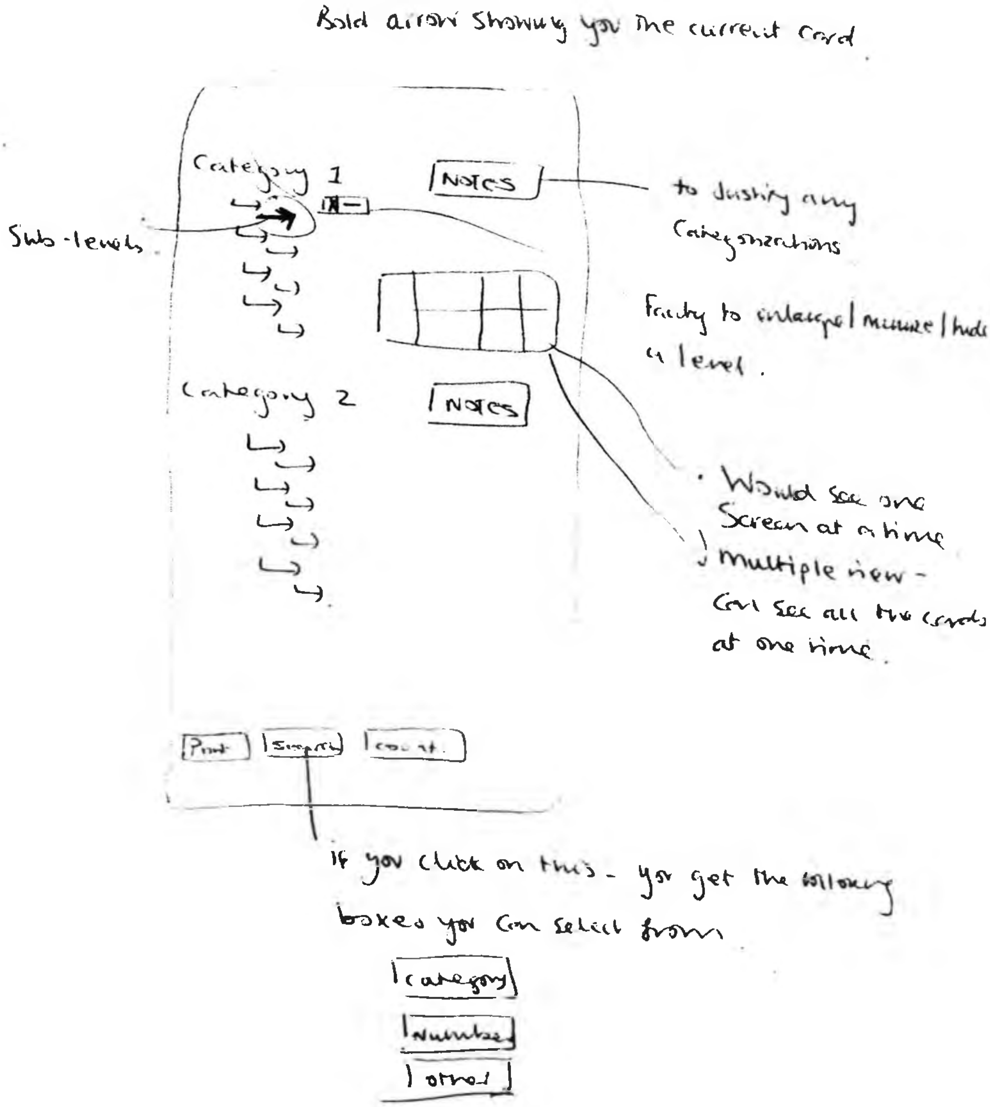
D.1.1 Pre-test Questionnaire

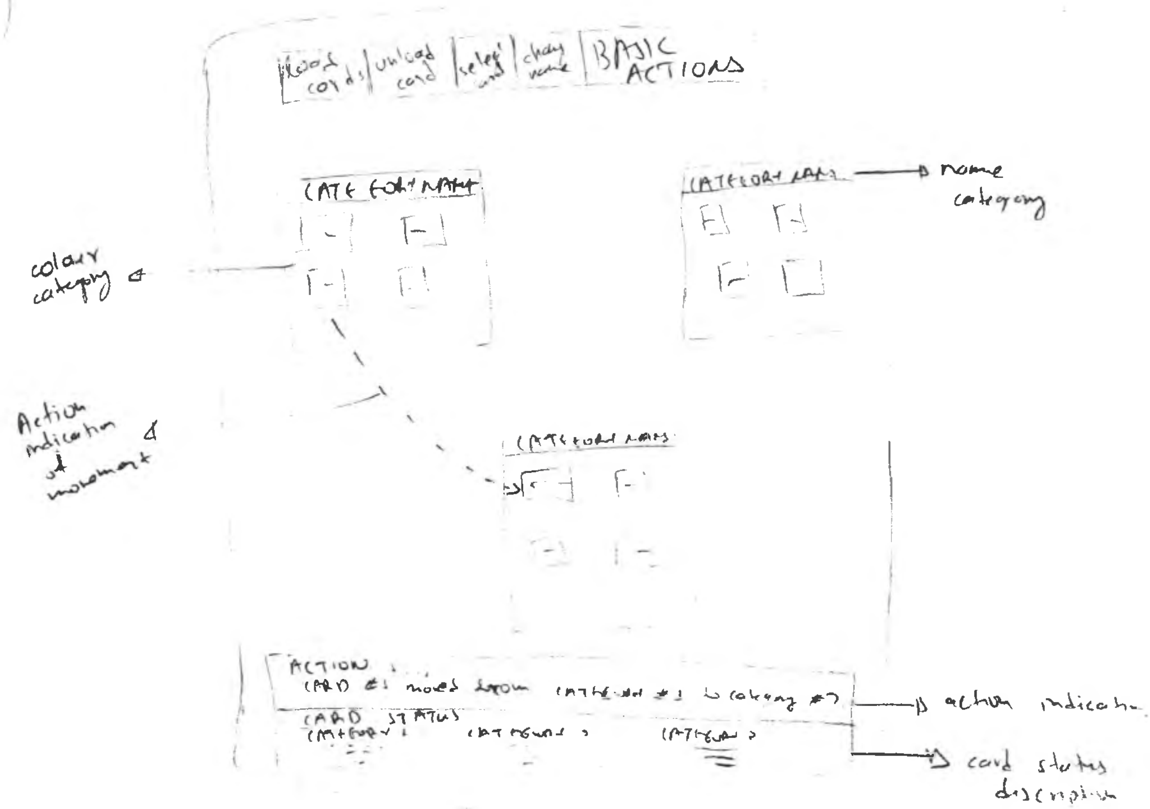
Pre-test questionnaire
Age
Gender
Level of education
Current programme title
Ever done a course in HCI before?
Ever taken part in a psychological experiment before?
How long have you used computers?
Which operating system do you use regularly?
How long have you used the internet?
Which web browsers do you use?
Ever filled a web form online before?
Do you know what java is?
Ever used java before?
Do you know what card sorting is?
Ever done a card sort before?

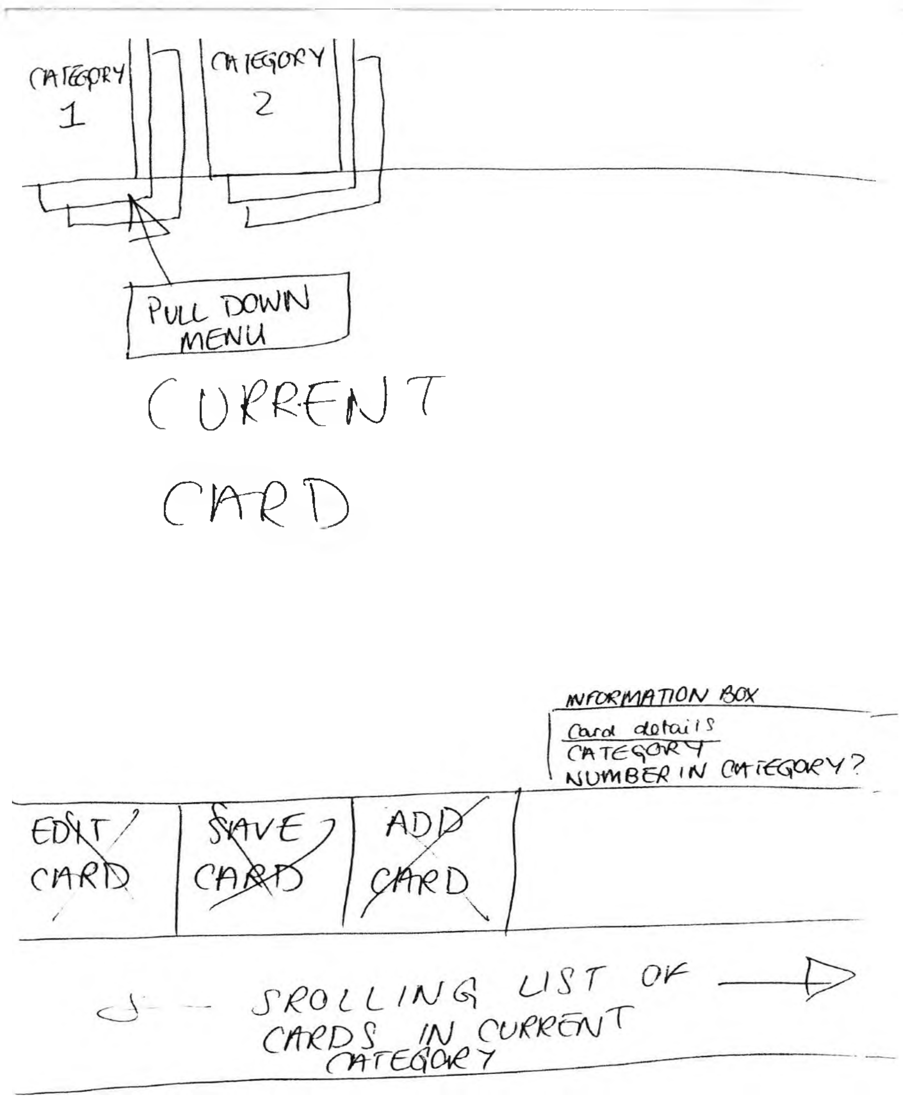
D.1.2 Post-test Questionnaire

Post test questionnaire
Did you find the tool easy to understand? 1-5 likert scale with 5 being yes
Easy to navigate? 1-5 likert scale with 5 being yes
Refer to help file?
Accomplish the task set? 1-5 likert scale with 5 being yes
Learnt something about mobile devices?
Consider card sorting useful?

