CARTOGRAPHIC USER RESEARCH IN THE 21ST CENTURY: MIXING AND INTERACTING

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Abstract
This article gives an overview of how the mixed methods approach can be implemented in cartographic user research. Mixing methods can serve many different goals and can be used in a variety of settings (e.g. simultaneous or sequentially; in controlled laboratory experiments or in a realistic – possibly field-based – structure). First a theoretical overview regarding these goals and settings is presented, which are then demonstrated through a number of case studies. These are recent user studies conducted in the field of cartography and geographic information systems. Most importantly, the benefits of implementing a mixed method approach in these different settings are illustrated to indicate their value for future studies.

Keywords: *Cartograhpy, User Research, Mixing Methods, Case Studies*

INTRODUCTION

At the beginning of the century, Kraak (2001) defined a rough web map classification based on how the map is or can be used. He distinguished between static and dynamic maps on the one hand and between view-only and interactive maps on the other hand. Today, however, almost every map on the Internet is ‘clickable’ and produces dynamic responses such as animations or videos. Moreover, the line between ‘map maker’ and ‘map user’ has become very vague since the introduction of Web 2.0, facilitating the creation of volunteered geographic information (VGI), mashup maps (e.g. with social media data) in the context of neocartography (Turner 2006; Field 2008; Haklay et al. 2008; Hudson-Smith et al. 2009; Batty et al. 2010; Field & O'Brien 2010; Kraak 2011; Cartwright 2012). Because of the increasing amount of digital cartographic products, based on fast evolving technologies, it is of utmost importance that these products maintain a link with their actual end users: their requirements but also their (cognitive) capabilities (Cartwright 2012; van Elzakker & Griffin 2013).

Cartographic user research can be approached from two different angles: focussing on usability issues of a specific product or focusing on the user’s cognitive issues. In her PhD, Bleisch (2011) makes the distinction between *in vitro* and *in vivo* research approaches. *In vitro* research approaches are hereby focusing on perception and cognition and are characterized by mainly quantitative research methods which are employed in controlled experiments and analysed through statistics. *In vivo* research approaches focus on the evaluation of specific applications through case studies, with a tendency to employ qualitative research methods. These latter studies are characterized by an increasing level of context, tactic knowledge and (data and task) complexity (Bleisch 2011). One can indeed make a distinction between qualitative and quantitative research methods, but there is no strict one-to-one relation with the *in vivo* and *in vitro* research approaches.

When conducting user research (*in vitro* and *in vivo*) it is of utmost importance to select the most appropriate research method to measure the variables or factors under investigation. However, one must keep in mind that, as Carpendale (2008) perfectly states, “methods both provide and limit evidence”. Therefore, it can be good practise to combine several methods, as the evidence that one method provides can cover the limitations of another. In this context, a mixture of qualitative and quantitative methods is often advised (e.g. Jick 1979; Kaplan & Duchon 1988; Brannen 2005; Polit & Beck 2010). The advantages of mixing methods can be brought down to three main elements: complementarity, triangulation and expansion (e.g. Carpendale 2008; Bleisch 2011).

This mixed method approach is not new (e.g. Jick 1979; Kaplan & Duchon 1988), but it has only recently been introduced in cartographic user research (e.g. Çöltekin 2015). In the next sections, we aim to present a number of case studies related that implement a mixed method approach to illustrate their gains in different settings.

MIXING METHODS IN CARTOGRAPHIC USER RESEARCH

As can be derived from the review of Nivala et al. (2007), usability research is slowly being integrated when considering the development process of cartographic products. Since that review, this has only gained importance, but the number of digital products that have been released in mean time known an even steeper increase. What is more, in the context of validity, users should be able to interact with the (cartographic) products as they would normally do. Especially in the light of the fast technological evolutions, it is essential that the dynamic and interactive nature of the cartographic product can be implemented in user studies. Consequently, mixing methods in user research – both *in vitro* and *in vivo* – is gaining importance to be able to obtain useful, valid and reliable results. In the next paragraphs we present different settings in which a mixed methods approach can be used in the context of cartographic user research. Finally, a number of case studies are presented in cartographic user research to illustrate the gains that can be obtained.

