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USABILITY PERSPECTIVES FOR THE DESIGN OF INTERACTIVE MAPS

by

Annu-Maaria Nivala

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Abstract

Recent changes in information and communication technology have led to new methods for visualising geospatial data and to interactive map applications. Consequently, traditional map design and evaluation methods may no longer be suitable for the new range of users, use situations and devices. The hypothesis of this study was that user-centred design (UCD) has a fundamental role in designing interactive maps, which involve new ways of interacting. The study was initiated to assess the suitability of usability engineering (UE) methods in the development of interactive maps, and to examine the user requirements for interactive maps; both in a static desktop environment and on mobile devices.

The problems involved in bringing UE into map design were approached through five research topics. First, a state-of-the-art study was carried out to investigate how familiar map developers were with UE methods. Second, a usability evaluation was conducted for web mapping sites, in order to find out whether there are usability problems in the current design and, if so, to issue guidelines on how they could be avoided. Thirdly, the user-centred design process and the different UE methods were used in developing a mobile map service, while experiences of using the methods in practice were gathered at the same time. The fourth research goal was to gather information from each individual study included in this thesis and conclude the benefits, disadvantages and challenges of including UE methods in map design. The fifth objective was to gather information from each study to give a general idea on what the characteristics of user-friendly interactive maps are (or what they should be).

The innovative aspects developed in the design process during the study support the suitability of the UCD for map design. New technological possibilities create the potential for new design approaches, and the UCD approach can therefore be used as a method of incorporating material and increasing designers' knowledge of user requirements. By using an iterative UCD approach, while simultaneously taking into account the novelty and diversity of users and their tasks together with the characteristics of maps, application developers would be able to design products that have a higher quality of use. Understanding the context of use becomes especially critical with mobile maps, because they can be used in various situations and for various purposes. Future research topics are identified at the end of the thesis.

Keywords Usability engineering; User-centred design; Usability engineering method; Map; Cartography; Geographical information system; Web mapping site; Mobile map

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Tiivistelmä

Viimeaikaisten laite- ja ohjelmistokehityksien myötä paikkatiedon käyttömahdollisuudet ovat muuttuneet. Paperikarttojen ohella käytetään myös vuorovaikutteisia Internet-karttasovelluksia sekä paikkatieto-ohjelmia käyttäjien mukanaan kantamilla päätelaitteilla. Muutoksen myötä sovelluskehittäjät ovat joutuneet uusien haasteiden eteen, sillä perinteiset kartta-suunnittelu- ja arviointimenetelmät eivät enää välttämättä ole riittäviä uusien käyttäjäryhmien, käyttötilanteiden ja päätelaitteiden huomioonottamisessa. Tämän tutkimuksen hypoteesina oli, että käyttäjäkeskeisellä tuotekehityksellä tulisi olla merkittävä rooli vuorovaikutteisten karttasovellusten suunnittelussa. Työn tavoitteena oli kerätä tietoa karttojen käytettävyystutkimuksesta ja tarkastella käytettävyysmetodien soveltuvuutta karttasovellusten tuotekehitykseen.

Tutkimusongelmaa lähestyttiin selvittämällä käytettävyysmetodien tunnettuutta karttasovelluskehittäjien parissa ja kartoittamalla nykyhetken tilanne käytettävyysmetodien hyödyntämisestä. Tämän jälkeen arvioitiin eri menetelmillä neljän Internet-karttapalvelun käytettävyyttä. Havaintojen perusteella annettiin suosituksia tuotekehittäjille käytettävyys-ongelmien välttämiseksi karttasovellusten suunnittelussa. Kolmannessa tutkimuksessa kerättiin käytännön kokemuksia iteratiivisen käyttäjäkeskeisen tuotekehityksen ja käytettävyysmetodien soveltuvuudesta mobiilin karttasovelluksen tuotekehitykseen. Neljäs ja viides tutkimusnäkökulma kokosivat tietoa tämän työn yksittäisistä tutkimuksista. Aluksi tunnistettiin käytettävyysnäkökulmien hyötyjä ja haasteita karttasovellusten tuotekehityksessä, ja tämän jälkeen identifioitiin alustavia näkemyksiä siitä, mitä käytettävyys tarkoittaa kahden eri laiteympäristön karttasovellusten kohdalla: Internet-karttasovelluksilla joita käytetään PC:n ruudulla, sekä käyttäjän mobiilin päätelaitteen näytöllä esitettävillä karttapalveluilla.

Tutkimuksessa todettiin, että tuotekehityksen innovatiivisuuteen saatiin tukea käyttäjäkeskeisen tuotekehityksen kautta. Realistisia ja käyttäjiä miellyttäviä karttasovelluksia voidaan suunnitella vain selvittämällä todelliset käyttäjävaatimukset. Käytettävyysmetodien tarpeellisuus korostui erityisesti eri käyttäjäryhmien ominaisuuksien ja tarpeiden selvittämisessä, erilaisten käyttäjätehtävien analysoimisessa, sekä mobiilin käyttöympäristön asettamien vaatimusten tutkimisessa. Työn lopussa identifioidaan tulevaisuuden tutkimusaiheita karttasovellusten käytettävyyden tutkimukseen.

Asiasanat Käyttäjäkeskeinen tuotekehitys; Käytettävyysmenetelmä; Karttasovellus; Kartografia; Paikkatietojärjestelmä; Internet-karttapalvelu; Mobiili karttasovellus

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PREFACE

‘ “Brains first and then hard work. Look at it! That’s the way to build a house,” said Eyore proudly’.

That is exactly the way it went. First you do the research and then you have to sum it all up. It is hard work but it is now finished. However, I would not have been here to complete this thesis without the help of a large number of people.

First of all, special thanks are reserved for my thesis instructor and co-author Tiina Sarjakoski, Doc., D.Sc. (Tech.). She is inspiring, supportive, but also critical, and therefore a great person to work with. Her support and belief in my research were the most important reasons for the existence of this thesis today. I would also like to thank the other co-author of my work, Prof. Tapani Sarjakoski, for his support and valuable comments during my research.

‘Pooh said good-bye affectionately to his fourteen pots of honey, and hoped they were fifteen’.

I kept thinking that there is still another study that I would like to carry out and another paper I would like to publish before my thesis is ready. I was lucky to have a thesis instructor, who knows when a Ph.D candidate is ready to go on to the next stage. I would like to express my gratitude to Prof. Marko Nieminen from the Helsinki University of Technology, Software Engineering and Business Laboratory. His encouragement for this multidisciplinary work and his innovative and very useful comments on my thesis have helped me throughout the process.

‘Piglet told himself that never in all his life, and he was goodness knows how old – three, was it, or four? – never had he seen so much rain’.

I know a place like that, too. I spent one exchange year in Scotland, Glasgow – a city which a friend of mine calls “the factory of clouds”. Nevertheless, I had a really good time during that year, which is largely due to Prof. Stephen Brewster, my other co-author, who included me in his Multimodal Interaction research group, like I was one of his postgraduate students. We had countless discussions about my experiments, and through these discussions he gave me valuable guidance on HCI research. My other Glaswegian colleagues (Andy, David, Chris, Saheer, Brad, Jose, Lorna, Steve, Johan and Eve), were also a great help during my exchange year in Scotland, both during work and leisure. I am looking forward to continuing co-research activities with all of you.

‘As soon as he saw the Big Boots, Pooh knew that an Adventure was going to happen’.

A big part of this research was carried out as the R&D project, Geospatial Info-mobility Service by Real-time Data-integration and Generalisation (GiMoDig). The Finnish Geodetic Institute coordinated the project. The other participants were the University of Hannover, the Federal Agency for Cartography and Geodesy (Germany), the National Survey and Cadastre (Denmark), the National Land Survey of Sweden and the National Land Survey of Finland. I am grateful for the funding I received and appreciate the opportunity of being able to work together with these highly professional researchers. I would like to thank all the people involved in the project for their fruitful co-operation and also for the adventures and the good times we shared at different meetings around Europe.

Furthermore, I would like to thank my other co-authors, Eija Kaasinen, D.Sc. (Tech.), Antti Jakobsson, D.Sc. (Tech.) for their productive collaboration. I also warmly appreciate all the help that Ari Ahonen, M.Sc. (Tech), M. Psych. and Rolf Södergård, MA. gave me by participating in designing

and carrying out the first field trial in the GiMoDig project, and in analysing the results. Dr. Tumasch Reichenbacher made a valuable contribution during the final evaluation phase in GiMoDig, which is gratefully acknowledged. I kindly thank my other colleague, Dr. Mark Hampe, D.Sc. for the encouraging and enjoyable scientific discussions during the whole process (you made it first!).

‘ “What’s twice eleven?” I said to Pooh: “I think it ought to be twenty-two.”
“Just what I think myself, “ said Pooh’.

Being a young scientist is tough sometimes. There is no limit to your self-criticism. It is good to have people to guide you, if you feel unsure. I would like to express my gratitude to the pre-examiners of this thesis, Dr. Corne van Elzakker, and Timo Jokela, Ph.D. Their very useful and critical comments enabled me to improve this thesis quite a bit, I think. There is another person I would like to thank here, Paula Ahonen-Rainio, D.Sc. (Tech.), who gave me a valuable insight into the world of maps.

‘ “I wasn’t afraid,” said Pooh, said he. “I’m never afraid with you.” ’

During the entire process I was given a lot of support from my colleagues at the Finnish Geodetic Institute and I would like to thank everyone for the good atmosphere that we have. I am especially grateful for the insightful conversations with my colleagues, some of whom I consider as friends. I am especially grateful to my colleagues, who work, or have worked, in the past with me at the Department of Geoinformatics and Cartography: Juha Oksanen, Ulla Pyysalo, Jaakko Kähkönen, Lassi Lehto, Petteri Torvinen, Pyry Kettunen, Mari Laakso, Tapani Rousi, Tomas Ukkola, Tommi Koivula, Mikko Hämäläinen and Kirsti Filen.

‘Pooh was walking round and round in a circle. Thinking of something else.
And when piglet called to him, he just went on walking’.

During this research I became an absent-minded, slightly crazy scientist, who sometimes got lost in my own thoughts, but my family and my friends were there all the time. My sincerest thanks go to my family, especially to Äitee, Ellu, Irma and my ‘little sisters’. I would also like to thank my friends (especially Anne, Riikka, Aki, Tanja, Matti and Tomi) for all their love and support during my studies. There are also a number of other family members and friends who I am not able to list here due to the lack of space, but you all know who you are. Thank you all. Let’s meet up for a coffee soon!

‘Pooh and Piglet walked home thoughtfully together in the golden evening,
and for a long time they were silent’.

Finally, I would like to thank my ‘wee family’; Janne-Joonas and Mörkö – I am so happy to have you both in my life. You are my home and my future.

‘I have just remembered something that I forgot to do yesterday and
shan’t be able to do tomorrow (Pooh)’.

What happens now? I think it is time for me to read an entertaining detective story. My own ‘stories’ have been told for a while. But not forever, I can tell you that already now…

Annu-Maaria Nivala
Masala, 25th October, 2007

Quotations from A.A. Milne, 1928: The House at Pooh Corner

LIST OF PUBLICATIONS

The thesis is based on the following scientific papers, referred to in the text by their Roman numerals:

I NIVALA, A.-M., SARJAKOSKI, L.T. and T. SARJAKOSKI, 2007. Usability Methods' Familiarity among Map Application Developers. *International Journal of Human-Computer Studies*, 65 (9): 784-795, Elsevier.

II NIVALA, A.-M., BREWSTER, S. and L.T. SARJAKOSKI (submitted). Usability Evaluation of Web Mapping Sites. Special Issue of *the Cartographic Journal* on Use and User Issues.

(Shorter version of the paper already published in: NIVALA, A.-M., BREWSTER, S.A. and L.T. SARJAKOSKI, 2007. Usability Problems of Web Map Sites. *Proc. of XXIII International Cartographic Conference*, Cartography for everyone and for you, Moscow, Russia, August 4-10, 2007, Theme 12, CD-ROM.)

III NIVALA, A.-M., SARJAKOSKI, L.T., JAKOBSSON, A. and E. KAASINEN, 2003. Usability Evaluation of Topographic Maps in Mobile Devices. *Proc. of the 21st International Cartographic Conference*, August 10-16, 2003, Durban, South Africa, pp. 1903-1913, CD-ROM.

IV SARJAKOSKI, L.T. and A.-M. NIVALA, 2005. Adaptation to Context - A Way to Improve the Usability of Mobile Maps. A book chapter in Meng, L., Zipf, A. and T. Reichenbacher, (eds.), *Map-based Mobile Services, Theories, Methods and Implementations*, Springer, NY, pp. 107-123.

V NIVALA, A.-M. and L.T. SARJAKOSKI , 2007. User Aspects of Adaptive Visualisation for Mobile Maps. *Cartography and Geographic Information Science*, Towards Ubiquitous Cartography, 34 (4): 275-284.

VI NIVALA, A.-M., SARJAKOSKI, L.T. and T. SARJAKOSKI, 2005. User-Centred Design and Development of a Mobile Map Service. In Hauska, H. and H. Tveite (eds.), ScanGIS'2005 – *Proc. of the 10th Scandinavian Research Conference on Geographical Information Science*s, June 13-15, 2005, Stockholm, Sweden, pp. 109-123.

AUTHOR’S CONTRIBUTION

This thesis consists of an introductory part and six scientific publications. The introductory part introduces the research problem and goals, gives an overview of related research, describes the research methods, summarises the results and provides a discussion and conclusions of the findings from each of the publication. The publications themselves provide fuller details and can be divided into three parts:

The first part (**Paper I**) examines how familiar map application developers are with usability methods. The study was designed, conducted and analysed by the present author. The co-authors supervised the design of the tests, analysis of the results and preparation of the paper.