D.1.3 Expert Paper Prototypes for CAKE




BASIC ACTIONS
name category
colour category
Action indication of movement
action indication
card status description


CATEGORY 1
CATEGORY 2
PULL DOWN MENU
CURRENT CARD
INFORMATION BOX
Card details
CATEGORY
NUMBER IN CATEGORY?
EDIT CARD
SAVE CARD
ADD CARD
SCROLLING LIST OF CARDS IN CURRENT CATEGORY

D.2 Example Output from CAKE (EZCalc compatible format)

```
>Cardnames
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
>Person
exp5, exp5@
>Groupnames
graphics
input devices
ui
prototyping
human response
>Sortresult
1,1
1,1
2,2
1,1
1,1
3,3
4,4
5,5
4,4
5,5
3,3
2,2
3,3
3,3
3,3
1,1
5,5
5,5
5,5
5,5
4,4
5,5
3,3
3,3
```

D.3 Participant Study – Task Sheet Examples

Group Experiments Name:______________________________

Experiment 1: Non-Linear, Non-electronic Card Sorting, Expert Domain
You have 15 minutes to communicate as a group and sort the given cards into a maximum number of **eight category names** which you have to come up with as a group. You can of course create less than eight categories but **each card (1-25) must end up with a category name**. Write the category names below, followed by the card numbers.

Category name	Card numbers (e.g. 1,6, 19)

Group Experiments Name:______________________________

Experiment 3: **Linear**, Non-electronic Card Sorting, Expert Domain
You have 15 minutes to communicate as a group and sort the cards **in the sequence that they are given** into a maximum number of **eight category names** which you have to come up with as a group. Once you have seen and placed a card into a category please do not change the category that you have put it into (thus it is linear nature) – your first impressions are the important factor to be captured. You can of course create less than eight categories but **each card (1-25) must end up with a category name**. Write the category names below, followed by the card numbers.

Category name	Card numbers (e.g. 1,6, 19)

Individual Experiments Name:______________________________

Experiment 10: **Linear**, Non-electronic Card Sorting, Non-Expert Domain

You have 15 minutes to work on your own and sort the cards **in the sequence that they are given** into a maximum number of **eight category names**. Once you have seen and placed a card into a category please do not change the category that you have put it into (thus it is linear nature) – your first impressions are the important factor to be captured. You can of course create less than eight categories but **each card (1-25) must end up with a category name**. Write the category names below, followed by the card numbers.

Category name	Card numbers (e.g. 1,6, 19)

Individual Experiments Name:______________________________

Experiment 12: **Linear**, **Electronic** Card Sorting, Expert Domain

You have 15 minutes to work on your own and sort **using a PDA,** the cards **in the sequence that they are given. Please do not create more than eight category names**. Category names are added via the PDA keyboard. You continue through the card sort placing cards into existing or new categories until it is finished. Your first impressions are the important factor to be captured. Upon completing the experiment the data will automatically be stored by pressing the submit button.

D.4 Participant Study – Example Data Collected from Card Sorting Variations

Experiment 1: Non linear, Non electronic card sorting, expert domain

Category name	Card numbers
(Interface) GUI	1, 4, 10, 16, 21
Prototyping	7, 9
Evaluation	22, 23, 24, 25
Requirements	17, 18, 19, 20
Interaction Styles	2, 3, 5, 6, 8, 11,12,13,14,15

Experiment 2: Non-linear, Non-electronic card sorting, non-expert domain

Category name	Card numbers
Formatting layout	1, 4, 8, 9, 12, 14, 17, 20
Properties	6, 7
Interaction	3,
Standards	5, 16, 19
Usability	2, 10, 11, 13, 18, 21, 22, 23, 24, 25
Tools	15,

Experiment 3: linear, Non electronic card sorting, expert domain

Category name	Card numbers
Navigation	1,4,5,12,16, 21
Suggestions/feedback	8,10
Analysis Techniques - evaluation	22, 23,24,25
Interface manipulation	3,6,11,13,14,15
Initial requirements capture	7,17,18,19
Analysis Techniques	2, 9, 20

Experiment 4: linear, Non-electronic card sorting, non-expert domain

Category name	Card numbers
Web related characteristics	5, 22
web page characteristics	2,4,6,7,8,12,17,20,25
web page interaction	3,10,11,18,21,24
Styles	1,9,13,14,23
External software	15,
Guidelines	16, 19

Experiment 7: non linear, Non electronic card sorting, expert domain	
Category name	Card numbers
Interaction	1,2,3,5,6,8,10,12,16
Prototyping	7, 9
Elicitation	17,18,19, 20, 21
Evaluation	22,23,24, 25
Human sensory recognition	4,11,13,14,15
Presentation	1,2,4,9,17,20,23,24
Clarity	3,6,7,10,13,25
Function	5,12,14,15,22
Interactivity	11,18
Information	8,16
Adherence	19,21
Evaluation	17,18,19,20,21,22,23,24,25
Virtual Reality	2,3,8,10
User Input	5,6,11,12,13,15, 16
Prototyping	1,6,7,9,10,13,14,15
Formatting	1,3,4
Requirements collection	17,18,19,20,
Evaluation	22,23,24,25
Interface Interaction	1,2,3,6,10,12,16
Prototyping	7,9
Input Methods	4,5,11,13,14,15
don't know	21
Interfaces	1,3,4,5,6,10,11,12
Collection of results	17,18,19
Sensory measurement	2,8,13,14,15
Evaluation	9,22,23,24
Navigation	7,16
Rules	20,21,25

Experiment 8: non-linear, Non-electronic card sorting, non-expert domain	
Category name	Card numbers
Format	1,9
Interface	2,3,4,5,6,7,8,11,12
Accessibility	10,14,15,16,18,19
again are together but don't know name	17,20,21,22
Don't know but are together.	23,24,25
Presentation	1,4,10
Interaction	2,6,8,11,12,13,14
Control	3,5
Perception	7,9,15,16
Requirements	17,18,19,22,23,24,25
Formatting	1,2,4,6,7,8,9,12,17,20,24,25
Style	1,4,8,9,11,14,17,20,23
HTML parameters	1,2,4,6,7,9,12,17,20
External Tools	3,14,15,16,19,24
Improving usability	5,10,13,18,21,22
Accessibility	3,10,11,16,19
Accessibility	5,13,18,21,22
Website rules	1,2,4,6,7,9,12,17,20
Formatting	1,2,4,6,7,8,9,12,17,20,24,25
Interfaces	1,4,8,9,11,14,15,23
Tools	3,14,15,19,24
Visual	1,3,4,6,7,9,23,24
Navigation	8,10,12,17
Certifications	16,19
Inputs	5,11
Processes	14,15,22
Others	2,13,18,20,21,25

Appendix E

E.1 User Centred Design of SAW

E.1.1 Affinity Diagram Branches for SAW

Affinity Diagrams

Basic functions

- load cards
- process cards e.g. make changes/correct mistakes on cards
- load graphics and own drawings
- simulate post-it notes creation
- add keyboard text

Categorisation

- categorise cards
- view post it notes within a category
- reorganize within and across categories
- add new/delete categories
- edit category name
- move category windows (backward or forward)
- restructure cards
- post it notes manipulation

viewing/navigation

- view all post its/cards
- multiple views
- one card at a time view (slideshow navigator)
- arrows showing movement of cards between different groups
- back/forward/save buttons
- zoom view/overview