Mixing Sequentially or Simultaneously?

Mixing methods can be done in two settings: simultaneously or sequentially. Mixing sequentially refers to the situation when different experiments are conducted and their outcomes are linked to each other. These experiments are often conducted in a larger context: the outcome of one experiment is only one part of the puzzle to reach a main research objective. Typically, the separate experiments focus on different aspect of this main objective, each using the most appropriate method to study the specific research question at hand. However, to make inferences on the level of the main research objective, the outcomes of the different experiments need to be linked. Even within the same experiment, it is common to sequentially mix different methods: questionnaires of often used in a pre or post experiment setting to gather individual characteristics of a participant, independent of the main method used during the experiment (Carpendale 2008). Simultaneous mixing refers to situations when data from multiple methods is gathered at the same time: e.g. thinking out loud while the participant's eye movements are being recorded, recording eye movements and mouse actions. Examples of both settings will be provided in the case studies.

Complementarity: Covering the limitations of a single method

Every methods has its limits regarding the measurements and evidence it can provide. Nevertheless, the limits of one method might correspond to the core measurements that are provided by another. This is also stressed in the PhD of Bleisch (2011): mixing methods with "complementary strengths and nonoverlapping weaknesses" (Johnson & Onwuegbuzie 2004, p. 18). For example, users' might perform a certain task in a certain system very fast (thus efficient), which gives a positive impression on the usability of the system. Nevertheless, if the users indicate (e.g. in a post-study questionnaire) that they found it frustrating to work with the system, its usability is questionable. Because of the distinction between qualitative and quantitative methods, they fit well in the "complementary strengths and nonoverlapping weaknesses"-strategy. A good overview of the distinction between qualitative and quantitative research methods is given by Nielsen (1993) and by Carpendale (2008). Quantitative methods are – because of their controlled nature – characterized by a high level of generalizability and precision. Qualitative methods are used in a holistic approach which enables studying the interplay between factors in the most realistic setting. It results is very rich data sets, which are typically very labour intensive to collect and analyse. Nevertheless, Carpendale (2008) stresses that qualitative methods are already commonly used in laboratory experiments (or *in vitro* research), such as questionnaires with open questions.

Increase Validity and Reliability

Carpendale (2008) discusses three important factors related to all types of user research: generalizability, precision, and realism. Some of these concepts are also linked to the issue of validity of user studies. Generalizability corresponds to external validity, which is related to he question to what extent the results of the study are applicable in another context (situation, users, etc.). Realism is linked to ecological validity, or the question whether the experimental settings sufficiently reflect the actual situation. Precision is related to how definite one can be about the level of control (measurements and factors) during the study. This is associated with measurement validity (are we really measuring the proposed dependant variables?) and reliability (are the recordings consistent and repeatable?). Measuring the same factor through multiple different methods allows to verify whether the same conclusions are derived from the different sources, which increases the validity and reliability of these conclusions.

Targeting Different Elements of Usability

When looking at *in vivo* research approaches, usability is the key element (e.g. Nielsen 1993; ISO 1994; Bevan 1995; Hartson et al. 2003; Hornbaek 2006; Rubin & Chisnell 2008). Usability is defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 1994; Earthy et al. 2001). Consequently, when evaluating the usability of a product, the context in which the product will be used need to be implemented and the appropriate end users need to be selected as participants. Both these elements are related to the realism of the study. Besides effectiveness, efficiency and satisfaction, other factors that influence usability are considered, such as memorability, learnability, accessibility (e.g. Nielsen 1993; Rubin & Chisnell 2008). Roth et al. (2015) consider the interplay between three U's: user, utility and usability. Nivala et al. (2007) did a review on the implementation on usability engineering in the development of map services. They found and slow but rising trend, but concluded that most map making companies lack the knowledge to implement it in their processes. In order to be able to evaluate the usability of a product, it is clear that different factors need to be considered: Is the system effective? Is the system efficient? Is the user satisfied when working with the system? Are sufficient utilities available for a certain user? Is the system suitable for novice users? How steep is the learning curve for the system? etc. There is no single method that can provide data to evaluate all these factors; typically a specific method focusses on a specific factor. For example: efficiency is measured through completion times, effectiveness through scoring the participants' answers and satisfaction through questionnaires (e.g. Nielsen 1993). Mixing methods fits in the strategy of complementarity and expansion. Complementary methods need to be selected so that one methods covers the limitations of the other. Because of this, multiple factors that attribute to usability can be evaluated, which is linked to expansion.