The second part (**Paper II**) presents a usability evaluation study of different web mapping sites. The present author conducted the studies and analysed the results. The co-authors advised in the design of the test, analysis of the results and preparation of the paper.

The third part of the work (**Papers III-VI**) was carried out in collaboration with the members of an EU-funded research and development project (GiMoDig), in which a prototype of a mobile map service was developed following user-centred design approaches.

Paper III describes the arrangements and results of field tests for evaluating the usability of topographic maps in mobile devices with the aim of identifying preliminary user requirements and design principles for maps on small displays. The present author performed the tests, analysed the results and prepared the paper with the co-authors.

Paper IV is a further analysis of the user requirements of mobile map users. A new categorisation for mobile contexts in map services is proposed and discussed. The present author conducted the studies, analysed the results, developed the context categorisation, and prepared the paper equally with the co-author.

Paper V introduces a design implementation method for delivering maps for different types of mobile users with symbols adapted for user-specific needs. This was collaborative study with a number of GiMoDig project members. The present author conducted the usability evaluations, analysed the results and prepared the paper with the advice of the co-author.

In **Paper VI**, examines the practical aspects of including an iterative user-centred design (UCD) model for the development of a mobile map service. The need to integrate usability issues into map applications is also discussed. The present author conducted the studies, analysed the results and prepared the paper in consultation with the co-authors.

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CHAPTER 1

INTRODUCTION

Software development businesses have been increasingly focussing on usability issues, which has led to a growing number of these organisations to integrate usability practices into their software engineering processes. The ISO 13407 standard (Human-centred design processes for interactive systems) gives instructions on how to meet user needs by utilising a user-centred design (UCD) approach throughout the entire life cycle of a system (ISO, 1999).

Usability engineering (UE) is a term used to describe methods for analysing and enhancing the usability of software (Nielsen, 1993; Mayhew, 1999). The purpose of UE methods is to collect information in order to gain greater understanding of the users, their tasks and environments and to apply this to the product design. Wider discussion of the benefits of UE and UCD was prompted by the publication of a book by Bias and Mayhew (1994), in which several researchers discuss the cost-benefits of usability aspects in product design. Rajanen (2003) reviews the different approaches to usability cost-benefit analysis and concludes that the usability cost-benefit models can be categorised into four groups according to the nature of the benefits related to: 1) product development (fewer resources needed, prioritisation of product features, less need for future redesign), 2) marketing and sales (gaining competitive edge, increased customer satisfaction), 3) customer support (reduced cost of product support, less need for end-user training), and 4) customer and end-user (increased productivity, less need for support).

Improved ways of identifying user requirements as well as understanding what usability means in new technological, multimodal, mobile, ubiquitous and distributed computing settings, may provide essential knowledge for designers. However, it is not always straightforward to apply methods originating from one application area to another. This type of interdisciplinary task, in which usability evaluation methods adopted from software engineering are used for the development of applications in other research fields is challenging, because the required knowledge for integrating UE into specific product development may not exist. Several researchers have observed that there is a gap between usability and software engineering practice. Accordingly, there is a need to offer software developers a way to integrate usability activities and techniques into their existing software development process (e.g. Mayhew, 1999; Ferre et al., 2005; Seffah et al., 2005; Nebe et al., 2006).

Furthermore, it has been observed that the host of techniques offered by human-computer interaction (HCI) make it difficult to select the most appropriate ones for a given project and organisation (Juristo and Ferre, 2006). Ferre (2003) noted that because HCI is founded in psychology, sociology, industrial design and graphic design, this very multidisciplinary characteristic is the main obstacle to integrating HCI with software engineering.

At the same time map design processes are going through immense changes. Cartwright et al. (2001) stated that technological changes involving both cartography and computer graphics have led to changes in modern cartographic representation: a wider range of maps can now be produced faster and less expensively, and real-time interaction with visual displays is almost a reality. Recent technological developments have also provided a vast number of tools and techniques of interest to map design, especially for interface and interaction design, such as 3D approaches and animation. Furthermore, research has emerged within the field of cartographic visualisation relating to augmented reality (AR), virtual reality (VR) and ubiquitous computing (e.g. Darken and Cevik, 1999; Bitters, 2007; Gartner, 2007). Along with mobile computing came location-based services (LBSs), from which map data can be delivered to a user's mobile device according to either the location of the user or a user-specified location. This development shifts the emphasis from static to dynamic map use and to new requirements for the design of interfaces for dynamic representations.

As changes in information and communication technology have led to new methods for visualising geospatial data, the traditional design of maps and conventional evaluation methods may no longer always be valid. Koua and Kraak (2004) crystallised the main problem by stating that map use studies which have long been carried out in the field of cartography are not fully compatible with new interactive visualisations, which can have new representational spaces and user interfaces. So how can it be guaranteed that today's maps using different (new) technologies will fulfil user requirements? How can we ensure that maps produced with these interactive technologies are easy to use, gain user acceptance and attract investment interest? One approach is that the user-centred design could play a fundamental role in the design of future maps – to ensure maps continue to be useful.

Like graphical user interfaces (GUIs) in software engineering, digital maps can also be regarded as user interfaces (UIs); for example, Peterson (1995) suggested that the word interface can be related to maps in two ways: maps are, firstly, interfaces with the real world and, secondly, composed of UI elements. The layout of the map, its legend, colours, tools and symbols, are all aspects of the map's UI, and there is an interaction between the map and the user when the map is used. Kraak and Ormeling (1996) described maps as interfaces with geographic information systems (GISs). Kraak and Brown (2001) stated that due to the multimedia nature of the Internet, maps can be seen as interfaces to additional information.

If we consider a map on a computer screen as one type of GUI, the design principles for maps should follow the same standard design methods as those used in other GUI design. Accordingly, in recent years a number of researchers have emphasised the need to include UE in map design.

1.1 Background

The literature review in section 2 ('Usability-related research in cartography') shows that cartography has a long history of perceptual-cognitive research into the use of maps, and that several usability evaluations and a considerable amount of user testing have been conducted in cartographic research. Montello (2002) observed that map design research includes much of what has variously been called 'perceptual cartography', 'the human factors of maps', 'evaluation research', 'usability research', 'communication research' and 'experimental cartography'.

However, usability studies only deal with one specific problem at a time (Nivala, 2005). Systematic UE throughout the life cycle of map applications (including user requirements, design and iterative evaluation) is rare. The usability studies carried out appear to have concentrated either on evaluating GUIs (of GISs or mobile guides) or different types of map visualisations. They do not, in general, include joint studies related to both map visualisation and interaction with the GUIs of the maps. This may have to do with the fact that current maps were evaluated by two different groups of researchers: 1) cartographers and GIS specialists, or 2) HCI engineers (especially in the case of mobile maps), and the results have also been reported in different conferences and journals. The overall usability of maps and map applications has therefore not been fully investigated, or at least not reported in academic research papers (Nivala, 2005).

Several other researchers have also observed the lack of thorough usability engineering in map design. MacEachren and Kraak (2001) stated that there is a lack of established paradigms for conducting cognitive or usability stu dies with highly interactive visual environments. Consequently, one of the crosscutting challenges is the need to develop a human-centred approach to cartographic visualisation, i.e. geovisualisation (the word geovisualisation here refers to visualisation with a geographical component). Fairbairn et al. (2001) emphasised the need to advance ways of transforming information about the world into models suited to digital cartographic representation that can lead to effective visualisation. Cognitive issues associated with personalised and flexible map use should be studied with an expanded range of map forms in relation to such models.

Slocum et al. (2001) listed six areas in geovisualisation in which cognitive and usability issues should be considered: 1) geospatial virtual environments, 2) dynamic representations (including animated and interactive maps), 3) metaphors and schemata in UI design, 4) individual and group differences, 5) collaborative geovisualisation, and 6) evaluating the effectiveness of geovisualisation methods. In addition, van Elzakker (2005) listed a usability research agenda for maps under the following main headings: user profiles and requirements, usability testing, UCD and research methods and techniques. Cartwright et al. (2001) emphasised that the main challenges are to identify the ways in which geospatial interfaces should be different from other interfaces, how geovisualisation interfaces should be adapted or created for new and emerging devices, what are the most appropriate interaction methods for different users and applications, and how users with different expertise interact with interface tools.

Slocum et al. (2001) pointed out that the focus of geovisualisation on facilitating work related to ill-structured problems may make it difficult to apply standard usability engineering principles. Fuhrmann et al. (2005) stress that it is sometimes difficult to make out the difference between usable and useful when applying HCI methods, because in geovisualisation the data exploration and knowledge discovery tasks are not straightforward enough to allow the goal to be specified or to monitor progress towards its achievement. They emphasise the need to assess additional, mostly qualitative information, as well as to consider the presentation of geovisualisation theory under more formal guidelines in the design process in order to ensure that geovisualisation is both useful and usable. This theory could be constructed from different disciplines, such as perceptual science, cognitive science or HCI science. The role of geovisualisation researchers would be to extend and refine the theory to make it specific to geovisualisation (Fuhrmann et al., 2005).

1.2 Focus of the study

The aim of this thesis is to suggest more formal guidelines on how to include usability aspects in the map design process. The hypothesis of the study was that UCD should have a fundamental role in designing *interactive maps*.

A map can be considered interactive if it includes a user interface with graphical icons, a pointing device, tools for users to interact with the map and the nearly instantaneous display of maps (Peterson, 1995). The term ‘interactive maps’ is used here to refer to different types of interactive geo-applications in which map displays have a central role.

The focus of this study is on *web mapping sites* and *mobile maps*. Web mapping sites, or simply web maps, are interactive maps that are accessed through web pages (Mitchell, 2005). A special case of web maps are mobile maps, or map-based mobile services (Meng and Reichenbacher, 2005), which are displayed on mobile computing devices, such as mobile phones, smart phones and personal digital assistants (PDAs). Other interactive maps, such as animated web maps, analytic web maps, online atlases and collaborative web maps, were excluded from this study.

The research presented here is multidisciplinary: the research themes include usability engineering, geovisualisation, cartography, geographic information science, cognitive science and computer science. The aim of this thesis is to adapt knowledge from each discipline and contribute to the expanding research field of usability research on interactive maps.

1.3 Research goals

The study was initiated to assess the suitability of UE methods in the development of interactive maps, and to examine the user requirements for interactive maps. The specific research goals of the thesis are as follows:

1) Assessment of the familiarity of map developers with usability methods (Paper I)

The aim was to find out the extent to which usability engineering methods are currently used among map developers.

2) Usability evaluation of web mapping sites (Paper II)

The aim was to identify potential usability problems of web maps in order to provide guidance for the future design of such services. The objective was also to compare the suitability of different evaluation methods for finding out usability problems of web mapping sites.

3) UCD in the development of a mobile map service (Papers III-IV)

The aim was to assess the suitability of UCD and UE methods in a mobile map design process. The study included three sub goals:

a. To observe the use context of mobile maps and to identify usability aspects for the design of topographic maps in mobile devices using UE methods.

b. To study the user requirements for adaptive map visualisation using UE methods.

c. To apply and assess the different UE methods in the development of a mobile map service.

4) Suitability of UE methods in the design of interactive maps (Papers I-IV)

The goal was to gather information from each individual study included in this thesis and to draw conclusions considering the benefits, disadvantages and challenges of including UE methods in map design.

5) Usability characteristics of interactive maps (Papers I-IV)

The objective was to use information from each individual study included in this thesis for the purposes of establishing the actual (or ideal) characteristics of user-friendly interactive maps.

1.4 Contributions

New tools and techniques for interface and interaction design of maps and map services are becoming more familiar to ordinary users as the technology develops. Nowadays, many people use map services for locating places and businesses, and for planning visits to unfamiliar places. Figures gathered from the Internet pages of different web mapping sites give an indication of their popularity; one map service states that it has over 40 million unique visitors each month (MapQuest, 2007). Another one maintains a unique user base of over 10 million, ranking consistently in the top 10 websites by traffic in the UK (Multimap, 2007). Web mapping sites are often freely accessible (at least the basic functions), and provide not only maps but different map tools (e.g. zooming and panning) and map related services (e.g. searching for addresses and routes). Mobile map applications are also becoming more widely available, for example in mobile phones. However, the use of map services is not always straightforward, and the services may not always fulfil user needs.

The ISO 9241 standard (Previously Part 10, now revised to 110, Dialogue principles, ISO 1997) presents a set of usability heuristics that apply to the interaction of people and information systems. The same standard (Part 12) includes recommendations on how to present visual information on screen so that users can easily perform perceptual tasks. These guidelines are a good starting point for designing any type of software. However, the general software engineering guidelines are not able to take into account the specific characteristics of all application areas.

