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A mixed methods research approach for 3D geovisualization evaluation

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The mixed methods research approach

Method description and application:

When research questions are complex, as is often the case with the evaluation of geovisualization techniques, then a mixed methods research approach has great potential. Such an approach combines elements of qualitative and quantitative research approaches to achieve deeper understanding of the aspects under study. Single method studies in isolation tend to suffer from one of two problems: problem (over)simplification - for example where controlled experiments conducted with a large number of participants lead to restricted but often generalisable conclusions; lack of generalizability, which is the case whereby an issue is explored more fully – for example through a case study with a small number of expert users, giving deep insights into a technique or application that are not normally easily generalised. A mixed methods study design, however, should "*strategically combine qualitative and quantitative methods, approaches, and concepts in a way that produces complementary strengths and nonoverlapping weaknesses*" (main principle of mixed methods research according to Johnson et al. 2007, p. 127). They regard 'complementary strengths' as the use of different data collection methods and analysis techniques that allow the research question to be answered. The 'nonoverlapping weaknesses' concept refers to the combination of methods with different weaknesses to accommodate potential study design weaknesses with alternative evidence. Applying these principles effectively is an important source of justification for mixed methods research (Johnson and Onwuegbuzie 2004). Mixed methods research is often partnered with the philosophical worldview of pragmatism (e.g. Johnson and Onwuegbuzie 2004). If we look more closely at many geovisualization studies that have been undertaken, we find that quantitative approaches are often combined with qualitative ones in a pragmatic manner. Most often this is for triangulation which is one of the five purposes for conducting mixed methods research (Greene et al. (1989) cited in Johnson and Onwuegbuzie (2004)). The other four purposes are "*complementarity (i.e., seeking elaboration, enhancement, illustration, and clarification of the results from one method with results from the other method); […] initiation (i.e., discovering paradoxes and contradictions that lead to a re-framing of the research question); […] development (i.e., using the findings from one method to help inform the other method); and […] expansion (i.e., seeking to expand the breadth and range of research by using different methods for different inquiry components.*" (Johnson and Onwuegbuzie 2004, p. 22).

Advantages and disadvantages:

The main reasons for employing a mixed methods research approach are that they lead to richer data and may result in deeper understanding (Bryman 2008). Words and pictures may be employed to add meaning to numbers or numbers may add precision to words and pictures (Johnson and Onwuegbuzie 2004). Additionally, it may be possible to answer a more complete set of research questions as more than one method can be used. Conclusions from mixed methods research may be based on stronger evidence as findings from different methods are combined. An extensive list of strengths and weaknesses of mixed methods research can be found in (Johnson and Onwuegbuzie 2004). Onwuegbuzie and Leech (2004, p. 770) call it the "*the real 'gold standard' for studying phenomena.*" On the other hand, mixed methods research is intense and difficult to conduct as it needs knowledge about different methods and techniques and a wide range of skills and thus may be difficult to be carried out by a single researcher. Additionally, it is more time consuming and expensive and there are more opportunities to make mistakes and more potential sources of criticism as formal methods for combining methods are difficult to define and still under development by

mixed methods researcher.

Typical mixed methods research designs:

Mixed methods research is a combination of traditional quantitative and qualitative research methods. The details of many of these methods can be found elsewhere (e.g. in other chapters of this book). Johnson and Onwuegbuzie (2004) emphasise that the research questions are key within a study. The design of a study should incorporate any combination of appropriate methods in any order needed to effectively answer the research questions. Additionally, they proposed a typology for mixed methods research. This typology is quite simple but still helpful as it addresses many of the decisions a mixed methods study designer faces. A first design subdivision is made according to when the mixing takes place along the research process. Johnson and Onwuegbuzie (2004) differentiate between mixed-model designs (mixing takes place at or within all stages of the research process) and mixed-method designs (including quantitative and qualitative phases into the research study) whereas there are many subtypes of these two. Additionally, study designers have to determine the balance between quantitative and qualitative methods, which may not be used with equal emphasis. An important influence on the outcomes of the study is the decision as to whether the different methods are used concurrently or in sequence. While concurrent studies may make it easier to integrate or mix the data and findings, subsequent use of different methods has the potential for using one part of the study to inform the next. However, in the latter case it is important to consider the impact of different orderings on the outcomes of the study (e.g. using a questionnaire as preparation for a case study will yield different results than using a case study to inform the design of a subsequent questionnaire). As detailed in the application description below, we believe that mixed-method designs employing and combining different quantitative and qualitative research settings may be most valuable for the pragmatic evaluation of geovisualization techniques.

Study participants:

The number, selection and recruitment of study participants are dependent on the goal of the study, the different methods employed, and the application domain. A mixed methods research approach can use the same or different participants for each part of the study and/or each different method used. Additionally, the goal and application domain of a study greatly influences the availability of suitable participants to be tested. For example, a study that aims to evaluate the effectiveness of a specific navigation feature within Google Earth can potentially access a large user base. However, a study that aims to explore the effectiveness of a geovisualization technique for the generation of insights into a particular data set needs to evaluate with data and/or visualization experts who are much rarer. Details about different sampling strategies that might be used for mixed methods research can be found in Teddlie and Yu (2007).