Mixing throughout the User Centred Design life cycle

User Centred Design (UCD) is closely related to usability engineering (e.g. Nielsen 1993). The UCD life cycle originates from software engineering, where it is adopted when developing a certain product. The user is involved in the different stages of the development process in order to be able to align the product with his needs as best as possible. These different phases are presented schematically in Fig.1. In a first crucial phase, the user's requirements need to be gathered. This can take the form of, for example, focus groups, interviews, questionnaires, etc., resulting is a very rich qualitative data set. This is used as input for a basic initial prototype, which is again evaluated with the user's to verify if this corresponds to the needs that were gathered. In a number of iterative cycles, the product is redesigned and evaluated until the user's needs are met. In the final stages of these evaluations, the focus shifts from general needs to details in the product's usability which contribute to its efficiency (e.g. completion time), effectiveness (e.g. error rate) and satisfaction towards the user. Consequently, this shift in focus corresponds with a shift in methods from qualitative to quantitative. During the past decade, researchers in the field of cartography and geographic information systems have recognized the benefits of this approach (Nivala 2007; van Elzakker & Wealands 2007; Haklay & Nivala 2010; Ooms 2012; Roth et al. 2015).

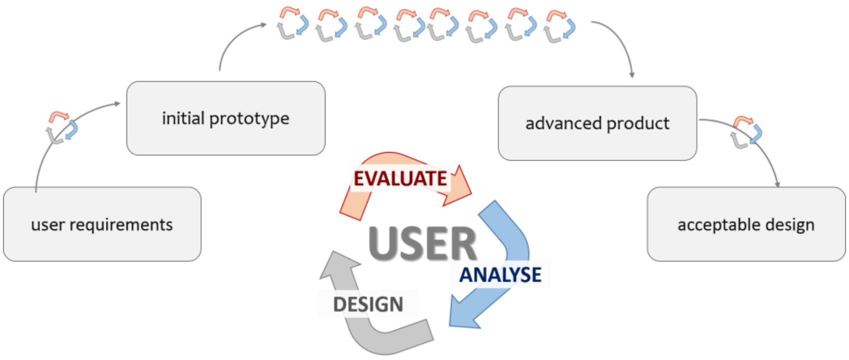

Figure 1. Schematic representation of the UCD-life cycle

Targeting Different Cognitive Processes

Processing (visual) information follows a number of cognitive steps supported by the available cognitive system (e.g. reading, interpretation, analysis, working memory, long term memory, etc.). A good overview on this can be found in (MacEachren 1995; Slocum et al. 2001; Montello 2002; Matlin 2009; Montello 2009). Some researchers have focused on factors that influence these processes, such as personal differences (age, gender, expertise), differences in the map design (e.g. saliency of certain map objects) and external influences (e.g. Hegarty et al. 2010; Popelka & Brychtova 2013; Ooms et al. 2015). Nevertheless, technological evolutions have also impacted significantly how the information is presented to the user and especially, how the user interacts with the information. Still little is known about the influence of these highly dynamic and interactive visualization on the user's cognitive systems and its limitations (van Elzakker & Griffin 2013; Hall et al. 2014). Nevertheless, specific cognitive processes need to be measured by specific methods. In order to obtain insights in the interplay between there processes these measure need to be combined, resulting in a mixed method approach. Also in these type of experiments, a distinction can be made between subsequent and simultaneous mixing to target different cognitive processes that occur simultaneously or in a sequential order. Both settings will be considered in the case studies.