There are a number of map characteristics for which more detailed design guidelines are needed, as well as discussion of the methods to be used. The challenges in designing map applications lay in their functionality and their visual characteristics. Map applications are also often large and complicated systems with a lot of different functions and with access to large databases. They typically have one application inside another, e.g. map application with map-specific tools as part of a larger map service (e.g. a website) used with a specific device (desktop or mobile). The challenge is to consider all the aspects at the design stage: how the map works, how is it visualized, how is it related to the application or map service, how the different devices with varying screen properties affect

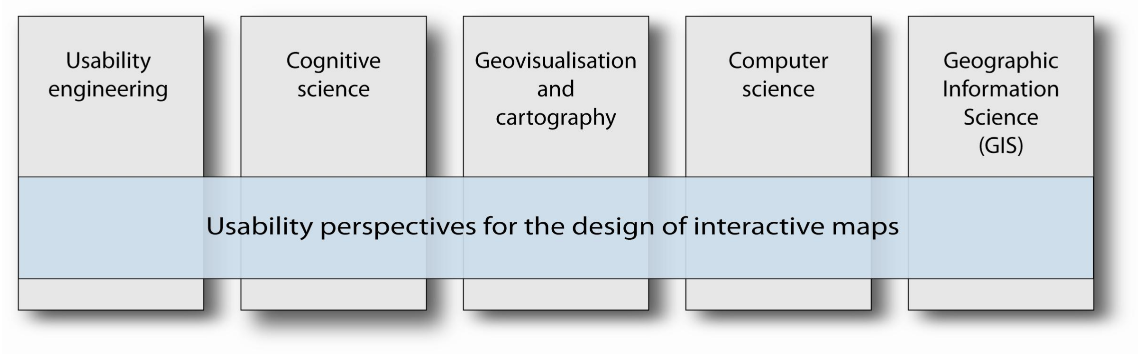

Figure 1. Multidisciplinary nature of this thesis.

the whole application, and so on. The varying use contexts of mobile maps also bring their own design challenges.

Research on interactive maps and usability has developed greatly in recent years. The present author began studying usability and cartography in 2003. A lot of interest in the subject has since arisen within the cartographic research community. Several conferences on cartography now have their own sessions for usability related research. The author has been actively involved in the International Cartographic Association's 'Use and User Issues' working group which was set up in 2005. In recent years the author and her research results have been widely referred to in this research field.

Due to the multidisciplinary nature of this thesis, the contribution of any single related research field cannot be measured specifically. Instead, the scientific validity of this thesis is based on its horizontal nature (Figure 1).

The most important scientific contributions of this thesis and of each paper are as follows:

- § Presentation of the state of the art through compilation of a literature review of usability-related research on cartography. **(Chapter 2)**
- § Examination of the extent to which UE methods are currently used among map developers. **(Paper I)**
- § Listing of design guidelines for usable web mapping sites (i.e. web maps), and an initial discussion of the suitability of different evaluation methods for the usability evaluation of such sites. **(Paper II)**
- § Identification of usability problems of topographic maps on mobile devices, and proposals for the future design of such applications. Experiences of the UE methods used in the evaluation are also discussed. **(Paper III)**
- § Presentation of a theory concerning relevant contexts for mobile map use, based on the identified user requirements. **(Paper IV)**
- § Discussion of a way of providing context awareness on maps to improve the usability of mobile maps. **(Paper V)**
- § Presentation of experience with the user-centred design approach and different UE methods in the development of mobile map services. **(Paper VI)**
- § Identification of the advantages, disadvantages and challenges of incorporating UE methods into map design. **(Papers I-VI)**
- § Identification and discussion of user requirements for different types of interactive maps, and discussion of preliminary ideas on what makes a usable interactive map. **(Papers I-VI)**

CHAPTER 2

USABILITY-RELATED RESEARCH ON CARTOGRAPHY

Due to the multidisciplinary nature of this thesis, valuable connections between *usability engineering* (*UE)* and *cartography* were established in a literature review of both disciplines. Particular emphasis was placed on usability-related research carried out by cartographers.

Usability engineering is a term used to describe methods for analysing and enhancing the usability of software (Nielsen, 1993; Mayhew, 1999). *Usability* is defined in the ISO 9241 standard (Ergonomic requirements for office work with visual display terminals) as "the effectiveness, efficiency, and satisfaction with which specified users achieve specified goals in particular environments" (ISO, 1997). Another definition, outlined in the ISO 9126-1 standard (ISO, 2000), includes the term "quality in use", which means the capability of the software product's ability to enable specified users to achieve specified goals effectively, productively, safely and satisfactorily within specified contexts of use.

User-centred design (UCD) (often referred to as human-centred design, human factors engineering, ergonomics and usability engineering) can be seen as an iterative process (Figure 2), which starts by recognising the potential users, their contexts of use and tasks (Norman and Draper, 1986; ISO, 1999). The design process continues by using this information to set the user requirement specifications and usability goals

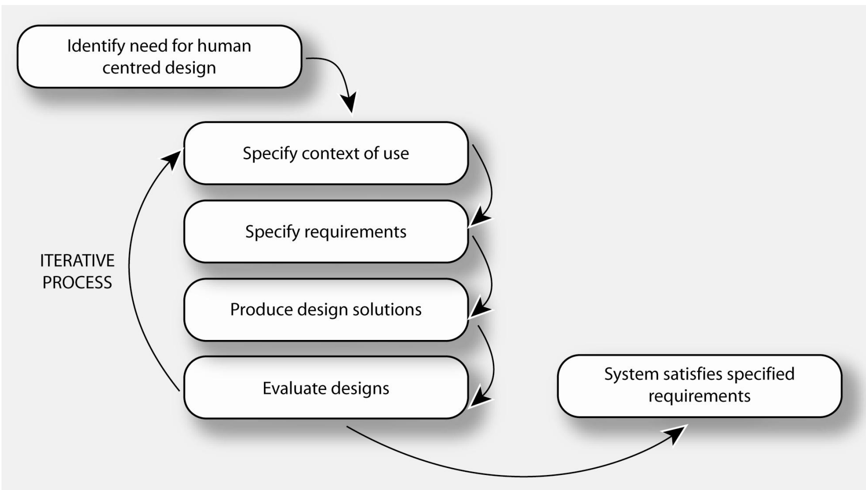

Figure 2. Human-centred design processes for interactive systems (ISO, 1999).

for the product. A *user requirement* here means "any function, constraint, or other property that is required in order to satisfy user needs". (Kujala, 2002, p. 8).

The next step is to illustrate the design to the users and, on the basis of user feedback, to evaluate the design against the goals established earlier. Through this, user requirements may be refined or new requirements identified. The feedback may also lead to changes in implementation. The iterative process continues until the usability goals are achieved. A review of usability engineering methods can be found in the present author's Licentiate thesis (Nivala, 2005), and in short form in **Papers II** and **VI**.

The review of usability research in cartography is divided into five partly overlapping thematic entities. First, the basics of cartographic visualisation and the map reading process are introduced. The second part reviews the studies that have been undertaken in cognitive map design research, and the third part discusses different usability aspects relating to GIS and digital maps. The fourth part discusses usability approaches concerning screen maps. Usability-related research concerning maps on mobile devices is reviewed in the fifth section. Short reviews are also presented in **Papers II** (previous usability evaluations of on-screen maps) and **V** (the map reading process and previous user-centred design with mobile cartography).

2.1 Cartographic visualisation and the map reading process

Due to the multidisciplinary nature of the thesis, a definition of *cartography* is required at the outset: "Cartography is the art, science and technology of making maps together with their study as scientific documents and works of art" (ICA, 1973, p.1). A *map* can be described as "a symbolised image of geographical reality, representing selected features or characteristics, resulting from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance" (ICA, 2007). The term *geovisualisation* is sometimes preferred over the term cartographic visualisation, because it integrates approaches from visualisation in scientific computing, cartography, image analysis, information visualisation, exploratory data analysis and GISs to provide theory, methods and tools for visual exploration, analysis, synthesis and presentation of geospatial data (MacEachren and Kraak, 2001). GIS can be defined as a computer-based system that provides four sets of capabilities for handling georeferenced data: 1) input, 2) data management (data storage and retrieval), 3) manipulation and analysis, and 4) output (Aronoff, 1989).

Objects or phenomena in reality are the visualisation sources of geospatial data. Map design consists of the choices made by the cartographer: the *graphic variables* for symbols (size, value, texture, colour, orientation, and shape) (Bertin, 1983) and the *mapping method* (Kraak and Ormeling, 2003). Colour can also be further divided into hue, value or chroma (saturation). Web maps also employ other means of visualisation, such as blur, focus, transparency, shadows and shading, and multimedia elements (e.g. sound, animations, text and (video) images) (Kraak and Ormeling, 2003).

Understanding the user's map reading process and the underlying principles of graphical communication are critical to the good over-all visual layout of a map. According to the Gestalt psychology approach, when people open their eyes they do not see fractional particles in disorder, but instead, see larger areas with defined shapes and patterns. Central to this is the idea of 'grouping'; how people tend to interpret a visual field or problem in a certain way. The main factors in determining grouping are: proximity, similarity, closure, simplicity, continuity, connectedness, figure-ground, familiarity-experience, good form-shape, and common fate (the rules were originally set by Wertheimer (1923) cited in MacEachren (1995)).

The laws of perception are essentially related to the map reading process, because every map symbol is affected by its location and appearance relative to all the other symbols. Therefore, people viewing maps see the maps structurally; some marks look more important than others, some shapes will 'stand out', some things will appear crowded, some colours will dominate, etc. The visual hierarchy of map symbols is a relevant issue to consider in cartographic design (MacEachren, 1995). Keates (1996) discusses the fundamental processes involved when using a map: detection, discrimination, identification, recognition and interpretation. According to Forgus and Melamed (1976), identification means that users are able to say what a specific symbol is or to name it, whereas recognition means that users are able to say that something looks familiar to them. In addition to these preconditions, interpretation is the stage where the perceived information is further processed by the user to resolve the tasks required of the map.

2.1.1 Communication theory

Shannon and Weaver (1949) first introduced the communication system in the classic Shannon information theory, which has been referred to by many researchers in computer science and also in cartography. In general, the communication theory divides a communication event into five different parts: 1) the source of the message, 2) the sender of the message, 3) the message, 4) the receiver of the message, and 5) the interpretation of the message by the receiver.

This also applies to the map making and reading processes; the source of the message equals the data used for compiling the map, whereas the sender of the message is the cartographer. The message is the map product, and the receivers are the map users and their sensory perception. Robinson (1952) emphasised that the function of maps is to communicate with people, with the message being dependent on the visual appearance of the map, which in turn depends on the design decisions made by the cartographers. In order to understand and improve a map's function, cartographers have to understand the effects of design decisions on the minds of the users, and systematically observe and measure how people study and interpret maps.

The theory of the cartographic communication model was developed in the 1960s, for example, by Kolacny (1969), who argued that map production and use should be understood as a single process of communicating cartographic information (Figure 3), in which the overall reality includes both the reality presented in the map and the reality of the map user. Morrison (1976) elaborated the model and defined the encoding process as the cartographer's cognitive system and the decoding process as the recipient's cognitive system.

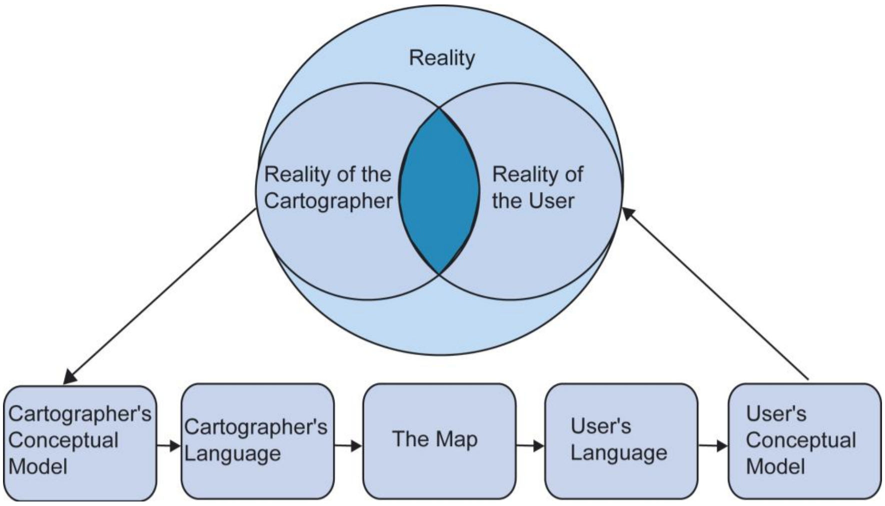

Figure 3. Principles of the map communication model (after Kolacny, 1969).

2.2 Cognitive research on map design and use

Montello (2002, p. 283) asserts that “the recognition that map design is about the design of human cognition might be termed intuitive map psychology”, and continues that in realising this, cartographers of the 20th century began to understand that intuitions about map cognition could be developed more systematically by applying sciences and theories related to psychology.

The influence of cartographic design on map comprehension has also been studied using other individual map symbols (Ekman et al., 1961; Olson, 1975; Brewer et al., 1997). According to Montello (2002), during the late 1970s and 1980s, psychophysical approaches were criticised for focusing too much on low-level map tasks (e.g. for only considering isolated symbols), instead of high-level tasks such as reasoning and inference, which required greater consideration of the symbols’ relation to maps (e.g. Gilmartin, 1981). Petchenik (1983) stressed a need for design-research in which users would be shown real examples of maps under evaluation, rather than maps made for testing purposes, which isolate the variable to be studied.

Since the 1980s, a number of studies have examined the differences in people’s abilities to process spatial information, for example the differences in map-use skills between men and women (e.g. Gilmartin and Patton, 1984; Self et al., 1992; Montello et al., 1999), and individual differences in map reading abilities (Streeter and Vitello, 1986; Mark et al., 1999; Lobben, 2004; Lloyd and Bunch, 2005). Map reading behaviour has also been studied from the perspective of the user’s eye movements (see citations in Steinke, 1987; Brodersen et al., 2002). Recording speech and observing accuracy in searches for particular targets or answering particular questions are also among the methods used in studying map perception. According to Montello (2002), perceptions of a variety of symbol and map designs have also been studied. Cognitive topics recently considered by cartographers have also included the learning processes used for maps and graphics (Lloyd, 1994), use of colours in maps (Brewer et al., 1997), and visual search processes used in map graphics (Lloyd, 1997).