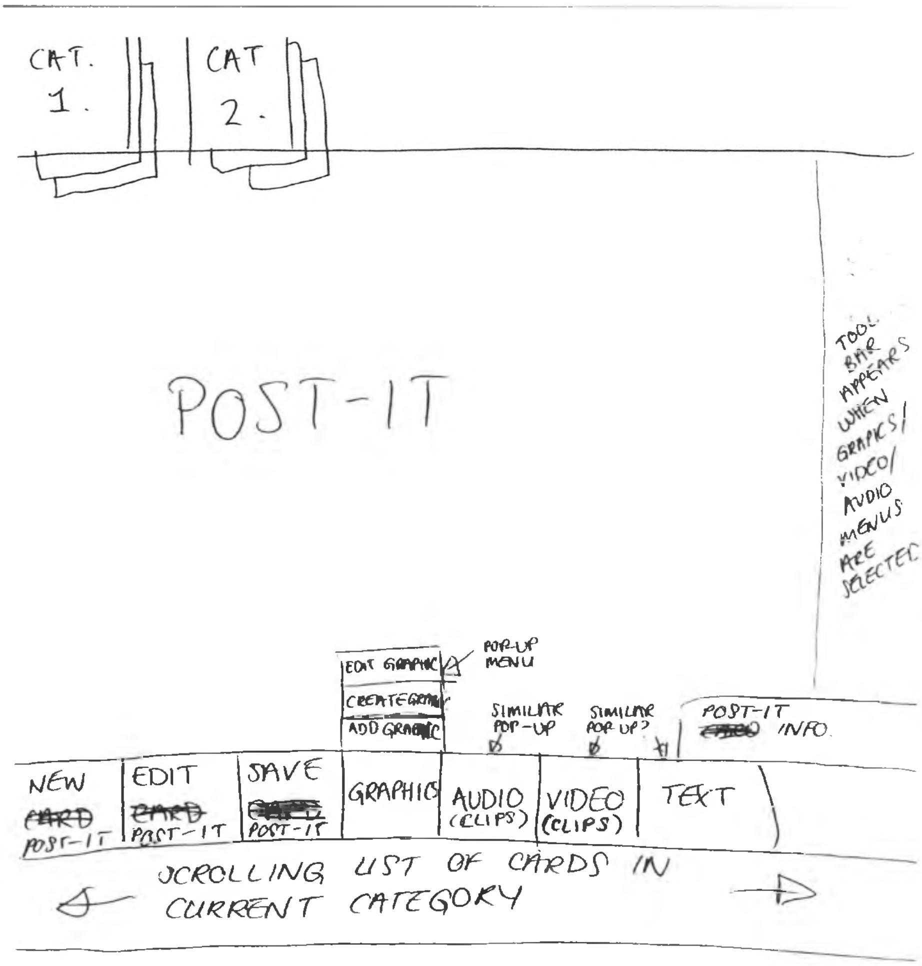
File/edit menu

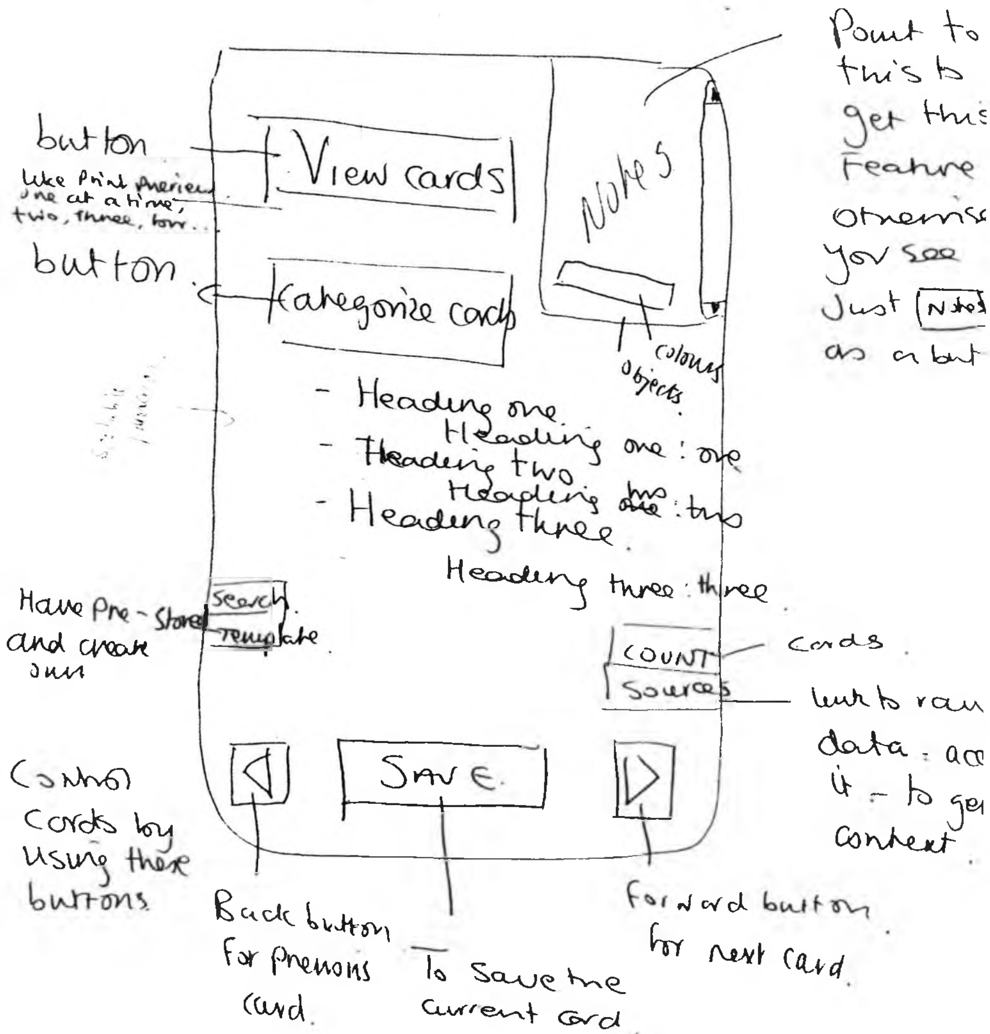
- add, copy, paste, edit, save, delete, print notes
- save screenshot of affinity diagram for emailing to others

Progress info in real time

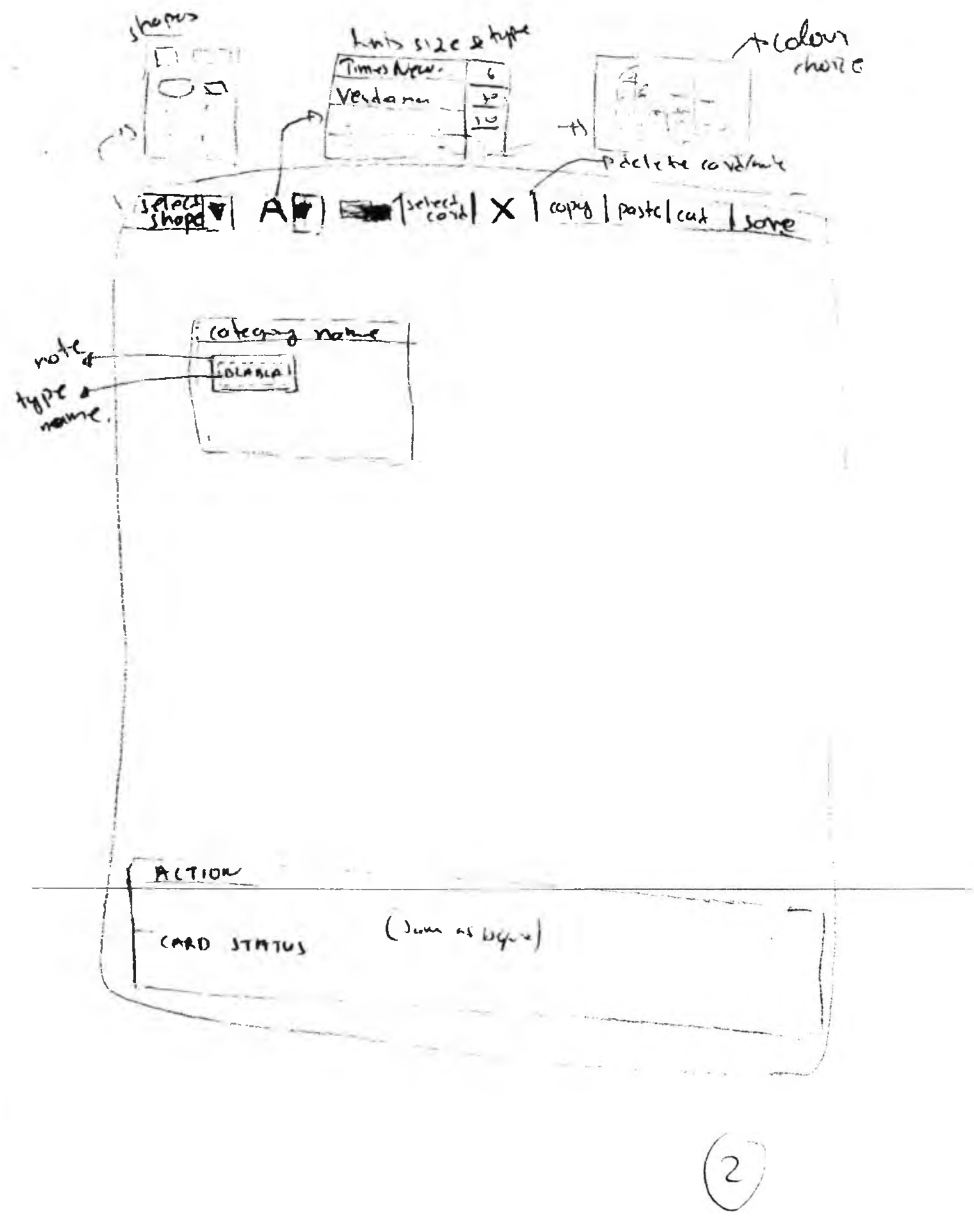
- textual indication of action e.g. "moving card 3 into group 2"
- textual description of all groups

E.1.2 Expert Paper Prototypes for SAW





button
View cards
button
Categorize cards
Notes
colours objects
- Heading one
- Heading two
- Heading three
Heading one : one
Heading two : two
Heading three : three
Search
Template
COUNT
Sources
cards
SAVE
Back button for previous card
To save the current card
Forward button for next card
Control cards by using these buttons
Have pre-stored and create own


shapes
fonts size & type
Times New
Verdana
6
8
10
+colour choice
delete card/note
select shape
A
select card
X
copy
paste
cut
save
category name
note
type a name.
ACTION
CARD STATUS
(same as before)
2

E.2 Affinity Diagramming Case Study B Participants Sheet

Affinity Diagrams

Work in your groups for these exercises

Introduction

Affinity diagramming is a popular **team-only technique** whereby members in a team can organise ideas and opinions from a general topic, and break down complex concepts into more manageable atomic units, both visually and textually. It is used for giving structure to large or complex concepts and acquiring an agreement from a set of knowledge team members over the categories that should be used to represent atomic units.

Affinity Diagram Experiment

Based on the already given scenario for Web Accessibility Guidelines, you are to construct an affinity diagram in your groups.

To create an affinity diagram, create a list of ideas and concepts from your scenario using the post it notes (15 minutes), and then place them on the provided A3 sheet creating groups of related ideas (15 minutes). Label your groups with headings using the post it notes (10 minutes). The last 15 minutes will be used to discuss your categories.

As you sort through your post it notes, think about the following:

1. It isn't important to define why they belong together.
2. Should the small sets look as they belong in a larger group?
3. Do large sets need to be broken down further?

E.3 Data collection for Chapter 7 Case Study B

E.3.1 Case Studies Participant Consent Form & Pre-Questionnaire

Consent Form

The purpose of these class experiments are to

a) allow you to become familiar with electronic/software based HCI tools and exemplify the methods which you are currently being taught

b) For us to evaluate the effectiveness of several software tools under research and development

c) For you to become familiar with the practical methodology of conducting HCI research

The results of these experiments will not affect your grades whether you are asked to use the software or to use existing methods. First you will be asked to fill out a pre-questionnaire. You will then be given the experiment tasks to carry out as described by the teaching assistants. While conducting the experiment sessions feel free to voice comments on your activity. Afterwards you will be asked to complete a post-questionnaire. All experiment items must be returned to a teaching assistant. If you have any questions now please ask.