CASE STUDIES

The case studies below illustrate the importance of mixing methods, but also the need for implementing realistic stimuli and tasks in the experiments. The gain in this approach can be found in the fact that the combination of methods results in more than just a sum of its parts.

Covering Weaknesses (Complementarity)

In an experiment conducted by Ooms et al. (2012), eye movements were complemented by, among others, the recordings of mouse actions. These latter recordings had two purposes: providing additional information (task completion times) and covering the limitations of the eye tracking recordings (correctness of the answer). During the experiment, a number maps – consisting out of a basic background on top of which a collection of labels were depicted – were presented to the participants. Only the (position and contents) of the labels were different in the stimuli. Five target labels were listed on the right side of the stimulus and the participants were asked to locate these on the map. In order not to disturb their natural search behaviour, they could chose the order in which the task was executed. However, using eye tracking alone, the experimenter cannot be certain if a target label was found. For example, the participant may have looked at one of the target labels in the map, but he was searching for another target label; or, the participants' gaze was directed towards the target label on the map while searching for this label, but he/she was actually not interpreting/processing the map's content at that moment. Therefore, participants were asked to click a mouse button to indicate that they found a label. The authors could have instructed the participant to click on the label in the map to indicate where the label was found, but this actions would have disturbed their cognitive processes. Similarly, the participants could have been asked to press a specific button (e.g. 1,2,3,4,5) to indicate which of the target labels was found, but this also requires additional cognitive thinking. By comparing the timestamp of the mouse action with the position of the recorded eye movement at that moment, it could be determined if the correct label was found, keeping the disturbance of the cognitive processes as limited as possible.

A second case can be found in the experiment of Ooms and Dupont (2016), in which eye tracking was used to study the participants' attentive behaviour while performing a task in GoogleMaps, using only panning. Different eye movement metrics are combined (e.g. fixation duration, saccade length) to make comparisons between the influence of, for example, map view and satellite view. However, these quantitative data sources only give limited insights in why the differences that were located occur. In order to cover this limitation of quantitative research, it is good practise to complement it with quantitative methods, such as thinking aloud. This gives insights in the participants' unfiltered thoughts while solving a task, and thus the cognitive processes associated with the recorded measurements. A significant difference in multiple eye movement metrics was found between the satellite and map view, but only from the thinking aloud data it could be derived that the satellite view corresponded to a chaotic search pattern as users experienced more difficulty to find the needed information.

Verifying a Method's Validity

Combining different research methods is often integrated in user research in order to cover the limits of a single method and triangulate findings across the registered data sources. Nevertheless, two different methods can be capable of capturing the same factors. Implementing both methods in the same user study gives the possibility to verify the results across the two data sources: are the same conclusion derived? Below we present two experiments in which a similar combination of two methods is employed. However, in these studies the authors aim to verify the (ecological) validity of a 'new' method by comparing the obtained results with these obtained by an established method.

The focus of the first experiment is on the identification of landmarks in indoor environments, conducted by Viaene et al. (2016). Participants had to complete a route in a building by following the experimenter. While moving through the environment, the participants' eye movements were recorded (using a mobile eye tracking device) and they were asked to formulate route instructions out loud (audio recordings using a headset). After the experiment, participants had to answer some general questions regarding the route they had taken and personal characteristics. The goal of the experiment was to compare the landmarks that were derived from the verbalized route instructions, with those derived from the eye movement data (fixation duration on the objects). Furthermore, these findings were linked with theoretical probability values for each of the landmark categories. The authors noted a strong correlation between the landmarks identified in the verbalised instructions and those identified using the eye tracking recordings, however variations regarding to the type of landmarks (e.g. structural) were found.