2.3 GIS user interfaces

The previous paragraph referred mainly to research carried out on printed maps. When considering computer-based maps, the usability of GISs is also a relevant issue that needs to be discussed. Research on GIS user interfaces began two decades ago (Gould, 1989; Mark, 1989; Mark and Frank, 1992). At the outset, research concentrated on studying how people perceive space and how GIS users could be modelled. Kuhn and Egenhofer (1991) regarded interaction with geometry-processing systems as communication with geometric models. Lanter and Essinger (1991) studied user-centred GUI designs for GIS and stated that traditional UI designs focused more on how to represent software functionality in the system interface than on how to fulfil user expectations. This often resulted in arbitrary design decisions that made it difficult to use the system.

Traynor and Williams (1995) analysed different design aspects that made GIS difficult for non-GIS specialists to use, and pointed out that navigation through most of the GIS interfaces was difficult for users, because the interfaces were designed to support the system architecture rather than support user tasks. Lanter and Essinger (1991) suggested that making use of graphic and symbolic clues could help make GIS easier to use.

Lindholm and Sarjakoski (1992) stated that because GIS technology is becoming available to an increasing number of non-experts, applications must have a clear and simple UI. They also stressed that the design of UIs for GIS applications lacked a firm theoretical foundation. Consequently, they presented an approach to building such a theory which involved information theory and user modelling.

HCI studies with GIS have been carried out from various perspectives by (e.g. Golledge, 1991; Egenhofer and Richards, 1993; Oviatt, 1996; Olson and Brewer, 1997; and Sharma et al., 1999). Andrienko et al. (2002) assessed the usability of interactive tools in an exploratory analysis of geographically referenced data, from the perspective of tool learnability, memorability and user satisfaction. The methods employed in the study included the use of a profile questionnaire and also involved users performing test tasks and responding to control questions.

In addition to interface functionality, design aesthetics have also been considered in various studies. Richards and Egenhofer (1995) compared two visualisations of a UI based on a map-overlay metaphor for GIS with a cognitive walkthrough method, to examine whether this approach would be useful for non-GIS experts from the perspective of applications ease of use. Davies and Medyckyj-Sott (1994) studied GIS usability from a user perspective using a postal survey. The user responses were measured using the Likert-scale and the authors gave recommendations based on their findings and general UI design principles. Attempts to understand and improve human interaction with GIS was also studied by observing users in their real work context. Davies and Medyckyj-Scott (1996), for example, arranged a workplace observation study, which involved structured interviews, checklists and video recordings of users working with GIS. Elvins and Jain (1998) designed a UI for traditional GIS functions and tested their approach by using heuristics, usability testing and cognitive walkthrough methods.

Bernardo and Hipolito (2000) reported that user complaints and low access numbers motivated them to incorporate a usability approach into the design process. The approach started with focus groups with the aim of finding out the user requirements for the service, and continued with iterative use of usability evaluations together with web design guidelines. Fuhrmann and MacEachren (2001) applied UE methods (focus groups and questionnaires) to designing interfaces that support movement within geovirtual environments (GeoVEs).

Haklay and Topon (2003) called for a UCD approach to public participation GIS (PPGIS) projects in order to guarantee that they are accessible and easy to use. PPGIS focuses on the use of GIS by non-experts and occasional users who usually have a diverse range of computer literacy, worldviews, cultural backgrounds and knowledge. Furthermore, MacEachren et al. (2005) used a human-centred approach in their study of a collaborative geoinformation interface using speech and hand gestures as a natural input. They stated that the development of more natural interfaces for computer systems has been part of HCI research for a while, and that this approach should also be incorporated into GIS applications in order to improve their usability.

2.4 Screen maps

In addition to UIs of GIS applications, studies on the usability of screen maps have been performed. The importance of gaining knowledge of target users and use contexts in map design was emphasised by Sainio (1992). Beverley (1997) studied the benefit of a dynamic display of spatial data reliability from the user's point of view with a test using map data for decision-making (both novices and experts included). Harrower et al. (1997) evaluated the design elements and communication quality of Internet maps for tourism and travel in a user survey with two different user groups: professional geographers and non-geographers. Studies have also been conducted on map animation and interactive tools (e.g. MacEachren et al., 1998), on learnability, memorability and user satisfaction with specific geovisualisation tools (Andrienko et al., 2002), and on the usability of zoomable maps with and without an overview map (Hornbaek et al., 2002).

Arleth (1999) studied the problems of screen map design and listed some of them: the map area was too small and both the legend and instructions too dominating on the screen. According to the study, the design process would be more manageable if it were divided into two phases: 1) the map interior (the map elements, symbolisation, etc.) and 2) the map exterior (the tools and functions for using the map). The study also discussed the different roles that cartographers and programmers have in the design process, and emphasised that cartographers should improve their knowledge of UE.

Leitner and Buttenfield (2000) investigated the effect of embedding attribute certainty information in map displays for spatial decision support systems by having test users perform specific tasks with test maps. Harrower et al. (2000) used a focus group method and structured user testing to find out how novice users understood and used a geovisualisation tool designed to support learning about global weather. Ahonen-Rainio and Kraak (2005) described a study that included iterative design with improved map prototypes and testing. The maps in the study were used to visualise geospatial metadata, which users analysed in terms of suitability for achieving the required objectives. It was emphasised that differences between user strategies for different representations could be investigated further.

Agrawala and Stolte (2001) studied how route maps are used by analysing the generalisations commonly found in hand-drawn route maps, in order to improve their usability. Ishikawa et al. (2005) evaluated climate forecast maps using an empirical study with test users. The results showed that in many cases qualified and motivated test users failed to interpret the maps in the way that the map designer had intended. Richmond and Keller (2003) carried out an online user survey to asses if the maps on tourism websites met the expectations of users. Jahn and Frank (2004) proposed an additional aspect for usability attributes: information quality (IQ), which aims to describe the importance of the data needed by the user and enables data quality to be adapted in an optimal way to meet user needs. The authors state that the critical aspect is to gather information about users and to group the information in a meaningful way.

Van Elzakker (2004) carried out user tests, including a think aloud method and a questionnaire, in order to investigate how maps were selected and used by users exploring geographic data. Koua et al. (2006) studied test subjects' ability to perform visual tasks in the data-exploration domain, and emphasised that the use and usability assessment of methods and tools is an important part of understanding the visual tools used for data exploration and knowledge construction. The UCD approach also played a central role in the development of the Atlas of Canada website, and Kramers (2007) observed that this was the factor responsible for increased user satisfaction and growth in overall use.

2.5 Maps on mobile devices

The convergence of mobile devices, network computing and wireless telecommunications with spatial technologies enables a new form of mobile map application. Most of the research has been carried out on different navigation systems that provide the user with route information (Marcus, 2000; Kray et al., 2003; citations in Burnett, 2000).

Many researchers have also compared 2D maps (either printed maps or on a mobile device) with more advanced visualisation techniques (mainly 3D visualisation). Rakkolainen and Vainio (2001) studied the usability of a 3D city model for a PDA using two methods: a laboratory test with a PC and a field test in a city using a prototype version. Laakso (2002) described the usability evaluation process of a 3D map prototype in a mobile device. According to the results, the 2D printed maps were faster to use in orientation and navigation, but 3D maps were more fun to use. People were also able to recognise real life objects from the 3D map without any additional help, which was seen as an advantage compared with the 2D printed maps.

The relevance of landmarks has been studied by several researchers, mainly due to the fact that current positioning methods are inadequate for narrow urban streets where people need accurate information on their location (e.g. Denis et al., 1999; Goodman et al., 2004; Hampe and Elias, 2004; Weissensteiner and Winter, 2004; Paay and Kjeldskov, 2005). May et al. (2003) studied information requirements for pedestrian navigation aids by asking users to give navigation instructions for a specific route either based on their own memory or during a walkthrough of the route. Chincholle et al. (2002) evaluated the usability of a mobile navigation system and LBS, and stated that downloading traditional miniaturised maps did not contribute much to meeting the needs of mobile users, whereas route directions were thought to be more valuable.

Kjeldskov et al. (2005) studied the suitability of different methods for evaluating mobile guides. They evaluated the usability of a mobile guide using field-evaluation, laboratory evaluation, heuristic walkthrough and rapid reflection (an applied ethnography method). However, the usability of the maps in mobile guides and the user interaction with the map were not studied or discussed. The existing studies mainly focus on tourist and route maps, and to date only a few studies have been published on usability evaluations of topographic maps on mobile devices (e.g. Edwardes et al. 2003; Pospischil et al. 2002).

Heidmann et al. (2003) studied design principles concerning the interaction of users with map visualisations on small screens in their location-aware guide project. They applied a UCD approach to validate the design principles. User requirements were established through a focus group method, on the basis of which two usage scenarios were devised. Two iterative rounds of design and laboratory testing with users were conducted, which produced a set of map design guidelines for mobile systems.

2.6 Further observations

Although it appears that cartography has a long history of research on the use of maps, the usability studies conducted seem often only to deal with one specific problem under investigation. Systematic UE throughout the life cycle of map applications (including user requirements, design and iterative evaluation) seems to be rare. This is perhaps due to the multi-disciplinary nature of map applications. On the one hand, cartographers are needed for map design, but at the same time they may not always possess the necessary information about other web design aspects. This works the other way, too: there are application developers who have the necessary knowledge of software design etc., but who also design map applications despite lacking knowledge of cartographic design aspects.

Van Elzakker and Wealands (2007) observed that user research is slowly being transformed from testing the effectiveness of existing map displays to covering all stages of the UCD process and dealing with the usability of the whole information system – rather than the map display alone. Although it might appear that an increasing number of usability evaluation methods are being used, Fuhrmann et al. (2005), for instance, stated that usability inspection methods are not widely used for geovisualisation at present. Meng (2004) observed that map usability tests have so far only focused on testing the effectiveness and efficiency of a map’s use, despite the map not fulfilling the requirements of the user (because these may simply not have been considered).

Slocum et al. (2001) emphasised that due to the novelty of geovisualisation and the difficulty of defining the nature of users and their tasks, applying UE might be problematic. They pointed out that novel geovisualisation methods will be of little use if they are not developed within a theoretical cognitive framework and iteratively tested using UE principles. They also argued that traditional cognitive theory for static 2D maps may not be applicable to interactive 3D and other dynamic representations. The insufficient number of usability attributes in research is becoming especially critical now when new technical environments, such as multimodal, mobile, ubiquitous and distributed computing settings, are available for geovisualisation applications.

CHAPTER 3

RESEARCH METHODS

The problem of bringing UE into interactive map design was approached through five research topics: 1) the familiarity of map application developers with UE methods, 2) usability evaluation of web mapping sites, 3) UCD in the development of a mobile map service, 4) the suitability of UE methods for the design of interactive maps, and 5) usability characteristics of interactive maps (Table 1). The following sections present the different methods used in this study in short. For more detailed descriptions, see **Papers I-VI**.

Table 1. Research objectives and the methods used in the study.

No.	Paper(s)	Objectives	Method
1	I	To find the extent to which extent UE methods are currently used among map developers.	Interviews with companies
2	II	To identify potential usability problems with web mapping sites and to assess the suitability of different evaluation methods for identifying usability problems of the web maps in question.	Usability test in a laboratory
			Expert evaluation: cartographers and usability specialists
3	III, IV	To observe the use context of mobile maps and to identify usability aspects for the design of topographic maps in mobile devices using UE methods.	Usability field test (with think aloud, observation and interview methods)
	V, VI	To study the user requirements for adaptive map visualisation using UE methods.	Intuitivity test for map symbols
			Expert evaluation of cartographic design
	VI	To apply and assess the different UE methods in the development of a mobile map service.	Heuristic evaluation for a PDA GUI
			Expert evaluation for a PC Web GUI (questionnaire)
			Usability test in a laboratory
4	I-VI	To identify the benefits, disadvantages and challenges of including UE methods in interactive map design.	All the methods listed in 1 to 3
5	I-VI	To identify the characteristics of user-friendly interactive maps.	All the methods listed in 1 to 3

3.1 Interviews with map application developers (Paper I)

The introductory section of this thesis and the author's earlier literature review on map usability-related research (Nivala, 2005) showed that many studies emphasise the need for UE methods in interactive map design. However, previous research has consisted largely of academic research projects, and there is still a need for research on the use of usability methods by application developers themselves.

The motivation for this study was to find out whether the results reported in academic research papers correspond to the current real-life situation of map developers. Are UE methods widely known and used among current map designers? And if not, why not?

A related research field, usability capability maturity (UCM), aims to assess how well UCD aspects are included in development organisations. The objective of UCM and related models is to improve the position and effectiveness of UCD through defining the UCM level of the organisation in question (Jokela, 2004). A survey of UCM models reveals that different models have different assessment scopes: some are used for examination of the user-centredness of individual development processes, while others aim to analyse the status of UCD from various organisational viewpoints (Jokela et al., 2006). These assessments are carried out because integrating UCD in software and product design is considered challenging in many companies.

The study presented in Paper I aimed at gathering information about the design process and the ways maps and their UIs are tested and evaluated during product design. Information was also gathered regarding the extent to which, and in what ways, end-users are involved in the current product design. The objective was to use this information to specify the type of situations to which each particular usability method would be most suited, needed and/or beneficial. The aim was also to examine the necessity for UE methods in map design.