Each experiments duration will not last longer than the hour allocated for your class time. If for any reason you are uncomfortable with the study you may end it at any time. If you are not in agreement of this consent form and do not wish to take part in this study please do not sign this form below and kindly inform a teaching assistant.

I, ______________________________ (**print name**) have read and fully understood the extent of the studies and any risks involved. I sign here acknowledging the above information.

Participant Signature: ______________________________

Date: ______________________________

Pre-Questionnaire

Full Name:

Email address:

1. General Information

1.1 Age:

under 18

18-29

30-39

40-49

50+

1.2 Gender: Male Female

1.3 Have you ever been an experimental participant in an empirical or HCI related experiment?

Yes No Don't know

2. Experience

2.1 How long do you estimate you have used computers? Please circle one

Under one year

1-3 years

4-5 years

5-10 years

Over 10 years

2.2 Do you use any software tools for designing rough drafts/drawings?

Yes No

If Yes please list them ______________________

2.3 Have you ever used software specifically for HCI tasks before? Please circle

Yes No
If Yes please list them ___________________________

2.4 Have you used any of the following mobile devices? Circle as many as required.

Regular Mobile Phone
Camera/Video phone
PDA/Electronic Organiser
MP3/Portable digital media file player
Handheld game system
GPS Positioning Device
Laptop Computer
TabletPC

2.5 Have you ever used a TabletPC before?

Yes No

E.3.2 Example Paper Affinity Outputs as Affinity Branches

Group 1

Images
- identify as image
- caption of image
- brief description

Colour
- indicate/identify colour
- indicate changes in colour
- associated link clicks
- use of colour standards

Movements
- Shortcut to important pages
- Scroll using arrows

Attention
- Avoid moving text/objects
- Pop up distractions

Contrast
- clear contrast between background and foreground
- contrast should be changeable

Audio

- all audio files should be convertible to text
- avoid indicating task complete with a "donk" sound

Group 2

Visually Impaired People (VIPs)

- Avoid frames
- Alternative text
- Braille
- Large fonts
- Good contrast
- Standard colours e.g. blue links
- Captions
- Text reader

Hearing

- transcript
- Blink screen

Learning disabilities

- Simple and clean backgrounds
- Voice box
- Voice activated system
- Dictionary spell check

Mobility

- Track ball
- Morse code
- Onscreen keyboard

Group 7

Avoid distraction

- Not moving images
- Minimise use of tables

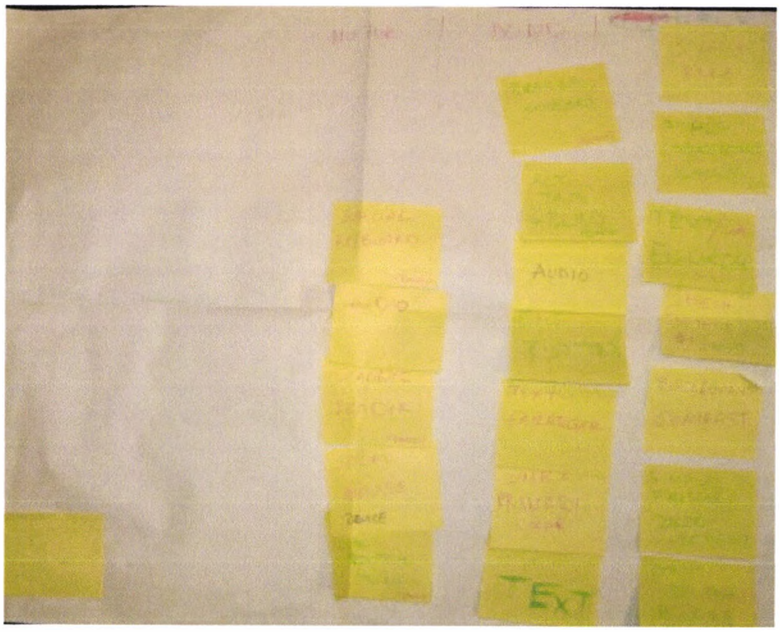
Visually clear

- good contrast
- large font
- big buttons

Alternative Communications

- Audio
- Label frames
- ALT-Tags for pictures and links
- Text links for image maps

E.3.3 Example Paper Affinity Outputs (photos)



E.3.4 Example SAW (Electronic) based Outputs as Affinity Branches

Group 3

layout
- Consistent between pages
- Big buttons
- Have high contrast between fore and background

Disability aids
- Speech input
- Speech output (screen reader)
- Using captions
- Use "alt" tag
- Don't use fast moving objects

Text layout
- Using paragraphs
- Using bullet buttons
- Use link standard conventions

Group 5

Foreground
- Contrast for background and foreground
- Consistent layout
- Alt tags
- Table and frame layout
- Non-vibrant colours

Alternative formats
- Text only version
- Audio format

Appearances
- Large buttons
- Bigger images
- Easy simple language

Help
- Special keyboards
- Braille reader
- Screen reader
- Special browsers

distractions
- no moving images and text

- no popups
- non moving objects
- help and support
- instructions

Group 6

Input
- Speech input
- Make the webpage compatible with assistive technology

Output
- Speech output
- Audio must be transcribed
- Video must be captioned
- Allow varied output services

Browser
- Use alt texts for images
- Don't rely on colour alone to communicate a message
- Use description for links
- Make sure pages work
- Test page with a variety of browsers

Layout
- Avoid tables for layout only
- Avoid scrolling text
- Large buttons
- Contrast
- Allow table content to be read in the right direction (e.g. top to bottom)
- Keep background clear
- Consistency in button navigation
- Make clear what is important

E.4 User Evaluation Methods for Chapter 7 Case Study B

E.4.1 Adapted CSUQ Questionnaire (Lewis, 1995)

Post Questionnaire – CSUQ Based Use of Paper Based Affinity Method

Name:
Group No.:

			1	2	3	4	5	6	7		NA
1.	Overall, I am satisfied with how easy it was to use the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
2.	It was simple to use the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
3.	I can effectively complete the given task using the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
4.	I was able to complete the task quickly with the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
5.	I was able to efficiently complete the task using the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
6.	I was happy to be using the paper based affinity method for the given task	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
7.	It was easy to learn to use the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
8.	I believe I became productive quickly using the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
9.	Overall, I am satisfied with the paper based affinity method	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
10.	It was easy for our group members to arrange things, given the size of paper for sticking onto	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
11.	It was easy for our group to make changes to the groupings	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
12.	The paper based affinity method assured agreement with group members	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
13.	It was easy for our group to make changes to the group labels	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
14.	The paper based affinity method has all capabilities I expect it to have	strongly disagree	○	○	○	○	○	○	○	strongly agree	○
			1	2	3	4	5	6	7		NA

E.4.2 QUIS Survey Template ((Chin et al, 1988; Slaughter et al, 1994)

Post Questionnaire: Effectiveness of Software (software participants)

List the most **negative** aspect (s) of the software:

1.
2.
3.

List the most **positive** aspect(s) of the software:

1.
2.
3.

OVERALL REACTION TO THE SOFTWARE		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**NA**
1.	terrible	○	○	○	○	○	○	○	○	○	○	wonderful	○
2.	difficult	○	○	○	○	○	○	○	○	○	○	easy	○
3.	frustrating	○	○	○	○	○	○	○	○	○	○	satisfying	○
4.	inadequate power	○	○	○	○	○	○	○	○	○	○	adequate power	○
5.	dull	○	○	○	○	○	○	○	○	○	○	stimulating	○
6.	rigid	○	○	○	○	○	○	○	○	○	○	flexible	○
SCREEN		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**NA**
7. Reading characters on the screen	hard	○	○	○	○	○	○	○	○	○	○	easy	○
8. Highlighting simplifies task	not at all	○	○	○	○	○	○	○	○	○	○	very much	○
9. Organisation of options	confusing	○	○	○	○	○	○	○	○	○	○	very clear	○
TERMINOLOGY AND SYSTEM INFORMATION		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**NA**
10. Use of terms throughout system	inconsistent	○	○	○	○	○	○	○	○	○	○	consistent	○
11. Terminology related to task	never	○	○	○	○	○	○	○	○	○	○	always	○
12. Position of messages on screen	inconsistent	○	○	○	○	○	○	○	○	○	○	consistent	○
13. Prompts for input	confusing	○	○	○	○	○	○	○	○	○	○	clear	○

		0	1	2	3	4	5	6	7	8	9		NA
14. Computer informs about its progress	never											always	
15. Error messages	unhelpful											helpful	
LEARNING		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**NA**
16. Learning to operate the system	difficult											easy	
17. Exploring new features by trial and error	difficult											easy	
18. Remembering names and use of commands	difficult											easy	
19. Performing tasks is straightforward	never											always	
20. Help messages on the screen	unhelpful											helpful	
21. Supplemental reference materials	confusing											clear	
SYSTEM CAPABILITIES		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**NA**
22. System speed	too slow											fast enough	
23. System reliability	unreliable											reliable	
24. System tends to be	noisy											quiet	
25. Designed for all levels of users	never											always	
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		**NA**