In the second experiment, the validity of mouse movements used as a proxy for eye movements was evaluated. Demšar and Çöltekin (2014) state that mouse movements can be recorded much more easily than eye movements because of the the latter's costs (e.g. equipment) and time investment (single user testing). Consequently, the goals of the experiment is to investigate how both measurements are linked. During a controlled experiment in a lab setting, participants had to complete a visual search task (find a certain region in a map) while their eye and mouse movements were recorded. They had to click on the map where they found the region the targeted region. The authors registered two types of responses: the mouse did not move until the target area was found, or, user the mouse movements reflect the gaze movements in terms of 'distance to the target area'. Further research on comparing the actual trajectories of both recordings is still needed.

Mixing Throughout a Project

The case study on which we will focus is the PhD of Susanne Bleisch (2011) "Evaluating the appropriateness of visually combining quantitative data representations with 3D desktop virtual environments using mixed methods". This research is structured into three research aims which are linked to three stages (I, II and III). Each stage is linked to different hypotheses or propositions/questions.

In this study, Bleisch aimed to measure the appropriateness of visualisations, which is based on the evaluation of efficiency and effectiveness. Efficiency is measured using task completions times and efficiency using error rates. Furthermore, utility is considered to evaluate how well task goals are met and is associated with insights that users could obtain, which are measured by rating their complexity, plausibility and noting the participant's confidence. During the study, the hypotheses will be evaluated, but at the same time a deeper understanding regarding the use of the 3D virtual environments is targeted. Bleisch states that the evaluation of the hypothesis is typically done using empirical quantitative techniques, while the second goal should be studied through case studies. Therefore, it is proposed to adopt a mixed approach which creates a bridge between *in vitro* and *in vivo* research approaches which results in "complementary strengths and nonoverlapping weaknesses" (Johnson & Onwuegbuzie 2004, p. 18). In the first stage, the hypotheses are tested through controlled experiments (*in vitro*) in a basic setting. The idea is to evaluate whether the selected visualisation is suitable for basic tasks before introducing complexity in terms of tasks, data and context, which is introduced in the next stages. In the *in vivo* approach (stage III), case studies are employed which consider multiple factors in a realistic context to be able to study their interplay. In between both, stage II is subdivided in two steps to be able to gradually increase data (stage IIa) and task (stage IIb) complexity.

Table 1. Stages with increasing complexity from controlled experiments to case studies

Stage	Description
I	• Evaluation of 3D virtual environments versus static 2D quantitative graphics • Recordings: Task completion time (efficiency), errors (accuracy/effectiveness), comments from participants
IIa	• Evaluation of 2D bar displays with multiple bars, depicted on a landscape, with more context • Recordings: Answers to tasks (open questions), confidence ratings and task completion time through an online questionnaire
IIb	• Evaluation of 2D bar displays with multivariate data • Same context information as in stage IIa • Same task complexity as complex tasks in stage IIa • Recordings: Insight reporting, confidence ratings and time to arrive at the insight
III	• Evaluation of 2D bar charts in virtual environments in real world settings • Three case studies which show a variation regarding important influencing factors • Propositions and research questions replace hypotheses • Recordings: answers + time as in stage I, questionnaire on the data set and analysis, report and observations during a semi-structured interview, questions send by email one week after experiment, additional data.

Over these different stages, a sequential mixed method approach is thus adopted to accommodate for the shift from controlled to realistic experiments. The data obtained in each stage is analysed on its own, but certain aspects are integrated across the different stages. This supports both forward and backward comparisons, contribution to the methods' complementarity, expansion of insights and triangulation. By comparing the results across methods and stages, (unwanted) influencing factors can be discovered and potentially controlled. Furthermore, a combination of statistical tests and a holistic view of different settings can be obtained. In the conclusion of the PhD it is stated that "It is appropriate to use a sequential mixed methods research approach with research stages guided by increasingly complex data sets and tasks to gain a holistic understanding of a visualisation technique" (Bleisch 2011 p. 144).