3.1.1 Procedure

The research was carried out in the form of semi-structured interviews with companies that develop different types of maps, map applications and GISs. The companies targeted were among the largest map application developers in Finland. Interviews were carried out with one experimenter and one spokesperson for the company, usually a person responsible for the product design process or otherwise a usability specialist. The interviews were recorded on audiotape and a qualitative analysis of the informants' responses was later conducted.

The results are presented briefly in section 4.1 ('Familiarity of map developers with usability methods'). See **Paper I** for more detailed information about the test set-up.

3.2 Usability evaluation of web mapping sites (Paper II)

The aim of this particular study was to assess how UE methods can be used in a multidisciplinary environment with a long tradition of design and research. A usability evaluation of web mapping sites) was carried out with two main objectives: to find out usability problems with current web maps, and to compare the suitability of different evaluation methods for investigating the usability problems of such sites. Information about possible usability problems could be used to identify user requirements and compile guidelines for the design of new interactive web maps. Armed with this knowledge, we would be one step closer to answering the question “What does the usability of interactive maps encompass?”

3.2.1 Method

Four different web mapping sites (Google Maps, MSN Maps & Directions, MapQuest and Multimap.com) were evaluated in this study using different usability evaluation methods. These sites all consisted of an interactive 2D map with zooming and panning options. Additionally, users were able to search for different locations and for route directions.

3.2.2 Procedure

Usability evaluations were carried out on the basis of the following scenario: *“A tourist is planning to visit London”*. Half of the evaluations were conducted as usability tests and the other half as expert evaluations. Usability tests were carried out in a usability laboratory, where each user performed predefined test tasks with two of the web maps. The expert evaluations were carried out by eight cartographers and eight HCI experts (or usability specialists), each of whom dealt with one mapping site. Altogether 24 participants were involved, and 32 different evaluations were carried out in the study. Each of the four web mapping sites was therefore evaluated by eight separate participants (four test users and four experts).

3.2.3 Analysis

The video data from the user tests was analysed by viewing the material and writing down everything that the users had problems with and/or commented as being a problem in some way. Positive comments were also recorded. The same was done with the expert evaluations; the evaluation reports were examined carefully, and all the negative and positive findings were picked up.

Afterwards, the problems were grouped under four different categories (1-4) according to the severity of the problem (Nielsen, 1993). Following this, the problems encountered were compared both qualitatively and quantitatively. Usability problems identified and the preliminary discussion of the different evaluation methods are presented briefly in section 4.2 (‘Usability evaluation of web mapping sites’). For a more detailed discussion of the test set up, readers are referred to **Paper II**.

3.3 UCD in the development of a mobile map service (Papers III-VI)

The hypothesis of this research was that UCD has a fundamental role in map designing for new technical environments such as mobile devices that involve entirely new ways of interacting. By using an iterative UCD approach, while simultaneously taking into account the novelty and diversity of users and their tasks together with the characteristics of the maps, application developers could design products that have a higher quality of use.

The aim of this particular study was to find out how a UCD approach could be included in the development of a mobile map service. The study began with a literature review that summarised UE principles and usability-related research carried out in cartography (Nivala, 2005). The review revealed that current map design projects are mainly carried out in two separate research fields: by cartographers and by software developers. Thus, there is a need for a multidisciplinary approach that merges the knowledge from cartography and UE. Based on the literature review, a synergy model for UCD and characteristics of mobile cartography was proposed, aiming to provide guidelines on

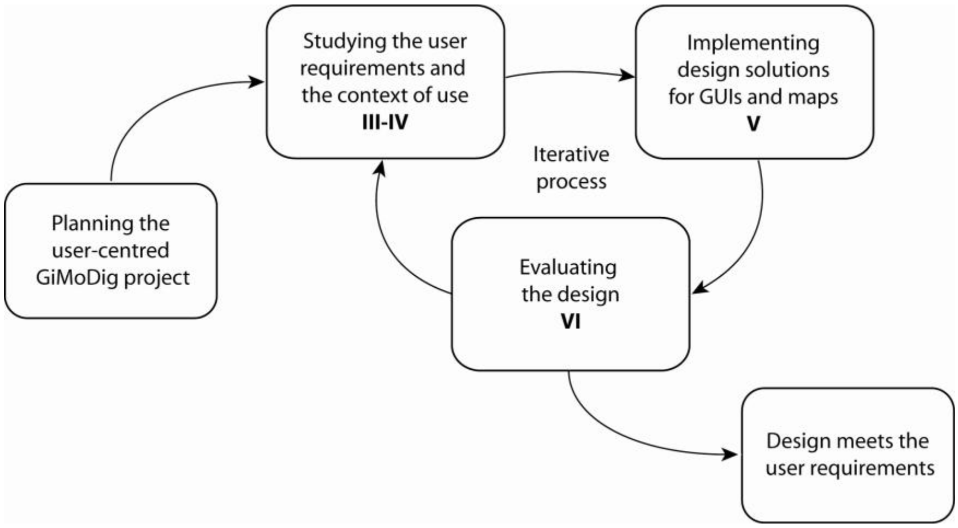

Figure 4. UCD in the GiMoDig project. Numerals indicate the paper describing the study.

putting the UCD approach into practice in the development of a mobile map service (Nivala, 2005).

Next, an iterative UCD approach was followed in developing a mobile map service. The research was conducted during 2002-2005 as part of the EU-funded GiMoDig project (Geospatial info-mobility service by real-time data-integration and generalisation) (GiMoDig, 2001; Sarjakoski and Sarjakoski, 2005). The main goal of the project was to deliver maps in real-time to mobile users. The project resulted in a prototype for a seamless, cross-border mobile map service based on open system architecture (Lehto and Sarjakoski, 2005). Topographic data from national mapping agencies was used to provide a vector-formatted, high-quality, scalable vector graphics (SVG) map displayed on a mobile device. The project was funded by the European Union's Information Society Technologies (IST) programme, which strongly emphasised the concept of user-centredness (IST, 2005). Therefore, development of a user-friendly application constituted a significant part of the GiMoDig project (Sarjakoski et al., 2004b).

Papers III-VI describe the implementation of an iterative UCD approach in the GiMoDig project (Figure 4). The study began with a definition of user requirements, and was followed by research into the potential user groups of the service and investigation of the context of use for mobile maps (**III**). The results were used to establish the user requirements and preliminary usability goals for the prototype to be developed (**IV**; Nivala and Sarjakoski, 2003). The study continued by describing how these goals were taken into account when designing the GiMoDig project's GUIs and maps (**V**), and how the implemented design was evaluated at different stages of the project from a usability perspective (**VI**).

The experience gained during the implementation of the UCD approach in the mobile map development process is discussed in Nivala (2005) and in **Papers III-VI**. The experience gained through these evaluations is also discussed in section 4.3 ('UCD aspects with mobile maps').

CHAPTER 4

RESULTS

This chapter summarises the main results of the studies. For a more detailed description of the results, readers are referred to the papers attached at the end of the thesis.

4.1 Familiarity of map developers with usability methods (Paper I)

The interviews revealed that although UE is slowly being incorporated into the design of interactive maps, knowledge on how to execute the methods is still almost non-existent. Most companies are interested in implementing this approach, but the problem is the lack of resources and insufficient knowledge on how to implement this type of approach. However, there was also positive experience of bringing usability methods into the design. Including the UE approach in the design stage was thought to be an advantage in the competition for market dominance and in increasing the saleability of a product.

The map design process varied a lot according to the extent of customer knowledge about the system to be developed, the type of application being developed and the type of project. Design was mainly carried out by software engineers and GIS professionals, but cartographers, graphic designers, usability specialists or informaticians were sometimes also involved.

4.1.1 Usability testing

Usability testing was seldom included in the companies' offers to customers. Today, most of the product development is based on considerable know-how and experience and so, according to the companies themselves, at least the most obvious usability problems can be avoided. In terms of usability maturity (Earthy, 1998), the companies could be roughly categorised as belonging mostly to levels A and B, in which the importance of usability approaches is barely recognised. Only one of the companies interviewed could be regarded as being at level D, in which human-centred processes are already integrated into the product development process.

Systematic usability evaluations were also conducted: observations, interviews, and heuristic evaluations of the UIs, and in some cases usability tests. A few of the companies (larger ones for whom map development was only part of their software development) had their own specialist usability groups. Others carried out joint projects with usability research groups at universities or the like. Nevertheless, careful consideration was always given when deciding whether end-users' opinions of a product were critical or not, and whether additional resources were necessary for usability evaluation.

Five main reasons for including usability aspects in the map development process, together with examples of each type of situation, were given by the interviewees (Table 2).

4.1.2 Evaluation of the maps

Maps are often considered to be a work of art on their own. Despite this, they can contain many errors (e.g. texts can overlap, data can be inaccurate). Understanding consumers was considered important in order to be able to provide end-users with a map visualisation suitable for the purpose of the map. However, in general, end-users have not been included in evaluations; instead, it is often the corporate customer that approves the map visualisation. These customers have not usually had specific requirements for the maps, beyond the need for the data to be up-to-date, accurate and easily deliverable to users. Their comments mainly concerned the need to show thematic data on top of the background map distinctively enough. Customer comments also concerned functionality issues, such as why specific operations were not included, why the system was working slowly, or why the system was working in a specific way instead of another. However, these aspects were seen as mainly cost-related – the cheaper the product, the poorer its functionality.

Table 2. Examples of reasons for including usability aspects in map development (Paper I).

Description	An example
User requirements especially demanding	A usability test was carried out in a laboratory to simulate a web-based emergency information centre experiencing an alarm situation caused by fallen power lines due to bad weather. The user requirements in this situation were that use of the application should be easy to remember and that the application should be easy to take into use in a sudden emergency situation.
Usage situation especially demanding	Usability testing and simulation were carried out when an application was being designed for a critical usage situation (managing a fire rescue vehicle). The user requirements were especially demanding because the user had to drive at 100 km/h and use the UI at the same time. Usability aspects were considered relevant, as the system should not make the situation even more demanding.
User tasks unfamiliar to the designers	A company designed an application to be used for land-use planning, property designation and building construction control in municipalities. End-users were interviewed and observed in situ in order to understand their tasks before any implementations were made towards a new system.
Usage situation unfamiliar to the designers	For the design of a mobile application the usability specialists went into the field with maintenance men who were repairing and checking electricity power lines in order to observe the latter's tasks and use situations. This helped them understand the requirements for a mobile map usage situation.
Application targeted for a large number of users	A company developed electronic maps to be used together with Yellow Pages services. A total of 500 users tested the user interface and different cartographic variations of the maps (varying in colour, information density, etc.) over two weeks. Feedback was gathered on different visualisations.

Evaluation of the visualisation by end-users was more common for printed maps, especially if the product was developed to be on the market over several years. In these cases the company sent a draft of the map visualisation to users and asked for their opinion about it. The comments received were often very specific and related to the level of detail for road networks, place names, etc. These types of comments were less often made for screen maps, because they were viewed differently, as technical devices to aid in navigation. Printed maps are looked upon as a work of art, and people also judge whether or not they have an attractive appearance. Therefore, not all the user comments were included in the final design, because some opinions were too personal. It was also pointed out that the question "how should the map look?" does not have a single right answer, which is why the cartographic evaluation has to be stopped at some point.

4.2 Usability evaluation of web mapping sites (Paper II)

In all, 403 usability problems were found with the different evaluation methods (see *Total** in Table 3). As some of the usability problems were identified in more than one evaluation method, the total number of unique usability problems with each map site is less than the figure given under Total*. The number of unique problems encountered was 343: 69 in Google Maps, 83 in MSN Maps & Directions, 92 in MapQuest and 99 in Multimap.com (Table 3).

4.2.1 Usability problems

Although the total number of usability problems gives an indication of the usability of the map site, it is clear that the severity of the problem also plays an important role. The problems were classified under different categories based on how seriously they affected the use of the site. In total, 33 catastrophic problems were identified, in addition to 138 major problems, 127 minor problems and 44 cosmetic problems. From GM only one catastrophic problem was found, whereas MD and MM both had 13 such problems (Figure 5). GM also had the smallest number of major problems (21).

The usability problems were also grouped under four different categories according to which part of the site they belonged to: 1) *user interface*, 2) *map*, 3) *direction, address and place searches*, and 4) *help and guidance* provided to the users in an error situation.

Table 3. The number of usability problems found with different evaluations (Paper II).