E.5 Affinity Data Representation within SAW

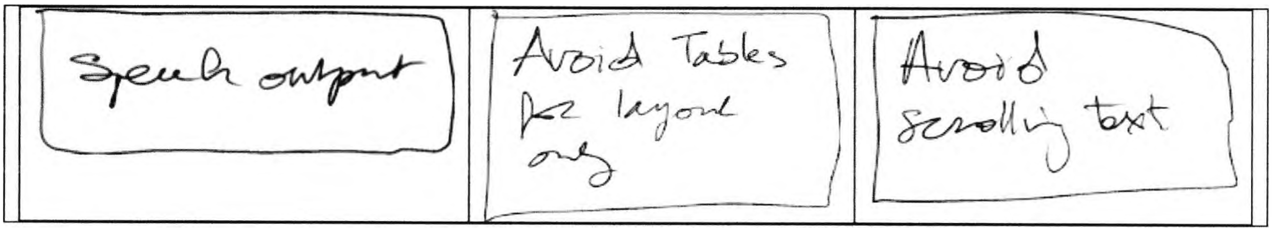
E.5.1 Sample SAW file output (a static instant in the affinity timeline)

```
16:41:44 20 September 2004
---
1
C:\tests\2004_9_20_16_23_0_864\9.gif
112
189
---
2
C:\tests\2004_9_20_16_23_0_864\8.gif
112
122
---
3
C:\tests\2004_9_20_16_23_0_864\7.gif
113
53
```

```
---
3
C:\tests\2004_9_20_16_23_0_864\7.gif
113
53
---
4
C:\tests\2004_9_20_16_23_0_864\6.gif
1
47
---
5
C:\tests\2004_9_20_16_23_0_864\5.gif
111
254
---
6
C:\tests\2004_9_20_16_23_0_864\4.gif
1
396
---
7
C:\tests\2004_9_20_16_23_0_864\3.gif
0
254
---
8
C:\tests\2004_9_20_16_23_0_864\2.gif
1
95
---
9
C:\tests\2004_9_20_16_23_0_864\19.gif
7
453
---
10
C:\tests\2004_9_20_16_23_0_864\18.gif
1
322
---
11
C:\tests\2004_9_20_16_23_0_864\17.gif
107
323
---
12
C:\tests\2004_9_20_16_23_0_864\16.gif
218
52
---
13
C:\tests\2004_9_20_16_23_0_864\15.gif
3
115
---
14
C:\tests\2004_9_20_16_23_0_864\14.gif
110
461
---
15
```

```
C:\tests\2004_9_20_16_23_0_864\13.gif
111
397
---
16
C:\tests\2004_9_20_16_23_0_864\12.gif
1
180
---
17
C:\tests\2004_9_20_16_23_0_864\11.gif
336
53
---
18
C:\tests\2004_9_20_16_23_0_864\10.gif
118
523
---
```

E.5.2 Example of ink-encoded cards created with SAW (group 6)



E.6 Semi-Dynamic Constructionism Output via MATE tool

E.6.1 Example output of constructs identified within a SAW affinity experiment for import into Excel (Group 6)

Group 6			
Time index	construction activity		
0	1	avg interval time	13.83
2	2	Number of actions recorded	51
2	3	Number of mediation points recorded	101
8	4		
10	5		
10	6		

10	7
12	8
12	9
14	10
14	10
16	11
16	12
18	13
18	14
20	14
22	14
22	14
22	14
26	14
28	15
30	16
32	16
32	16
32	16
32	16
34	16
34	16
60	17
80	17
80	17
80	18
80	18
86	19
86	19
86	20
86	20
86	21
86	21
94	22
94	22
130	23
130	23
140	24
140	24
170	25
170	25
176	26
176	26
178	27
178	27
178	28
178	28
182	29
182	29
182	30
182	30
188	31
214	32
240	32
266	32
298	33

298	33
300	34
300	34
328	35
328	35
392	36
392	36
400	37
400	37
428	38
428	38
434	39
434	39
482	40
482	40
484	41
484	41
500	42
500	42
510	43
510	43
520	44
520	44
524	45
524	45
530	46
530	46
534	47
534	47
534	48
534	48
542	49
542	49
544	50
544	50
584	51
624	51
624	51

Appendix F

F.1 User Centred Design of PROTEUS

F.1.1 Affinity Diagram Branches for PROTEUS

Paper Prototyping

Editing functions

- edit prototype
- save/copy/paste

- last update information
- freehand drawing
- auto recognition shapes rectangle, round box, arrows etc
- edit colours and line widths etc

Collaboration aids

- publish prototypes to the group asynchronously e.g. via the internet
- access to shared documents
- date/time calendar of a session time.

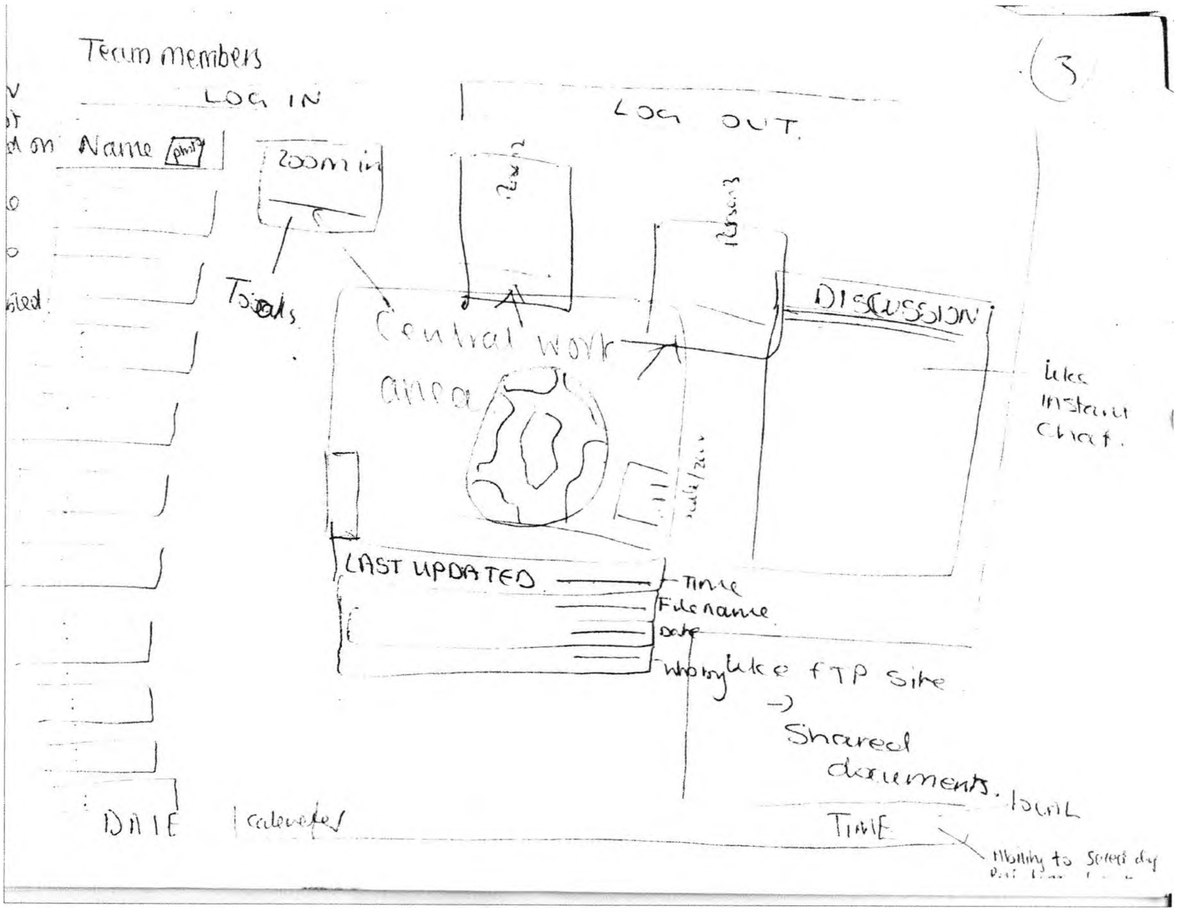
Viewing

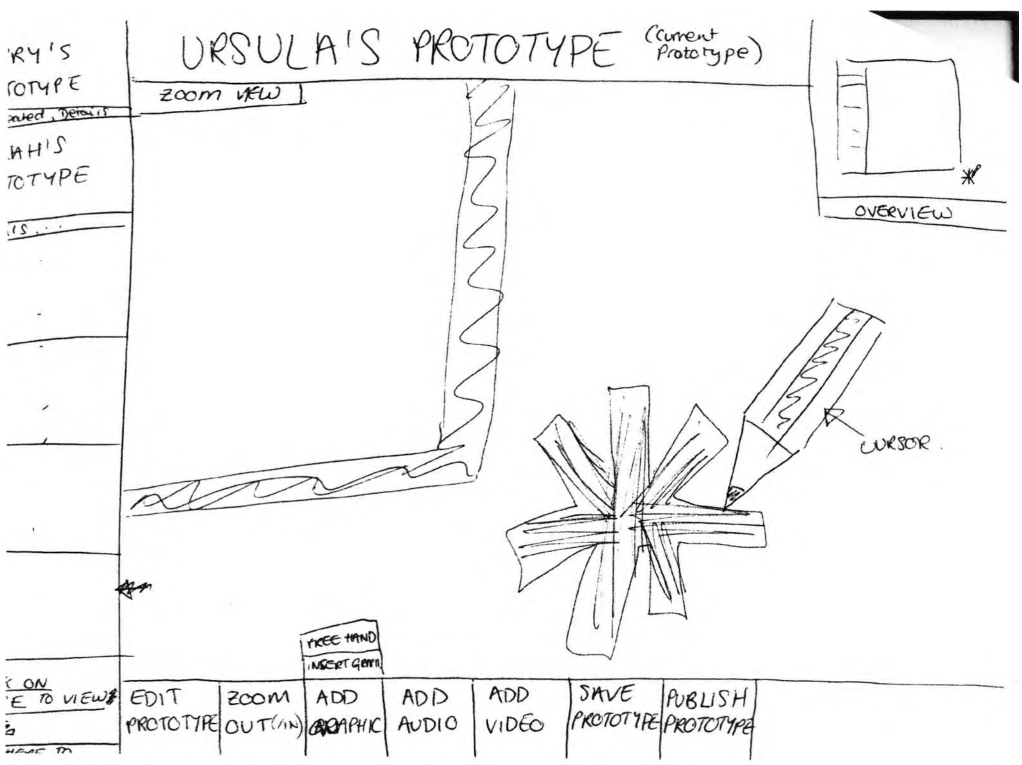
- zoom in and out for levels of detail in a prototype
- adjust drawing areas to fit on a screen