A similar sequential approach is found in the PhD of Kristien Ooms (Ooms 2012) "Maps, how to users see them?". She conducts a series of experiments in which she investigates how map users read and process visual information on digital maps. The first experiments in this work take to form of controlled experiments, recording (multiple sources of) quantitative data (e.g. time measurements, fixation durations, number of fixations per second) on a basic map design: same simple background, only variations in the labels. The participants were asked to locate a number of target labels in the map. In this case the focus was on the efficiency of locating the labels. In the second set of experiments, more realistic maps (based on topographic maps) were used as stimuli. In this case the user was asked to remember (store) the map's content as good as possible, in order to draw it again later on from memory. In this latter setting, a combination of eye tracking, thinking aloud and sketching was used to get insights in the user's cognitive processes from a more holistic view point.

Usability Evaluations

This case study from Brodersen et al. (2001) covers an experiment that has been conducted to evaluate whether a newly proposed symbology for a topographic map series results in an improved usability. The key element of usability in this case is the map reading tasks, which should be 'quick', 'certain' and 'correct'. The first item is measured through the time needed to solve the task, and corresponds to efficiency. The second is evaluated by registering the participants' eye movements (visual behaviour) and observations of the participant. The last corresponds to effectiveness, which is measured using a scoring system: number of correct answers on the tasks. A video camera was used to record and as such observe the whole scene (including non-verbal behaviour such as pointing or nodding). Furthermore, the participants' voice was recorded on the videos as they were asked to think-aloud during the test. A questionnaire was used to retrieve personal characteristics of each participant. Finally, the participants were debriefed with an interview in which they could give a subjective evaluation of the two maps, including difficulties to solve the tasks, ease of use of the maps, possible improvements and a personal evaluation on their performance. In this mixed methods settings, the tasks were chosen as such that they covered all standard map reading skills (localization, decoding of single symbols, combined decoding and interpretative understanding). Based on the correctness of the answers and the applied strategy, the experimenter attributed a performance score to each task a participant completed. In the analyses correlations between time and performance (score and strategy) and between eye movements (fixations) and performance (score, time and strategy) are determined. In their conclusions, the authors stress the importance of a combined use of eye tracking data and instructor ratings, as they both confirm and supplement each other, which supports "deeper and more objective insights into map reading". Furthermore, the mixed method approach is considered an interesting setting for other studies related to map reading and design.

In her PhD, Annu-Maaria Nivala conducts a usability evaluation of topographic maps on a mobile device to get insights in the context of use, usability issues of existing applications and design principles (Nivala 2007). The test was executed in a real life setting, a national park where they had to complete an orienteering task using the mobile topographic maps. Two usability methods were used in a simultaneous mixed setting (observations and thinking aloud) and a third one was applied at the end of the experiment (interview). The field test proved to be a strong asset as real life influence on map use were discovered, which are difficult to foresee in a (controlled) lab experiment. In their conclusion, the author lists the benefits of using UE methods in the map design process (e.g. saving expenses, meeting user requirements, understanding context of use, positive impression of the company), but also a number of challenges (e.g. lack of expertise and resources).

Application of UCD

User Centred Design is an interative process, passing several phases of user evaluations, until reaching a product that is of an acceptable level of usability for the end user. Each of these phases require a specific methodology to evaluate the product of prototype at hand, resulting in a (sequential) mixed method approach. This is nicely illustrated in the PhD of Ioannis Delikostidis (Delikostidis 2011) "Improving the usability of pedestrian navigation systems". In this PhD, the different phases of a UCD-approach are visited, including the different evaluation methods. A good overview of the different methods that can be used in different stages (analyse requirements, produce design solutions, evaluate designs) is presented on p.78.

The startpoint of this research is a review of existing mobile pedestrian navigation applications, including user tests that are conducted using these systems. These tests typically involve solving a certain task on the application. Based on this review, conclusions regarding best practises on a number of items are made (e.g. presentations of landmarks, presentation of contextual information, off-line or online use, interactions). Next the users' requirements are gathered. In this phase, a profile of the potential end users of the system is constructed and an experiment was conducted in the field. Participants had to fill out a questionnaire at the start of the test regarding individual characteristics. During the test they were asked to think out loud with audio and video observations and logging of the screen. Using this setting, the all participants' actions are recorded and can be linked to their thoughts. The test was concluded with a semi-structured interview which allowed to probe for issues when differences between participants were noticed. Finally, the participants were asked to sketch their mental map of the route they had followed, which also gives interesting information regarding the objects that were stored in memory and issues related to that. Because many different data sources were recorded simultaneously, a system was constructed that dealt with the synchronisation of all sources.