	Usability test	Carto eval.	HCI eval.	*Total**	No. of unique problems
Google Maps (GM)	38	17	25	80	**69**
MSN Maps & Directions (MD)	57	21	18	96	**83**
MapQuest (MQ)	50	26	32	108	**92**
Multimap.com (MM)	71	32	16	119	**99**
Total	**216**	**96**	**91**	**403**	**343**

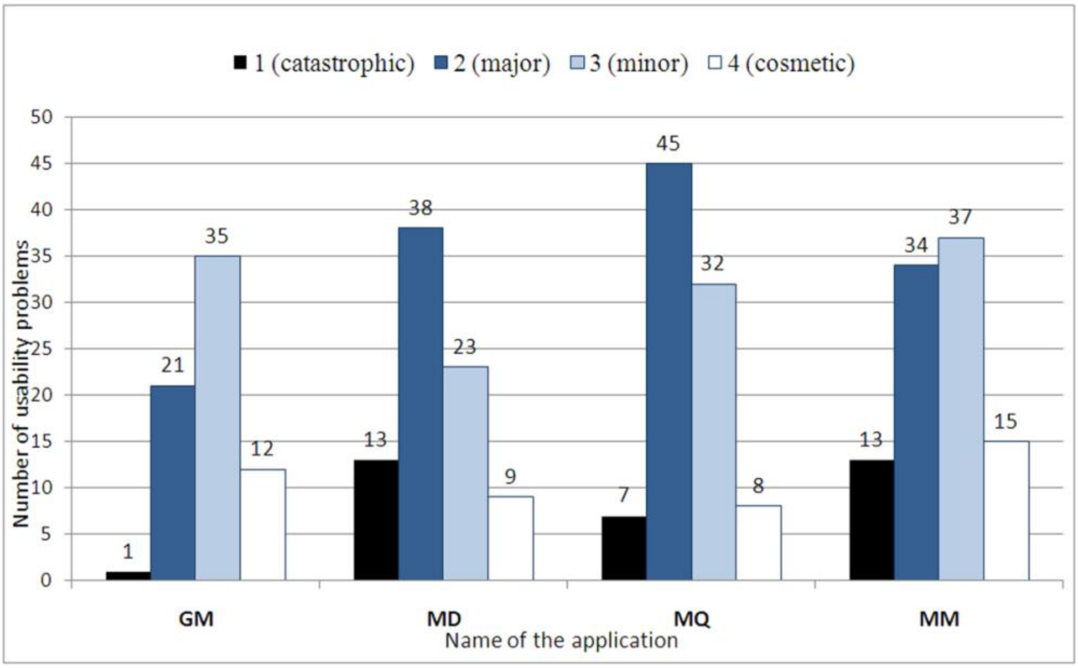

Figure 5. Distribution of the severity of usability problems in each of the web mapping site.

A detailed description and figure illustrations of the usability problems are presented in **Paper II**. Suggestions for design guidelines for web mapping sites based on the most severe problems encountered by the participants (either test users or experts) are also given in section 4.5 ('Usability characteristics of interactive maps') and in **Paper II**.

4.2.2 Method comparison

In all, 53% (216) of the problems were found with the usability tests, 24% (96) with the cartographic evaluations and 23% (91) with the expert evaluations (Table 3). There were as many evaluations carried out with the usability tests (16 in each case), though the usability tests were slightly more effective in identifying usability problems.

The most severe usability problems were more often identified by the usability tests: over 60% of category 1, and over 70% of category 2 (Figure 6). The minor problems were identified almost equally.

A comparison was also made of how many of the methods identified each individual problem. Most of the problems were identified by only one method (usability test, cartographic evaluation or HCI evaluation) (Figure 7). Only 13 out of the total of 343 problems were identified with all three methods. A detailed description of the method comparison is given in **Paper II**.

4.3 UCD aspects with mobile maps (Papers III-VI)

The results of the third part of the thesis are divided into four research topics, each of which is discussed in more detail in Papers III-VI. However, the topics are related, since together they describe how the iterative UCD aspects were incorporated into the development of a mobile map service in the GiMoDig project. The following sections give an introduction to each paper, but more detailed descriptions of the studies can be found in the attached publications.

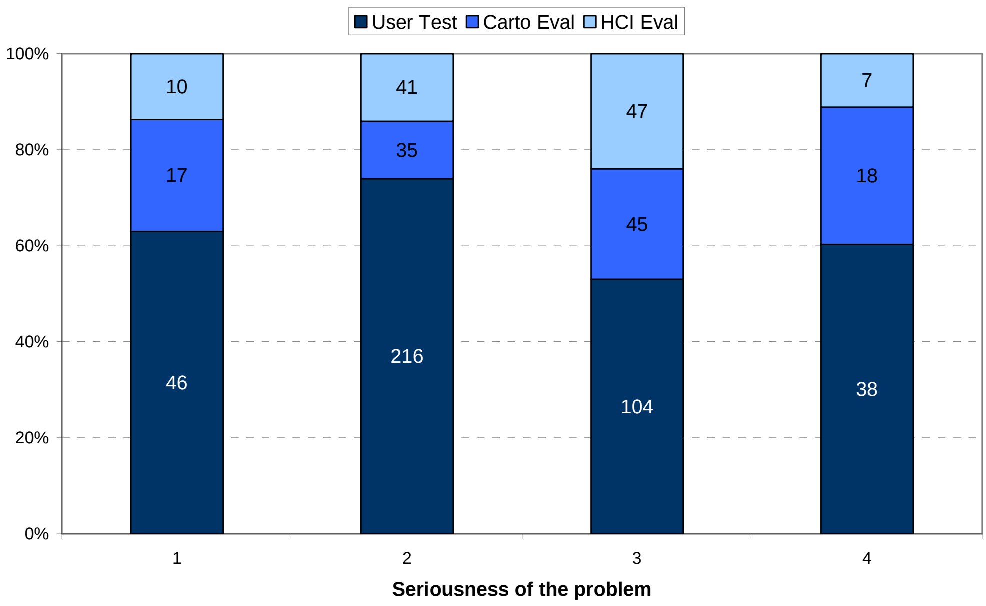

Figure 6. The percentage of usability problems found with different methods, grouped according to the severity of the problems.

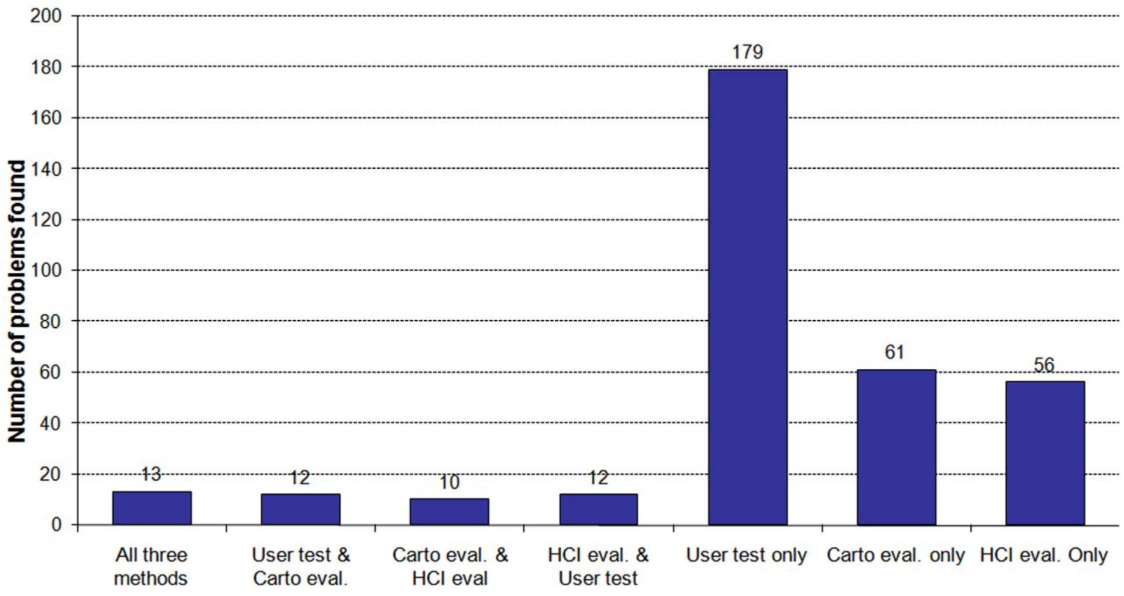

Figure 7. Distribution of individual problems identified with one, two or all three methods.

4.3.1 Usability evaluation of topographic maps (Paper III)

A field test was arranged in a national park under the following scenario: A Hiker in a National Park. The purpose of the test was to obtain basic information on user requirements relating to the use context, to find out the degree of usability of existing topographic maps on mobile devices, and to identify design principles for adaptive maps to be provided by the GiMoDig map service. The evaluation was conducted in cooperation with the KEN project (KEN, 2005).

The field test was devised using three usability methods: thinking aloud, observation and interviews. The user group in the study was small, since the aim was only to look for qualitative results. Along with six test users, one pilot-test user was included in the user group to make sure that the test set-up worked as planned. Test users were transported to Nuuksio National Park in Espoo, southern Finland. They were asked to complete predefined orienteering tasks using topographic maps on a PDA. Two observers monitored the users during the test and interviewed them in the field. Each test took approximately 3 hours. The tests were recorded on minidisk and partly on videotape.

The results of the field evaluation highlighted the fact that the cartographic presentation and symbols on current topographic maps were not well suited for mobile small-display devices. Problems with technical equipment and functionality of the software were also identified. The main benefit of the mobile maps (besides the location information provided by the GPS module) was felt to be the combining of additional information from various databases and its presentation over the topographic map data. In future, mobile maps, symbols, placement of symbols and other visualisation will have to be adapted for small displays (Table 4).

One objective was to see if the field tests were adequate for evaluating the usability of maps developed for mobile devices. The study showed that the tests were suitable, especially since various things can affect the use of mobile maps. These features are sometimes difficult to determine out in a laboratory environment. However, arranging field evaluations can take considerable time and effort. **Paper III** presents the design of the user evaluation and discusses its results in more detail.

4.3.2 Context categorisation for mobile map use (Paper IV)

During the field evaluations it was observed that users prefer meaningful maps that are adapted according to the context of use. In general, ‘intelligence’ can be incorporated into UIs e.g. by making them aware of the context of use; this is likely to apply to mobile maps, too. Current maps for mobile devices do not provide users with any scope for adaptation. Because context was found to be critical for a user-friendly map application, a study on context categorisation was carried out.

The literature search showed ongoing research on defining ‘context’. The available information was gathered and integrated with the results of the GiMoDig project field tests. Through this, mobile contexts were identified and categorised from the topographic map users’ points of view (Table 5).

Table 4. Examples of map symbols that users had problems with during the tests (Paper III).

Symbol	Meaning of the symbol	Users' comments
	Deciduous tree	Believed to be a small contour line.
	Coniferous tree	Tree symbols should be more illustrative or displayed as a coloured area.
	Boulder	Symbol unknown to all users, not descriptive enough.
	Precipice	Symbol unknown to some users.
	Outcrop	Symbol unknown, not seen very well in bright sunlight.
	Contour lines	Indistinct from path symbols. Should be more descriptive: several users suggested shadowing of the slopes.
	Weir	The symbol for the weir was unknown to all of the users. Suggestions were made for more descriptive symbols for man-made structures (e.g. houses, bridges).
	Residential building	
	Outbuilding	

Table 5. Categorisation of contexts and their features for mobile maps (Paper IV).

General context categories	Context categories for mobile maps	Features
Computing	System	Size of display Type of display (colour etc.) Input method (touch panels, buttons) Network connectivity Communication costs and bandwidth Nearby resources (printers, displays)
User	Purpose of use User Social Cultural	User's tasks User's profile (experience etc.) People nearby Characters, date and time formats
Physical	Physical surrounding Location Orientation	Lighting, temperature, weather conditions, noise levels Surrounding landscape User's direction of movement
Time	Time	Time of day Week, month Season of the year
History	Navigation history	Previous locations Former requirements and points of interest

Mobile map use contexts are not a simple topic. First of all, the context changes every time the user moves, or the area surrounding the user may change in various ways even if the user is not moving. Today, the most important context of use for mobile maps is location of the user. However, the users' needs with respect to also adapting maps in mobile devices to other context elements appear obvious; purpose of use, time, physical surroundings, navigation history, user and cultural and social elements. By using the context information available, the map service could adapt the visualisation for different usage situations and individual user needs. A detailed description of the different contexts relevant to mobile map usage is given in **Paper IV**.

4.3.3 Adaptive visualisation for mobile map users (Paper V)

In order to fulfil user requirements, a service able to deliver context-aware maps for different users in different usage situations was developed. The maps could be actively personalised with the support of a knowledge-based system. In active personalisation the user defines the preferences for the mobile maps (Sarjakoski et al., 2004a; Sarjakoski and Sarjakoski, 2005; 2007). A detailed description of the technical implementation of knowledge-based map adaptation in the GiMoDig service prototype is given in an article by Sarjakoski et al. (2007).

When users personalise the map service, different map visualisations are created for different users according to the following preferences: 1) use case (user's current activity); 2) identity (user's language, age group), and 3) time (time of year/day). *The use case* refers to the situation in which the map is going to be used. The users can choose between a set of use cases: outdoors, cycling, emergency and expert use. If the users are going hiking, for example, they can choose the 'outdoors' option. If they are cycling in an unknown city, they can choose the option that provides a map especially designed for cyclists.

Personalising the service according to *the identity* of the user consists of two parts: choice of language and choice of age group. The choice of language is reflected in the language of the user interface. The choice of age group changes the layout of the requested map, because different age groups are provided with different point of interest (PoI) symbols, satisfying special user needs appropriate to that particular age group. To make maps even more specialised for particular use situations, users can also define *the time* by selecting a season. Accordingly, the PoI symbols are adapted for seasonal activities, such as swimming places in the summer and ski tracks in the winter.

Following UCD, the adaptive cartographic design was also evaluated with UE methods at different stages of the project. Two methods were used for evaluating adaptive map visualisation: expert cartographic evaluations and intuitivity tests. The expert evaluations evaluated the overall design of the maps, whereas the intuitivity tests only evaluated isolated map symbols.

During the evaluations it was observed that new ideas in cartography were not welcomed by all users. This was evident especially when asking for opinions on the 'seasonal map' designs. The feedback was divided into two opposite opinions: some liked the idea, while some thought it was insignificant and not useful at all. This may also be a question of getting used to something: if a user expects to get a traditional map, a different visualisation may be irritating. But the maps for small displays need to be redesigned compared with traditional maps. Therefore, new experiments for cartographic visualisation were considered relevant at this stage.