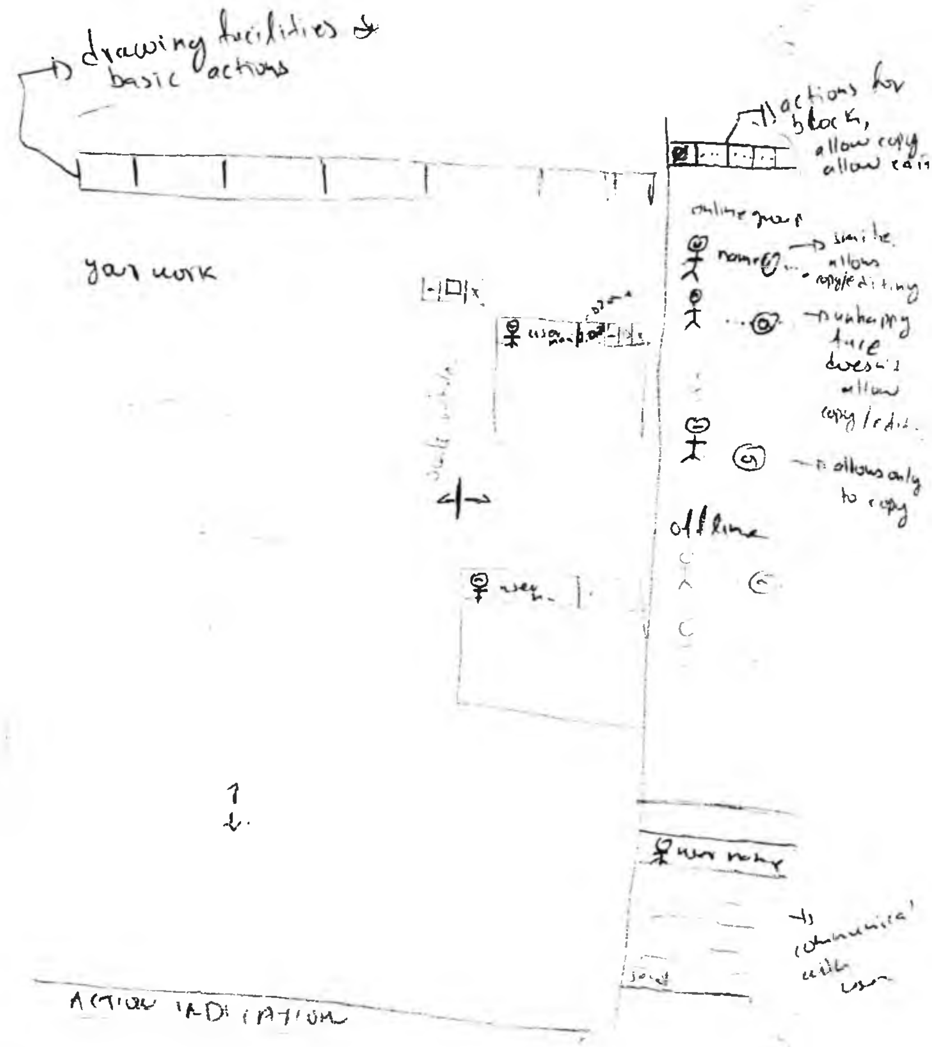
Non-critical but useful features

- configurable work area settings (e.g. load image into background, transparency for tracing etc)

F.1.2 Paper Prototypes for PROTEUS

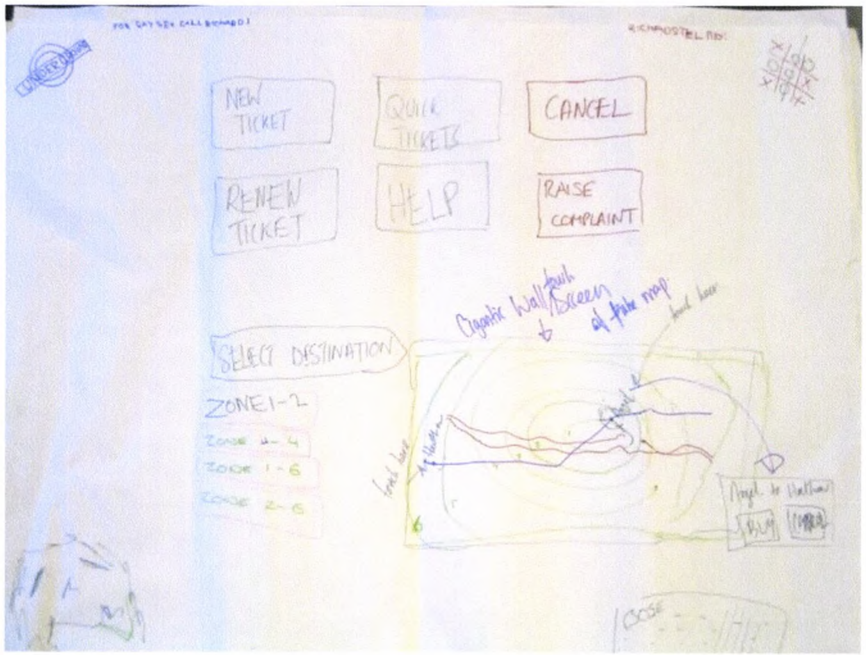

Team members
LOG IN
LOG OUT
Name
Zoom in
Tools
Central work area
DISCUSSION
like instant chat.
LAST UPDATED
Time
Filename
Date
like FTP site
Shared documents.
DATE
calendar
TIME

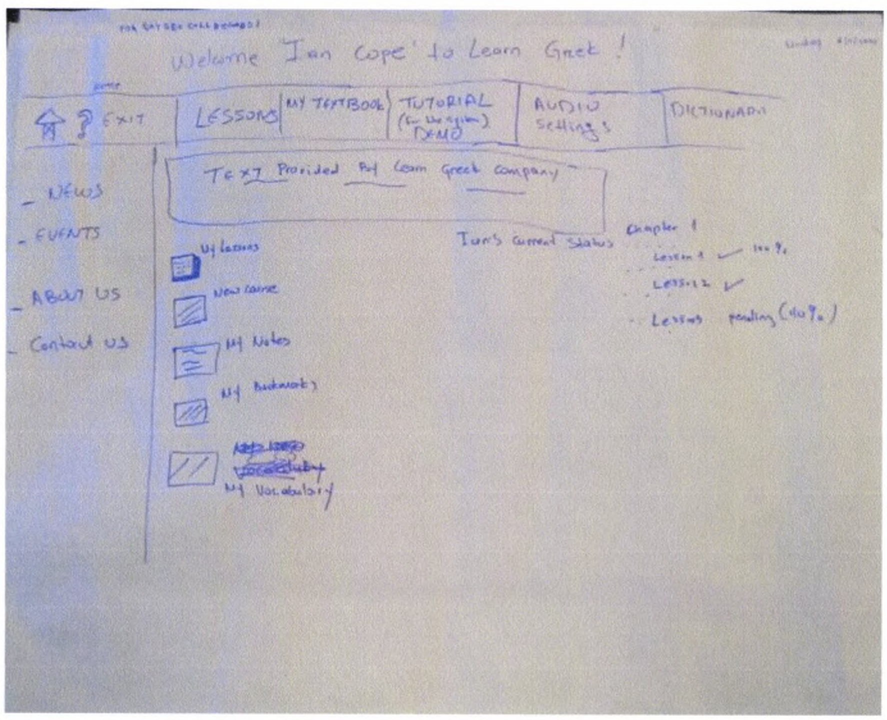

URSULA'S PROTOTYPE (Current Prototype)
ZOOM VIEW
OVERVIEW
CURSOR
FREE HAND
INSERT GRAPH
EDIT PROTOTYPE
ZOOM OUT(/IN)
ADD GRAPHIC
ADD AUDIO
ADD VIDEO
SAVE PROTOTYPE
PUBLISH PROTOTYPE


drawing facilities & basic actions
actions for block,
your work
offline
ACTION INDICATION

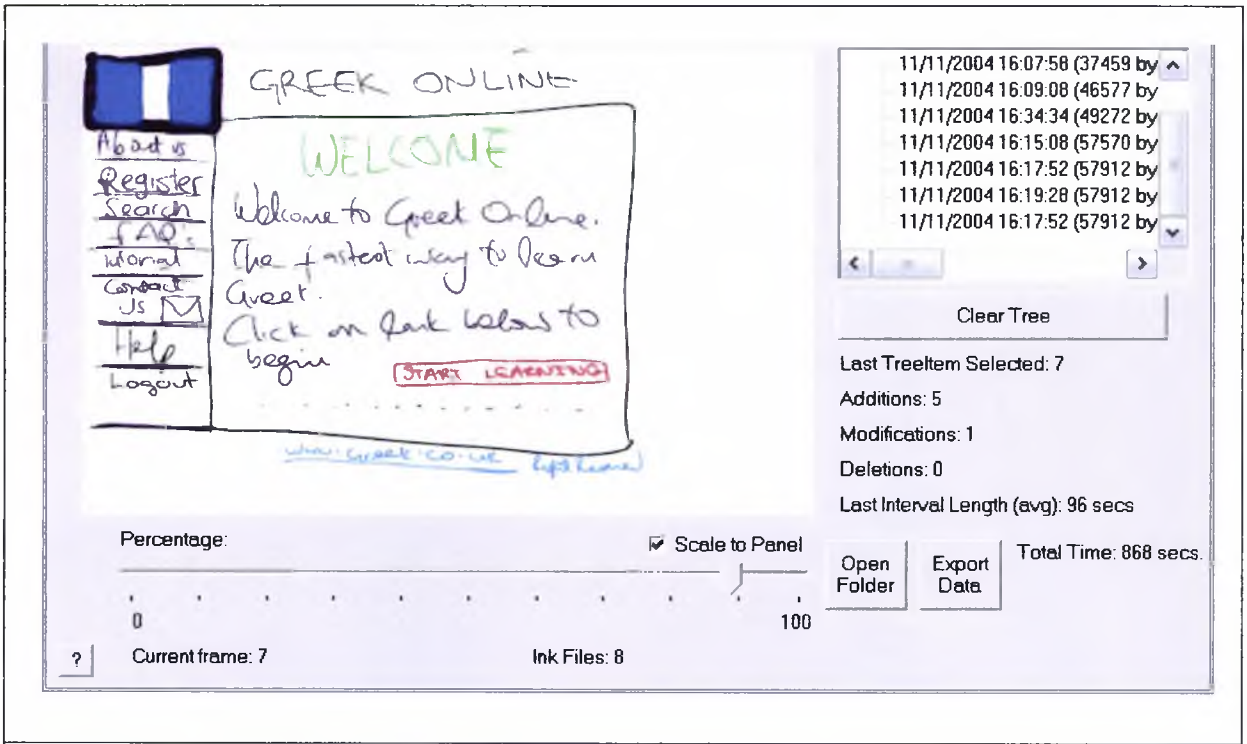
F.2 Data collection for Chapter 8 Case Study B