Based on the input from the requirements analyses, which investigated the users' behaviour in a real life setting, a (conceptual) prototype was designed and implemented. From the previous experiments, a number of scenarios are laid out, from which subsequent steps (common in all scenarios) regarding the use of the mobile navigation system are derived. These steps are then translated into user tasks that should be available on the system. Through the development of use case diagrams, considerations of the system design requirements, interface functionalities, inclusion of landmarks, design of icons and the prototype development environment a prototype was designed "LandNavin".

Next, in the light of the UCD approach, the prototype was integrated in a field-based user study to evaluate the proposed solutions and to which degree the user requirements were fulfilled. Also for this study, the importance of the real-life context is stressed, which cannot be obtained in a lab setting. During the test, participants had to navigation fom a starting point to an unfamiliar destination, using the system. Different scenarios were implemented to reflect different real use and user context. During the navigation process, the goal was to record the participants' reactions, action performance, feelings, mental processes and feedback as this is vital information to improve the system. A similar setting as in the previous stage was used – using thinking aloud with audio and video recording – but this was complemented with eye tracking data. Using a mobile eye tracking system, it could be recorded precisely where the participant was looking at on the mobile navigation device and in the environment. The obtained data sources were analysed in depth regarding the users' performance (effectiveness) on different (sub-)tasks. The questionnaire probed the participants for their opinions on a number of design solutions (landmarks, dual view, pop-up information, etc.). Based on these outcomes a number of solutions to improve the design are proposed.

In her PhD, Annu-Maaria Nivala evaluates the suitability of the UCD approach regarding the development of a mobile map service (Nivala 2007), focussing on three different aspects: (1) context of use and identify usability issues (2) user requirements and (3) application of different evaluation methods during the development process. Initial testing (development and development of prototype) included heuristic evaluations. The actual use of the map was evaluated using thinking aloud and screen logging, which resulted in a list of design related positive and negative items. Furthermore, an intuitivity test (through email correspondence) was conducted with different age groups to evaluate the symbols: recognition and comments on the symbol's design. Regarding the cartographic design, expert evaluations were conducted several times throughout the process. She concluded that the UCD approach was an important element in the development process and contributed to the level of innovateness of the design.

Finally, Roth et al. (2015) also focus on the application of UCD in the development of cartographic products. They start with a thorough overview of the UCD approach, including different types of evaluations methods with recommendations regarding when (or when not) to use them. Next they focus on a case study "the User-Centered Design of *GeoVISTA CrimeViz*". An iterative UCD approach was used, with (1) need assessment interviews, (2) an expert-based think aloud study on the alpha release, (3) a formative online survey to gather feedback on the beta release, (4) a summative online survey after the full release. In their conclusions they discuss the benefits of implementing a UCD approach, such as efficient use of development resources, covering all issues by applying overlapping evaluations, improvement of adoptation of the interface by the target users, etc .

Studying Cognitive Processes

The first case study focusses on a user study in which different cognitive processes are studied simultaneously through the application of multiple research methods. The article of Maggi et al. (2016) describes an empirical study which goal is to explore information extraction from animated maps (air traffic displays in this specific case) considering different map designs and user characteristics (e.g. spatial abilities, training). In the study, participants had to detect a moving target object among other (moving) objects. The accuracy and completion time of the participants' responses were recorded. Simultaneous psycho-physiological recordings create the possibility to triangulate and cross-validate the data sets (Maggi & Fabrikant 2014b, 2014a) and as such obtain insights in their cognitive processes while solving the task:

eye movements; electrodermal activity (EDA) which indicate emotional responses using a skin conductor; brain activity through electroencephalography (EEG). EEG signals indicate the level of arousal in participants; a high arousal suggesting both alerted cognitive and motivated emotional states. Furthermore, participants' self-reports (SSSQ questionnaire) allows cross-validating the psycho-physiological data (i.e., engagement, distress, and worry). Response accuracy can as such be linked to emotional states (e.g. level of arousal) or levels of engagement, distress en worry are compared across to different display times and user groups. These states can also be compared to the recorded eye movement data to evaluate saccadic eye-movement-related potentials (SERP) and eye-fixation-related potentials (EFRP). Nevertheless, the authors mention a number of methodological challenges regarding the synchronisation of the triangulated data: different signal latency durations and different temporal resolutions of the methods.

The second case study in this context implements a sequential mixed method approach to study different cognitive processes and covers the last experiment that was conducted in the PhD of Kristien Ooms (Ooms 2012). The goal of this experiment was to get insight into how visual information, on the one hand, is processed and stored in memory and, on the other hand, is retrieved from memory later on. Therefore, different subsequent cognitive processes are targeted during the study, using a sequential mixed method approach. The first part of the experiment (described in Ooms et al. (2013b) focusses on the interpretation process, whereas information retrieval is the key process in the second part (described in Ooms et al. (2013a)). The whole process is illustrated in Fig. 2. Furthermore, comparisons between the expert and novice map users' performances are made and influences related to the stimuli's content are considered in this.

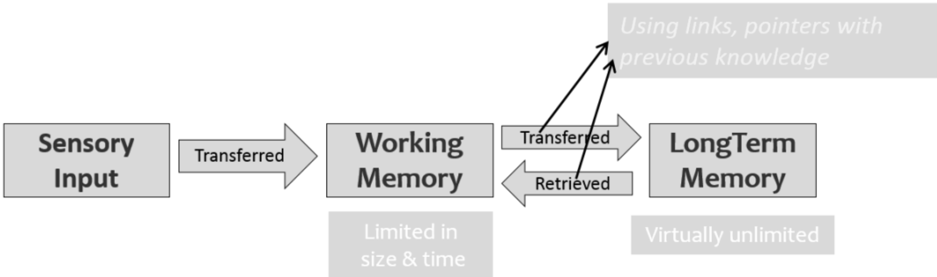

Figure 2. Schematic representation of the cognitive processes and structures when storing and retrieving (visual) information

During the information processing phase, participants are asked to remember the presented map (store in memory) as good as possible. During this reading and storage process, the eye movements of the participants are registered and analysed across the stimuli and participant groups (experts and novices). Special attention is devoted to spatio-temporal analyses of these eye movements linked to the objects depicted on the map. During the information retrieval phase participants had to sketch the map they studied from memory. Additionally, they were asked to say out loud any thought that came into mind. A scoring system was applied on the resulting drawings to get insights how many elements were present and if they were located correctly. The thinking aloud data gives insights in how these objects are structured in memory: descriptions, links to other objects, links to previous knowledge, etc. This data set is analysed in several ways. First, the individual words are counted and their use (frequency) is compared between both user groups. In order to capture the context of these words, sentences are also analysed using a hierarchical coding scheme. Finally, the order with which the objects were mentioned (and drawn) indicates the strength of the presence of the objects in the cognitive system (memory). Using this mixed method approach revealed clear differences in how expert and novice users process, store and retrieve visual information and map objects.

CONCLUSION

This article presents an overview of the mixed method approach in cartographic user research. This approach can be applied both in controlled laboratory experiments and more realistic (field) experiments. The benefits that can be obtained in the different settings are illustrated through a number of case studies regarding recent research in the field of cartography and geographic information systems. The main reasons for combination can be brought down to complementarity (covering weaknesses), expansion (covering more factors), and triangulation (investigating links between recordings and thus factors). Furthermore, the validity and reliability of the recordings can benefit significantly by simultaneous recordings. Especially in the light of modern interactive and dynamic products it is of utmost importance to record all factors that could influence the usability of the systems towards the user (and his cognitive processes), including the interplay between factors. Mixing methods is essential to be able to tackle this research challenge.

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