4.3.4 Iterative UCD (Paper VI)

The aim of this specific study was to test experimentally how a UCD approach could be included in the development of mobile maps. The evaluations were part of the GiMoDig project's iterative design cycle, in which each phase of the project was based on carefully defining the different user groups and their tasks and goals in a particular situation where the mobile map would be used. The evaluations started immediately after the first prototype became available. The usability goals for the map service were defined as 1) easy-to-use UI, 2) suitable cartographic presentation, 3) integration of different data sets, and 4) context-aware maps. The evaluations were carried out using four methods: 1) heuristic evaluation, 2) expert evaluations, 3) usability testing, and 4) intuitivity testing. Detailed description of the methods used for evaluation is given in **Paper VI**.

The first *heuristic evaluations* were carried out during the early development and design stages of the prototype. Preliminary results were needed quickly, which was also one criterion for choosing this method. One usability expert carried out the evaluations by going through all the menus in the UI and evaluating each step against Nielsen's (1993) heuristics. The evaluation highlighted problems with the GUI that needed to be improved for the next versions. Heuristic evaluations were repeated several times during the project, and improvements were made at each stage on the basis of the results.

As the design became more sophisticated, the GUI was evaluated by *experts* working in the area of cartography or geoinformatics. They went through the GiMoDig user interface and, at the same time, performed predefined tasks as instructed on a questionnaire. The main aim of the evaluation was to find out whether users managed to access different types of map through the service and whether the visual design of the GUI and the maps met with approval, and what users thought about the parameters and preferences used and the different types of maps they could access. Research was also carried out on user recognition of the different GUI buttons, i.e. how intuitive they were. A number of problems were identified and fixed accordingly.

Usability testing was conducted in the evaluation of the GiMoDig GUI to obtain more detailed information on the actual use of the maps. The tests were arranged so that users conducted certain tasks using the GUI following instructions given by a moderator. Users were also encouraged to think aloud during the test tasks. The PC screen that was being used by the user and their comments were recorded on video. The result of the tests was a list of usability problems encountered by users during the test situation, and a list of positive and negative comments relating to the design.

Four sets of PoIs for different user age groups were created and stored as SVG files in the symbol library. One of the sets was user-tested with an *intuitivity test*. The aim of the intuitivity evaluation was to ascertain the validity of the symbols, i.e. do users understand what the symbols mean? The test was carried out by e-mailing a test form to users. The latter were asked to look at each of the PoI symbols (a total of 46) one by one, and write down beside the symbol what they thought it signified. Twenty-two users responded to the test. Quantitative data were gathered on how many users recognised the symbols. Furthermore, as the aesthetic qualities of the symbols were not considered to be a measurable property, qualitative comments on symbol design were also gathered from the users.

The cartographic design was evaluated several times by *cartographic experts*. An evaluation form was provided for the evaluators, in which they were asked to assess each of the map objects (roads, tracks, lakes, forests etc.) according to the following: a) area fill colour, b) line or outline colour, and c) contrast compared with other map objects or symbols. The overall design of the maps was also studied using various questions, such as: Is the map harmonic? Are the symbol colours harmonic? Are the symbol colours associative? Are the symbols self-evident? Is the map easily understandable without a legend? What is the overall legibility of the map? As a result, qualitative data were gathered, and the cartographic problems emerging were redesigned for the next phase of map designs.

Since the maps were provided for two different media (PDA and a portable laptop PC), the cartographic design was also valuated separately for both environments. When evaluating PDA maps, the evaluators went outdoors to examine the maps in real settings (such as varying light conditions), whereas the laptop maps were evaluated indoors. During the evaluations, the cartographers found various problems with the cartographic design; these were listed and taken into account during the next design phase.

Experience was gained on how to implement usability evaluation methods and UCD successfully in a map project. Based on this experience, a set of instructions was created in accordance with general usability heuristics, which gave a preliminary idea of how to implement UE with mobile maps. More detailed information about the different usability evaluation methods and UCD aspects included in the study can be found in **Paper VI**.

4.4 Suitability of UE methods in map design (Papers I-VI)

Interviews with map developers revealed that some companies had used usability methods in their product design, and some even had their own usability specialists. At the same time, a usability evaluation of web map sites revealed that current maps had a lot of usability problems, some of which could probably have been avoided by arranging usability evaluations before releasing the product. It seems that the developers are aware of the need to consider usability aspects in the product design, but evaluations are not regularly used at the moment. In the following sections the reasons behind this ‘inconsistency’ are analysed with the aid of the findings concerning the benefits and challenges of including usability aspects in product design.

4.4.1 Benefits of UE

Map applications are often large and complicated systems with a lot of different functions and access to large databases. For this reason, understanding user requirements from the beginning of the project is essential, since changes at a later stage may require considerable resources. Including usability knowledge at the product design phase may also convey a positive image to the customer. The benefits of an iterative design are also clear, as it means that a product development project is not side-tracked so much during the design stage, since information about user requirements is constantly being updated. Table 6 presents the benefits of using UE methods in map development (based on **Papers I-VI).**

It was observed that UE aspects are becoming more important now as geospatial data is appearing on the screens of more and more mobile devices and being used by a large number of people. The varying technical properties of the devices underline the importance of testing with real end-users during the product design stage. The UCD approach can be used to expand designers' knowledge of user requirements, thus supporting innovativeness. Furthermore, the use of mobile maps while on the move sets different types of requirements compared with static desk-top maps. Since there will be wide differences between web map users – and their level of knowledge of GIS – designing a user-friendly application is especially challenging; for this reason UE methods are becoming more relevant.

Table 6. Benefits of including UE methods in map design (Papers I-VI).

Benefits of UE approach	
Saves expenses	The design concept was not clear during the early product launches, but became clearer when showing the design to users and asking for their feedback.
	If the information about user requirements is constantly updated using UE methods, product development may avoid getting sidetracked during the design process.
	Map applications are often large and complicated systems. Understanding user requirements from the beginning of the project is essential, since changes at a later stage are expensive.
	Arranging early evaluations of prototypes with users was also seen as a way of saving money; instead of developing sophisticated versions for customers to evaluate, primitive prototypes should be used.
Helps to design products that fulfil user requirements	Users and their level of knowledge about maps can vary widely, especially with web applications. Usability evaluation methods may help in understanding users and their tasks.
	Usability aspects are important when map applications are to be used by large numbers of users, such as Internet-based services, because they must be easy to use and attractive to explore.
	Finding out user requirements with UE methods is vital for new technology applications, since these requirements may not be the same as those for traditional applications.
	It was felt that including the UCD approach in the mobile map development process increased the innovativeness of design.
Helps to understand the use context	Compared to static desk-top application users, mobile map users have different types of requirements. Context of use studies, for instance, are relevant because it is difficult to imagine all the situations the user may face.
Gives a positive image of the company	If usability knowledge is included in the product design, it may give the company credibility and portray a positive image to the customer.
	Experience had shown that including usability aspects in the design increased the number of users, because the system became more attractive and easier to use.
	When there are a lot of different companies providing applications using the same technology, the one able to design the most usable application may win the battle for market dominance.

Among the comments it was noted that map application developers were initially doubtful about the benefits of UE methods, but that they then changed their minds when customers stated that a product was successful due to its usability aspects and the understanding of user requirements. One example was also that when a web map was redesigned with usability aspects in mind, the amount of users increased. Another experience was that when a usability group pointed out all the errors found during an evaluation and stated that these could have been avoided by including usability aspects in the early stages of project design, the product development team felt acutely aware of the potential cost-effectiveness of usability aspects.

4.4.2 Challenges of UE

The challenge of including UE aspects in the design of maps lies in multi-disciplinary nature of UE. The methods are not widely known and neither is the knowledge of which type of method should be used in a given situation. The lack of resources for carrying out usability evaluations is also a concrete concern, especially if the applications are designed for a small number of users. A further issue is the cost of including usability aspects in a project and, specifically, who will meet the cost. It was also pointed out that users are often satisfied regardless of any problems when they are provided with new technology, because new systems are generally better than previous versions, and that this is why the usability of a product is not so critical. Table 7 presents the observations regarding the challenges of using UE methods in map development (**Papers I-VI**).

Table 7. The challenges of including usability aspects in product design (Papers I-VI).

Challenges of using UE methods	
Tradition and know-how	Long tradition and extensive knowledge of how map applications have been developed in the past was considered to be sufficient for developing maps. Need for UE methods was questioned.
	If a usability group existed in a company, it had to do a lot of work at the beginning to convince others of the benefit of including usability methods in the design and of the cost benefits of using them as early on as possible in the project.
	The business model of map application developers is such that they never actually met the end-users, but are normally only in contact with the direct customers.
Lack of knowledge on methods	UE methods were not widely known among map developers or their customers. There was lack of knowledge on how to apply methods originating from computing science.
	All UE methods may not be suitable for map design. There were no examples or guidance on how to choose suitable methods for each type and stage of the design process.
	An additional challenge posed by using usability experts is the question of where usability expertise fits in from the organisational point of view. Should usability experts work via system developers or should they have direct contact with end-users?
Lack of resources	Map applications are not always designed for a large number of users. In this situation, there are no resources for carrying out usability evaluations.
	A further issue was who will pay for the inclusion of UE in a project. In the end, it is always the customer who decides what is emphasised in the design.
	Involving ordinary consumers in product development was not seen to be as important as it is with systems that are being designed for professionals, because it may be more difficult to understand the tasks in professional use than those of consumers. Professional users often have a higher status at the organisational level, and hence their acceptance of the product was considered more important.

In addition, the general business model of the companies focused on developing map applications for their own direct customers, who then go on to provide systems for end-users. For this reason, the companies did not always meet the end-users, and user requirements were specified through the customer company. This was considered problematic from the perspective of UE methods, which emphasise meeting real users. Furthermore, not all the methods used in traditional UE are either suitable or useful for map applications. It may also be that when usability methods are incorporated into applied disciplines, some adaptation of the methods may be necessary.

4.5 Usability characteristics of interactive maps (Papers I-VI)

The need to consider usability aspects in map design was considered especially relevant today as interactive maps are increasingly being used by private, non-professional map users. This must be reflected, for example, in the terminology used within the maps and their UIs; the use of map-specific terms such as ‘topology’, ‘coordinates’, ‘level of detail’, etc. is not straightforward. From a usability point of view, maps also include specific features that may be difficult for ordinary users to understand. Furthermore, zooming in on a map and how this relates to the map scale can be demanding for ordinary users. These aspects should be carefully considered by product developers.

4.5.1 Usability aspects of web mapping sites

Usability problems of current web mapping sites used on desk top PCs were identified and design guidelines proposed in **Paper II**. The usability problems were grouped under four different categories according to which part of the site they belonged to: 1) user interface, 2) map, 3) direction, address and place searches, and 4) help and guidance. The results give an indication of the main user requirements for web mapping sites and what the designers of future web maps should pay attention to (Table 8).

The first impression is relevant; the purpose of the web mapping site and the way in which it should be used must be clear from the beginning. Users should also be given information about what they are currently doing (or what is currently being done), and what they will have to do next. This is important when, for example, large map files are being loaded, as these take a long time to appear on the screen. To prevent frustration and avoid the impression that the map is not working, users should be told that ‘something’ is happening.

As web mapping sites are decidedly visual by nature, distractive advertisements and messy user interfaces were observed to be particularly detrimental. The number of critical comments given by ordinary test users about the messy and bad visualisation of the maps themselves has proved valuable in assessing the usability of web maps. Each map scale should be considered separately: attention should be paid to the type of information to be included and to how it should be visualised at each of the scales. Using maps that were originally designed as printed maps, or even worse, maps that are in fact printed maps but have been scanned and put on the Web, is no longer acceptable. Today’s map users are used to having access to a lot of free but well-designed services on the Internet, and if they are faced with a site that not only looks bad but is also difficult to use, they will rapidly start looking for a better alternative.

Table 8. Design guidelines of web mapping sites (based on Paper II).

Part of the application		Design guideline
UI of the mapping site	layout	• The home page should be clear and simple. • There should be only a limited number of adverts and animations and these should be located in such a way that they do not disturb the user. • Information presented on the UIs should be logically placed; attention should be paid to grouping of different tools. • The search box should be given a central role in the layout.
	functionality	• The design of the UI should be intuitive; the user should be able to start using the map immediately when entering the page. • The links in the UI should not be opened in the same browser window as the map. There should always be a short cut back to the home page.
Map	visualisation	• The map should be optimised for the screen. • The map should be visualised according to the screen properties. • Maps should be simple, intuitive and pleasant. Colours should be in harmony. • Each map scale should be considered separately. What information should be included and how should it be visualised in each of the scales? • Information about data accuracy and validity should be provided.
	tools	• Map tools should be distinctive, but should not block out too much information on the map. • A route-measuring tool would be beneficial (in addition to a scale bar). • New tools would be beneficial for users: an option to add markers on the map, to click on different objects in order to get more information about them, to customise the map by checking 'boxes' to show or hide different data layers or symbols (e.g. tourist attractions, hotels, restaurants) and an easy way to print and email the map. • The scale bar (and other) units should be customisable. • A continuous click-and-drag option would be best for panning.
	level of detail	• The step in visualisations between different scales should not be too big. • A continuous shift between different scales would allow users to follow a specific location while zooming in and out. • Scale numbers should not be used; scale should be indicated with more commonly used terms (such as street level, city level, country level etc.).
Search operations	functionality	• Different types of searches should be supported. • Users should know with what type of criteria the search is carried out. • It should be borne in mind that web maps are used by different types of users. • A list of users' previous searches should be saved and provided to them. • It should be made clear to users what the search results are based on and how they relate to the query.
	visualisation	• The results should be centred on the map and distinctively visualised; taking into account the symbols that are already used on the map. • The result symbols should not cover too much of the map and they should not overlap. • The default map scale should give enough information for the user to be able to check whether or not the result was correct. • It would be beneficial to show all the possible results on the map, so that the user can choose the right alternative among them. • Street and route search results should be visualised with a line. • Route search results should be displayed on a map scale adapted to the search result so that the user sees the entire route.
Help and guidance		• User should be provided with help in map use and in other functions in the site. • Error messages should be clear, informative and distinctive. • Users should be informed of current default settings and how they can be changed.