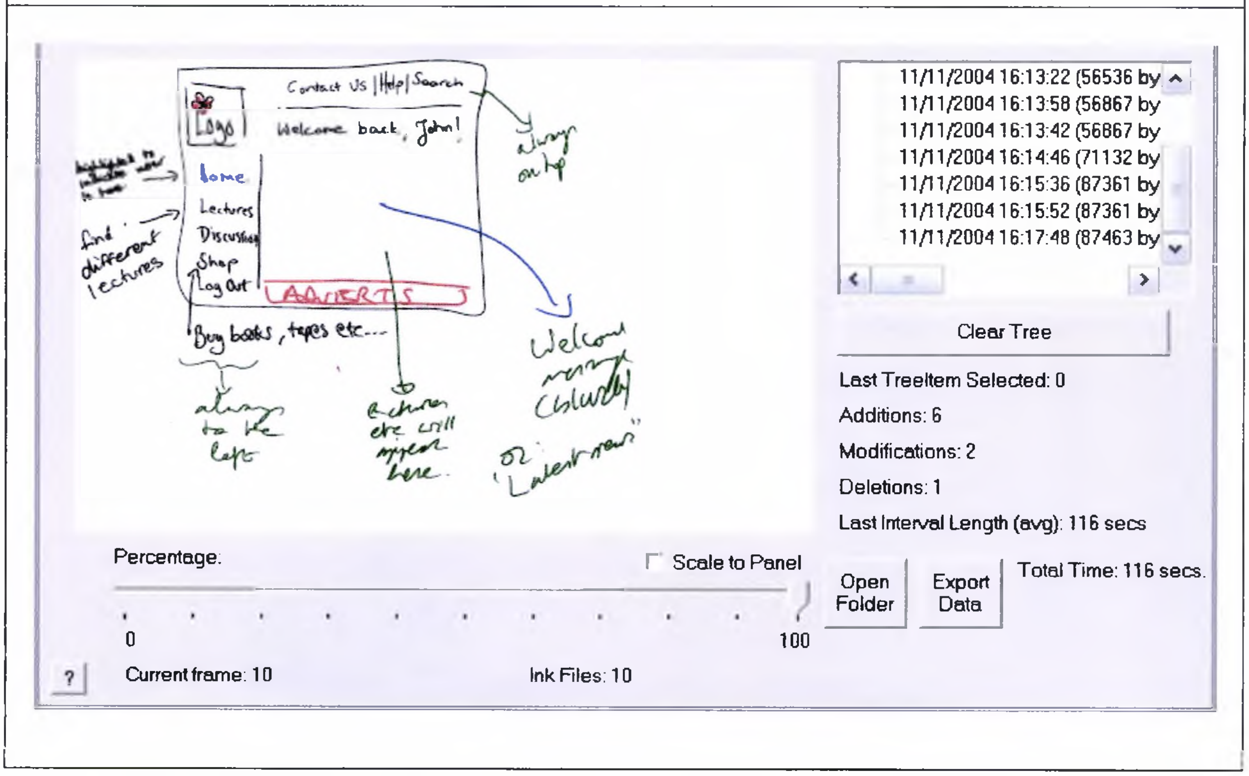
F.2.1 Paper Prototype Paper-based Examples

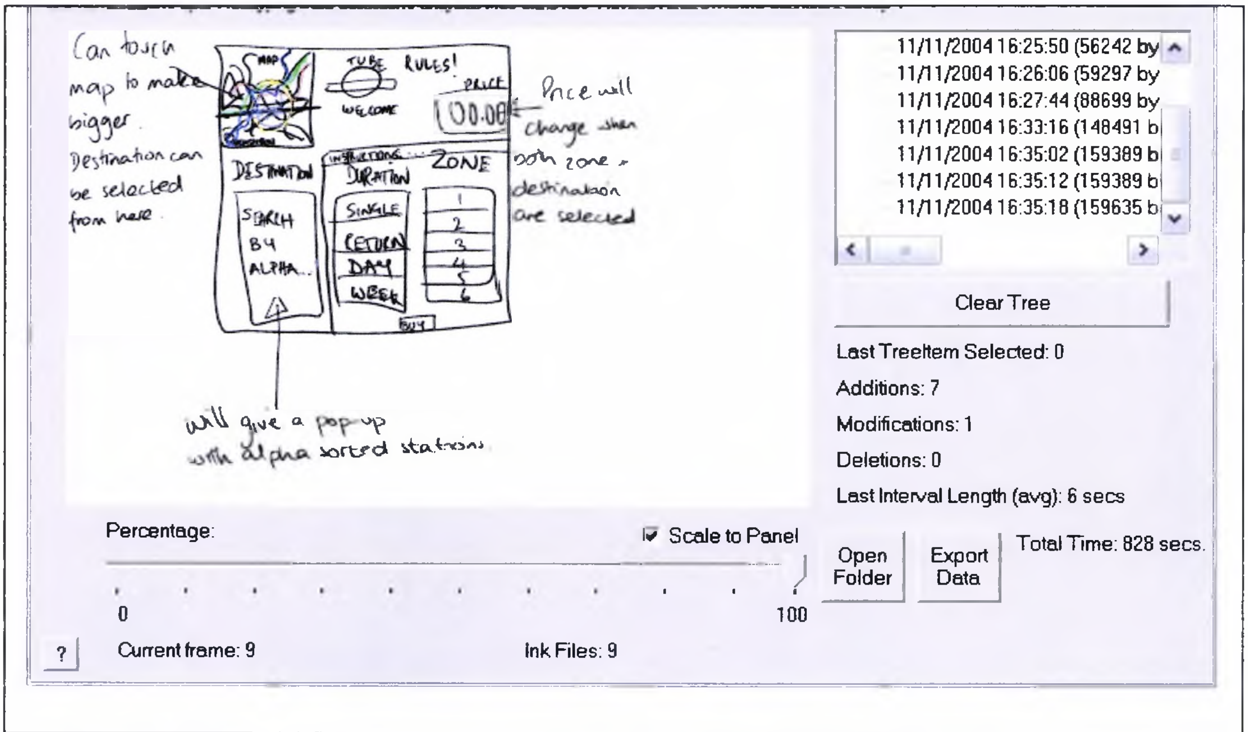


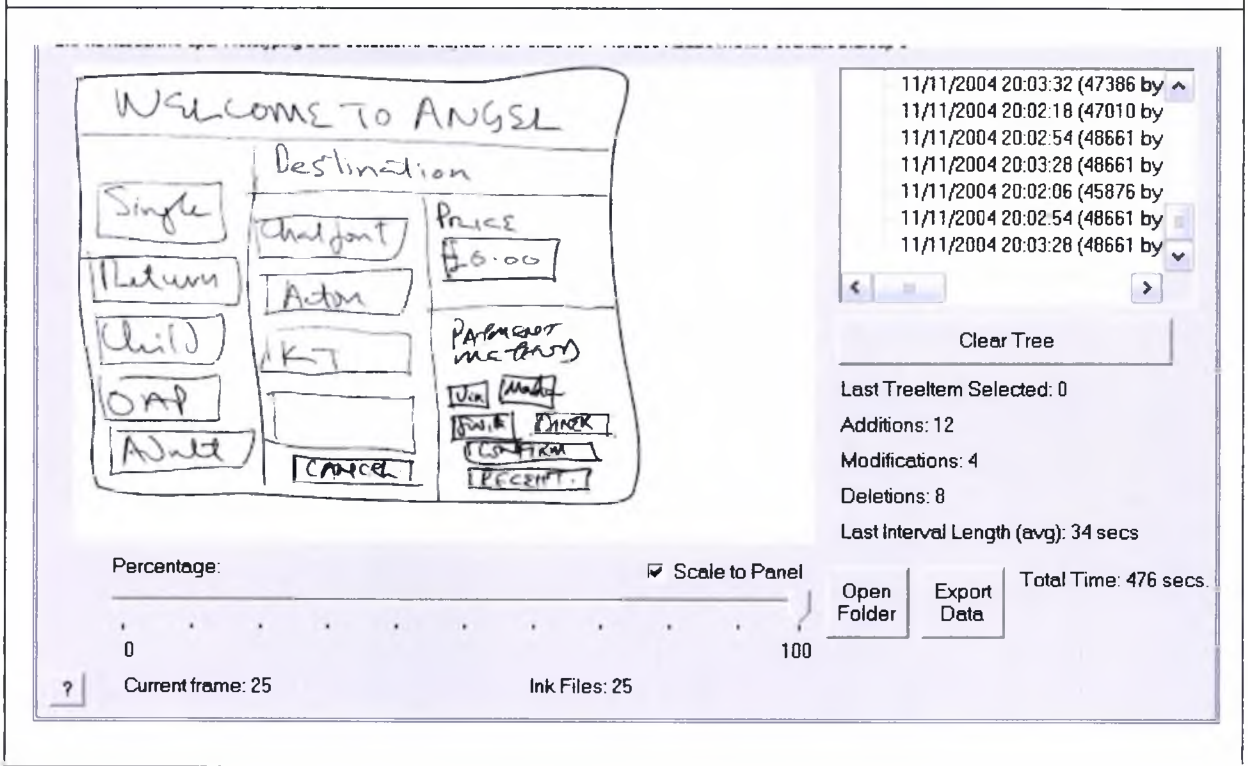


F.2.2 Proteus EVALUATOR sample screenshots






Can touch map to make bigger
Destination can be selected from here
TUBE RULES!
PRICE
WELCOME
Price will change when both zone + destination are selected
DESTINATION
ZONE
DURATION
SINGLE
RETURN
DAY
WEEK
SEARCH BY ALPHA...
BUY
will give a pop-up with alpha sorted stations
11/11/2004 16:25:50 (56242 by
11/11/2004 16:26:06 (59297 by
11/11/2004 16:27:44 (88699 by
11/11/2004 16:33:16 (148491 b
11/11/2004 16:35:02 (159389 b
11/11/2004 16:35:12 (159389 b
11/11/2004 16:35:18 (159635 b
Clear Tree
Last TreeItem Selected: 0
Additions: 7
Modifications: 1
Deletions: 0
Last Interval Length (avg): 6 secs
Percentage:
Scale to Panel
Open Folder
Export Data
Total Time: 828 secs.
0
100
?
Current frame: 9
Ink Files: 9


WELCOME TO ANGEL
Destination
Single
Return
Child
OAP
Adult
Chalfont
Acton
KT
CANCEL
PRICE
£6.00
PAYMENT METHOD
11/11/2004 20:03:32 (47386 by
11/11/2004 20:02:18 (47010 by
11/11/2004 20:02:54 (48661 by
11/11/2004 20:03:28 (48661 by
11/11/2004 20:02:06 (45876 by
11/11/2004 20:02:54 (48661 by
11/11/2004 20:03:28 (48661 by
Clear Tree
Last TreeItem Selected: 0
Additions: 12
Modifications: 4
Deletions: 8
Last Interval Length (avg): 34 secs
Percentage:
Scale to Panel
Open Folder
Export Data
Total Time: 476 secs.
0
100
?
Current frame: 25
Ink Files: 25

F.3 Dynamic Constructionism Output via PROTEUS Evaluator

F.3.1 Example output of constructs identified within a PROTEUS sketch experiment in CSV format for import into Excel (Scenario 1, Team 5)

```
Additions,Modifications,Deletions,Interval,AddDiff,ModDiff,DelDiff

1,0,0,36,1,0,0

1,1,0,18,0,1,0

2,1,0,54,1,0,0

3,1,0,270,1,0,0

4,1,0,146,1,0,0

5,1,0,64,1,0,0

6,1,0,174,1,0,0

6,2,0,0,0,1,0

6,3,0,2,0,1,0

6,4,0,30,0,1,0

6,5,0,30,0,1,0

764 secs Total Time
```

F.4 User Evaluation Methods for Chapter 8 Case Study B

(in addition to E.4.2 QUIS Template Survey, this easy of prototyping survey was created before CSUQ was known)

F4.1 Post Questionnaire: Ease of prototyping (paper and software participants)

Please circle:

1. Were you happier to be designing with:

(a) paper method (b) software method (c) both

2. The software allowed you to reuse your designs as templates that you saved. Did you use this feature at all?

yes no can't remember

3. The software allowed you to zoom into and out of your designs to enable you to add fine details. Did you use this feature at all?

yes no can't remember

4. The software enabled you to alter the properties within your designs as well as draw them, e.g. scaling, move ink around, change colours and change line widths. How did you find this?

(a) Useful (b) not useful (c) did not explore these features

5. List the most **negative** aspect (s) of the paper based method:

4.
5.
6.

List the most **positive** aspect(s) of the paper based method:

4.
5.
6.

6. What features of prototyping would you have liked to be able to use in ink software?

Appendix G

G.1 Publications Listing

Zaphiris, P., Dellaporta, A. & Mohamedally, D. (2006d) User needs analysis and evalution of portals. In Cox, A. (ed.) Portals: people, processes and technology, Facet Publishing, London UK.

Mohamedally, D., & Zaphiris, P (2006c) Constructionist Assessment with Mobile Software-based Paper Prototyping. ACM Intl. Journal for Human Computer Studies. Elsevier B.V. (submitted)

Mohamedally, D., & Zaphiris, P (2006b) Artefact Driven Constructionism in HCI Knowledge Elicitation Methods. Interacting with Computers. ACM Press. (submitted)

Mohamedally, D., Edlich, S., Klaus, E., & Zaphiris, P. (2006a). "MIKE's PET – A Participant-based Experiment Tracking Tool for HCI Practitioners using Mobile Devices" , In Proceedings of SPIE's 18th Annual Symposium for Electronic Imaging 2006, San Jose, California, USA.

Mohamedally, D., Zaphiris, P., & Petrie, H. (2005d). "PROTEUS: Artefact-Driven Constructionist Assessment within TabletPC-Based Low-Fidelity Prototyping". In Proceedings of HCI 2005 Edinburgh Volume 1, British HCI Group, British Computing Society, UK.

Mohamedally, D., Zaphiris, P., & Petrie, H (2005c). "Incorporating Digital Inking Methods in HCI Knowledge Elicitation". Presented at a BCS British HCI Workshop entitled "Improving and Assessing Pen based Input Techniques"; In Proceedings of HCI 2005 Edinburgh, British HCI Group, British Computing Society, UK

Mohamedally, D., Zaphiris, P., & Petrie, H. (2005b). "Mobile Interactive Knowledge Elicitation (MIKE) – Mobile Cyberscience in HCI Methods". In Proceedings of HCI International 2005, Las Vegas, USA.

Mohamedally, D., Edlich, S., Zaphiris, P., & Petrie, H. (2005a). "MIKE's CONKER - A COllaborative Non-linear Knowledge Elicitation Repository for Mobile HCI Practitioners", In Proceedings of SPIE's 17th Annual Symposium for Electronic Imaging 2005, San Jose, California, USA.

Mohamedally, D., Zaphiris, P., & Petrie, H. (2004d). "The Development of MIKE based tools for Human Computer Interaction", presented at a Mobile Internet Workshop entitled "You have the whole world in your hands - where to now?"; 5th Conference of the Association of Internet Researchers (AOIR v.5), Sussex University, Brighton UK.

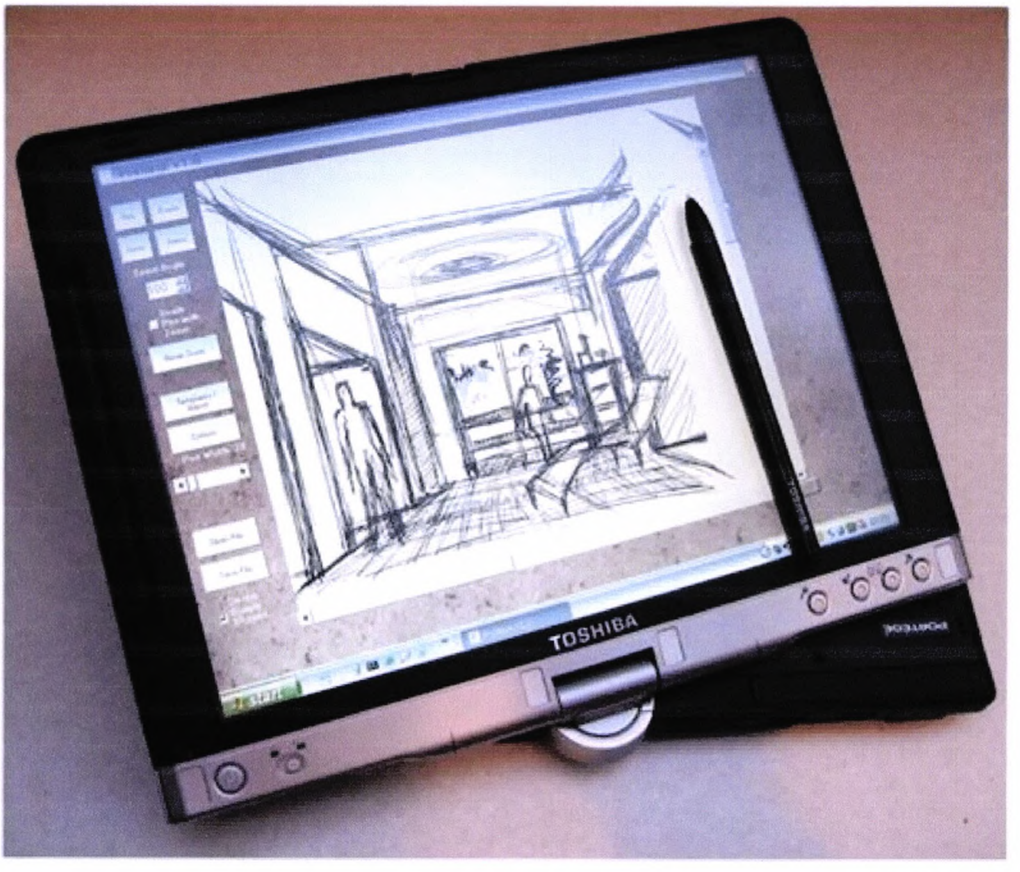
Mohamedally, D., Zaphiris, P., & Petrie, H. (2004c). "User Centred Mobile Computing". Encyclopaedia chapter in Multimedia Technology and Networks. (In Print). Idea Group Inc. IRM Press.

Mohamedally, D., Zaphiris, P., and Petrie, H. (2004b). Asynchronous Knowledge Elicitation Through Software Based Card Sorting in Collaborative and Geographically Dispersed Environments. In Proceedings of IEEE Prep 2004, Hertfordshire, UK.

Mohamedally, D. (2004a). "The Development of MIKE - Mobile Interactive Knowledge Elicitation Tools for Human Computer Interaction". MPhil Transfer Report & Presentation, Centre for HCI Design, City University London, UK.

Mohamedally. D, Zaphiris. P, & Petrie. H. (2003b). "A web based tool for HCI-orientated massively asynchronous linear card sorting", In Proceedings of HCI 2003 Bath, British HCI Group, British Computing Society, UK.

Mohamedally. D, Zaphiris. P, & Petrie. H. (2003a). "Recent research in mobile computing: A review and taxonomy of HCI issues", In Proceedings of HCI International 2003, Crete, Greece.



MOBILITY FOR HCI

City University
London