Map tools have to be logically grouped (map operating tools together, links together, other functions together, etc.). With current technology it is also easy to include new tools of benefit to users, such as a route measuring tool or an option to add markers on the map. However, traditional tools, such as legends and north arrows, should not be forgotten either, although they seem to be missing from many web maps. Tools in general should be distinctive, but should not block out too much information on the map. The level of detail is a critical aspect from the usability point of view; the steps in visualisations between different scales should not be too big, and a continuous shift between different scales would allow users to follow a specific location while zooming in and out.

Among the most common tasks with web maps are different types of searches carried out by users to look for addresses, routes, etc. It is important that the map and the search box occupy a central role on the map site. Different types of search operation can also present usability problems. Different people search things differently; some people are used to making web searches with search engines, and they also want to carry out map searches in the same 'free' manner. Others may need more structured/guided searches. As the most severe problems observed during the usability evaluation were related to the default settings of the web mapping sites, it is critical to guarantee that users know the criteria used in searches. The basis of the search results and how they relate to the search query should be also made clear to users. Visualisation of search results should take into account the scale of the map and the symbols that are used on the map.

Help and guidance functions are a necessity with web mapping sites. Different types of users should be supported; novices should be offered help and 'wizards', whereas experienced users should be provided with shortcuts to make map use quicker and easier, e.g. getting a default map, changing map parameters, carrying out searches and selecting different tools.

4.5.2 Usability aspects of mobile maps

Usability problems of topographic maps on mobile devices were studied in Papers III-IV. It was observed that the user requirements of mobile maps are related to three separate usability aspects: 1) the cartographic design of the map, 2) the GUI of the map, and 3) the mobile device. In addition, the heterogeneity of users and varying use contexts should be taken into account during the design stage (Table 9).

The design of mobile maps should therefore be based on a thorough knowledge of the potential users of the mobile maps and the situations in which the map is going to be used. It is important to meet the real users at the beginning of the project to establish relevant goals for the product so that it fulfils the user requirements.

The study also showed that every map user had specific user requirements, which is why the usability of mobile topographic maps would be greatly improved by adapting map presentation and content according to usage context. More information about the diversity of users and usage situations will be needed for providing users with adaptive maps, which could provide context-related information and assist in use in a given situation. An example of this is a field worker who has to write a message on his mobile device to inform his headquarters about a completed task. Writing a message in the field may be frustrating, and a better solution could be to provide him with a context-aware drag-and-drop menu, from which he could choose the words relevant for that situation and that specific message.

Table 9. Critical usability aspects of designing mobile maps (based on Papers III-VI).

Design aspect	Description
Cartographic design of the map	Cartographic design is the key issue when developing mobile maps. The choice of colours or symbols, map content, and level of detail should be wholly reconsidered compared with previous desktop maps. Maps should be readable, intuitive and aesthetically pleasing. The design could also be personalised to meet the different needs of different map users and map use situations.
Graphical user interface of the map	The graphical user interface also has to fulfil the needs of the user. One map developer stated that the main user requirement for a mobile map used by field workers is that there must be as few buttons as possible in the UI (maximum 3-5), and the users must be able to use the application while wearing gloves. Users must be also able to rely on the fact that the editing they perform in the field using a web-based application will always be stored in the database, regardless of any instability in the systems' Internet connectivity. It is also important that the device carried in the field is not simply a note tool, so that tasks can be finished in the field rather than back at the office.
Device	Both the disadvantages of a mobile device (small screen, limited number of colours available, non-robustness, low screen resolution, batteries running low) and the advantages (dynamic, interactive, adaptable, location aware) bring new aspects to the design, not to mention their capability of supporting advanced visualisations, such as 3D, virtual reality and animation..
Users	There are many different types of map user, each with their own requirements: children/elderly people, tourists/GIS specialists, etc. The question of cultural differences, including languages, is an issue to be taken into account when designing internationally used maps. User tasks may also vary a lot; for example, some may use the mobile map for orienteering in the forest, and others may use it for locating tourist attractions in an unfamiliar city.
Use context	Mobile maps can be used outdoors or indoors, for navigating in the forest or for tourist navigation in an urban area. A good mobile map design is therefore based on a thorough knowledge of the potential situations in which maps may be used. The mobile use context should be studied beforehand to compile realistic user requirements, and also during the process to ensure that the design is suitable for the use context.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

The present thesis gives an insight into UE aspects of interactive maps, specifically web mapping sites and mobile maps. The study was initiated to assess the suitability of UE methods in the development of interactive maps, and to examine the user requirements for interactive maps.

However, there are limitations to this study, as plenty of other web-based maps, such as animated web maps, online atlases, collaborative web maps, professional GISs and car navigation applications, were not considered. Although some of the results may be fully applicable to the other applications as well, it can be expected that each of them may also have their own user requirements. The topic should be further studied. Furthermore, although the interview study presented here gives a preliminary idea of how UE is currently applied by map developers, it must be noted that the interviews were carried out only within Finnish companies. It would be useful to repeat the study in other countries to see whether the findings support those presented here.

One possible bias in the study is the fact that the web maps included in the evaluation were well known and widely used. It could be expected that they have fewer problems than more unfamiliar applications because of their popularity and because there are likely to be a lot of resources behind them. Usability evaluation of the web mapping sites nevertheless identified a lot of usability problems, a considerable number of which were considered to be major ones. If this is the situation with web maps that are used every day by a large number of people, it would be interesting to investigate the usability of smaller, less familiar map applications. This study did not seek to do so, and the topic should be investigated in the future.

Furthermore, interpreting maps and locations is a subjective experience. For example, one of the participants commented: “I searched for London, and wondered what the criterion for the city centre was? And how should the centre be represented on the map?” The use of terms like ‘location’ and ‘place’ was also criticised because they are not objective terms, but always dependent on who is using the term. The challenge for future research is to find out how the needs of different user categories could be better met by web maps, so that map use tasks could be more easily carried out by a variety of people. Psychology and cognitive sciences are also relevant aspects to be considered in map design: how the users behave, interpret and interact with maps.

Some of the test participants had hardly used any types of map at all, and the use of the web maps was especially difficult for them. This is understandable, since maps can be difficult to use in any case, because they deal with complicated spatial data and may allow a lot of interactivity between the user and the map. Some of the users did not realise at all that the map scale could be changed or that searches could be carried out for different objects on the map. The challenge remains to design sites that people can use and in which they can make meaningful search queries without getting frustrated or without facing a lot of problems in using them. Further study of this is required.

Another challenge for the developers is to attract people who have never used a map at all, and specifically to help them realise the variety of maps available and their functionalities. The use of these maps will depend on whether the user perceives any benefit from using them. The observed lack of guidance on these sites needs to be addressed.

Interactive maps often offer links to different additional services (such as hotels and tourist attractions), but since these are links to their own web pages, they either have their own map interface or no map at all. If a user wanted information on how to use the underground rail network to get from one tourist attraction to a hotel, at least three different maps and services had to be opened at the same time: an underground route map, a map with hotels on it, a map with tourist attractions on it, and perhaps even a base map for combining all this information. If all of these have their own maps with different scales and visualisations, users will find it difficult to combine all the information. The best way would be to have all these embedded in the same map service, though this could prove quite difficult. Another way would be to have harmonised maps and UIs between different services. This is one of the usability challenges for designing future web maps.

Some of the web mapping sites have been in existence longer than others, which may bias the results of this study. It may be that users were attracted by the newer ideas, which may thus have received more positive comments. On the other hand, some users may value traditional types of service because they are used to them. The results may also be affected by the fact that some users are used to a particular type of map and try to do things the same way with another service. This was especially clear when discussing the different search criteria of the sites. Different people search things differently; some people are used to making web searches with search engines and also want to carry out map searches in the same ‘free’ manner. Others may not be so used to the web environment and need more structured/guided searches.

Consequently, application providers should be able to respond to the different levels of user needs and provide users with flexible systems. In many cases the GIS software packages are complicated and difficult to use, and without user training they can often remain on the shelf. Partly because of this, some of the emerging applications provide more guidance and are mainly designed to be used by non-professionals. They look more like standard ‘office’ style applications that most people are familiar with.

Integrating usability techniques into different types of software development processes is considered challenging from the developers' point of view. In order to support map developers in adopting usability methods in their product development, further research is required on how to apply these methods in map application design. Methods need to be further developed to suit the interdisciplinary nature of mobile map projects. Established map use research is to some extent still applicable, but it should be developed to suit the purposes of today's interactive, dynamic and location-aware maps. Therefore, a more systematic comparison of which methods should be used, and in which way, should also be carried out.

CHAPTER 6

SUMMARY

A number of studies have concluded that UE methods have a fundamental role in the design of maps for new technical environments involving entirely new ways of interacting. Despite this, no research has been reported on how map developers currently conduct their product design. The product developers have to operate in a challenging interdisciplinary field, and applying methods from other research disciplines may not always be straightforward.

This thesis addresses the underlying principles and methodologies that are important for the further development of map-specific usability guidelines and techniques. The aim was to study the different aspects encountered when using UE methods with interactive maps.

First, a state-of-the-art study was carried out to investigate how familiar map developers are with usability methods, and to consider the benefits and challenges of bringing these methods into the map development process. Second, a usability evaluation was conducted for four web mapping sites in order to see whether there are usability problems in the current design, and if so, to examine which parts of the site they are related to and how they could be avoided. Third, the UCD process and the different UE methods were used in developing a mobile map service, and at the same time information was gathered experiences with the methods in practice. The fourth research goal was to gather information from each individual study included in this thesis and to draw conclusions about the benefits, disadvantages and challenges of including UE methods in map design. The fifth objective was to gather information from each study to give a general idea of the existing (and ideal) characteristics of user-friendly interactive maps.

The experiences were consistent with the hypothesis of the study: UCD and UE methods appeared to be relevant for the design of interactive maps. The interviews with map developing companies showed that UE is slowly being incorporated into the design of maps. As expected, UCD was seen to be important for the development process. Five main reasons were stated for including the usability aspect at the design stage: 1) the user requirements were especially demanding, 2) the system was used in a challenging situation, 3) the user tasks were unfamiliar to the designers, 4) the usage situation was unfamiliar to the designers, and 5) the application was targeted at a large number of users. Most companies are interested in implementing a UE approach, but the problem is a lack of resources and insufficient knowledge of how to implement this type of approach. However, there was also positive experience of bringing usability methods into the design process. For example, it was thought to be an advantage in helping to gain market share and increase the saleability of a product.

Through a usability evaluation of four web mapping sites, user requirements for web maps were identified and discussed. It was concluded that the main aspects requiring attention in the design of web maps are: 1) user interfaces (visualisation, layout and functionality), 2) maps (visualisation and tools), 3) search operations (logics, default settings, results, route searches and visualisation of results), and 4) help and guidance provided to users. As map services are decidedly visual in nature, distractive advertisements and messy user interfaces were observed to be particularly detrimental for these sites. This does not only refer to the user interface aspects of the site, but also the maps.

In addition to web maps, the design of mobile maps must be based on an understanding of the context of use if user requirements are to be met. This was the conclusion of the third research topic. Mobile maps are used in mobile situations, where users are trying to find their way in an unfamiliar environment. New technological possibilities and restrictions create potential for new design approaches, and the UCD approach can therefore be used as a method for collecting information about users, their tasks and use contexts, thereby increasing designers' knowledge and supporting innovativeness. By including a usability approach at the product design stage, while also taking into account the diversity of users and their tasks, and the characteristics of the maps, product developers could design products that have a higher quality of use. In the study, a theory was put forward concerning use contexts relevant for mobile map use, based on the identified user requirements. A way of providing context awareness on maps in order to improve the usability of mobile maps was also developed and evaluated.

The concluding remarks of the thesis are set out with reference to the question the suitability of usability methods for map design and the user requirements for interactive maps. The fourth major outcome of the study was the identification of the advantages, disadvantages, and challenges of incorporating UE methods into map design. Lack of resources and a lack of knowledge on how to use methods from another discipline were considered to be among the challenges.

User requirements for different types of interactive maps were identified and discussed in relation to the fifth research goal. Preliminary ideas on what makes a usable interactive map were also discussed. One of the central findings was a realisation of the relevance of user-friendly interactive maps based on true, meaningful user requirements. This is especially important for new technology applications, since user requirements may not be the same as in traditional environments. Different ways of identifying user requirements and understanding what usability means in a new technological, multimodal, mobile, ubiquitous context or in distributed computing settings can provide essential knowledge for designers. Identification of the possible pitfalls in existing web maps and in maps on mobile devices allowed recommendations to be given about how to design interactive maps that are easy to use and attractive to the different groups of users.

This study gave preliminary perspectives for designing interactive maps using usability engineering methods in design. Map applications are often large and complicated systems with a large number of different functions and with access to large databases. It is a challenge to consider all these aspects in the interactive maps design process: how the map should function, how should it be visualised, how the map should relate to the map service and how different devices with varying screen properties should affect the map design? The characteristics of interactive maps enhance the need to provide more detailed design guidelines and discussion of the methods to be used. This topic should be studied further.

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