Mixed methods research costs:

As mentioned above when discussing disadvantages, mixed methods research studies are potentially more expensive and time-consuming than monomethod studies. They include different sub-studies or phases which are conducted concurrently or sequentially. While concurrent studies may be completed in a shorter time they may need more manpower as potentially several researchers are working on the study at the same time. Sequential studies can be carried out by a single researcher but may take longer. Additionally, to achieve the principle of complementary strengths and nonoverlapping weaknesses the study might need to collect redundant data through the use of different methods. The integration of the different findings, especially if they are conflicting, may be complex. Furthermore, as several methods for data collection and analysis are employed mixed method researchers need to acquaint themselves with different techniques and tools. Large mixed methods research studies certainly call for a team of researchers with a wide range of different skills and potentially also experience of different research domains.

Processing and analysis of data:

For the processing and analysis of the collected data one can potentially employ any known or standard method for quantitative or qualitative data analysis. Most often the mode of analysis may to some degree be dictated by the data collection method. However, it is also possible and sometimes desired that data may not be analysed the 'standard way' (e.g. "qualitizing" quantitative data; Tashakkori and Teddlie 1998). As the 'mixing' within mixed methods research can be done at all or selected stages of the research process (data

collection, analysis and/or inference) special attention has to be given to methods capable of combining the data collected with different methods. Onwuegbuzie and Teddlie (2003) have defined a framework for data analysis in mixed methods research. According to their framework typical stages of the data analysis process are data reduction, data display, data transformation, data correlation, data consolidation, data comparison, and data integration. Details about each part are provided in their book section on the subject, which indicates that the data analysis process may be iterative rather than sequential (Onwuegbuzie and Teddlie 2003). Additionally, Onwuegbuzie and Teddlie (2003) define a taxonomy of mixed methods data analysis techniques starting from the purpose of the data analysis (e.g. confirmatory or exploratory analysis). One of the characteristics of mixed methods research is that the findings of a subsequent phase or alternative method might shed light on a specific issue but also reveal that the data of another phase or method should be analysed differently or additional data needs to be collected. For example in the application case detailed below the experimental setting in the first phase revealed that users are faster and more confident in comparing bar heights in a virtual 3D environment if the bars are framed by a reference rectangle. This reference frame was questioned in the second phase and both questioned and deemed useful in a third experiment. The combined qualitative re-evaluation of the data of all phases shows a more differentiated picture: we can conclude that while the reference frames are indeed helpful for the data analysis they may be considered as having a cluttering effect on data displays when used in an applied scenario and thus demand more effort from the user, resulting in negative feedback being recorded.

Validation:

While discussions about validity and legitimacy of research results, their interpretation and use have a long tradition in quantitative and qualitative research approaches, in mixed methods research the concept of validity is complex and discussion on this issue continues in the community. Dellinger and Leech (2007) propose a validation framework based on validity concepts from quantitative, qualitative and mixed methods research to further this activity and contribute to the validation debate. Helpfully, they also explain how their validation framework may be applied to mixed methods research during the design stage of the study, while conducting the study, for the evaluation of a study or a body of literature or in examining the consequences of using the results of a study.

Publications:

Tashakkori and Teddlie (2003) have edited a "Handbook of Mixed Methods in Social & Behavioral Research" written by notable researchers in the field which is very helpful for the design and evaluation as well as many other topics concerning mixed methods research. An updated edition will be available in July 2010 (Tashakkori and Teddlie 2010). Current research on mixed methods is reported in the Journal of Mixed Methods Research by Sage Publications (http://mmr.sagepub.com/).

A mixed methods research approach case description

Computing resources increasingly enable us to interact with 3D models of landscape and ‘geobrowser’ has become a de facto standard for visualising spatial information on the desktop (Wood et al. 2007). However, elevation may also be important in geographic data analysis especially for data sets collected in mountainous environments and in analytical tasks where altitude needs to be considered to make sense of data. Consequently, the study presented here as example of mixed methods research evaluates a new geovisualization technique, which combines visually abstract numeric data with the surrounding landscape in 3D desktop-based virtual environments. The research aim is to test and explore the suitability of such displays for supporting a variety of (real world) geovisualization tasks. We display numeric data as bars or bar charts within 3D scenes of varying elevation (Bleisch et al. 2008). Such a combination may facilitate the analysis of a data set in relation to altitude and landform - but how do we effectively evaluate such a technique? Much cartographic research uses quantitative approaches, such as controlled experiments, to establish knowledge about cognitive responses to maps (see Montello 2002 for examples). Experiments usually involve large numbers of users, with little contextual information and thus no (or few controllable) influencing factors. In applied research settings very few users are typically involved and qualitative approaches are employed. Much contextual and tacit knowledge influences and enriches these studies and

many influencing factors exist that we cannot or do not want to control (Yin 2003). The complex nature of this study's research questions aiming to explore and understand 'in vitro' and 'in vivo' issues of a new geovisualisation technique call for a mixed methods research approach. We propose a meta-framework that relates studies using research methods that vary along a continuum from perceptual experiments (mainly quantitative, employing controlled experiments and questionnaires) to studies in applied settings (mainly qualitative, employing insight reports (Rester et al. 2007) and interviews) to address our research questions. Such a sequential mixed-methods research setting allows us to use the results of each stage to support and inform the following stage. However, the partial integration of the collected data at the analysis stage of the research process additionally allows inferences to be drawn across all of the methodological research stages. We argue that using complimentary research methodologies (selected from the continuum from controlled experiments to qualitative case studies in applied settings) in line with the mixed methods research principles of 'complementary strengths' and 'nonoverlapping weaknesses' (Johnson and Onwuegbuzie 2004) to evaluate a visualization technique ‘in vitro’ and ‘in vivo’ can help to build an appropriate and valuable 'bridge' of knowledge that draws upon general perceptual characteristics and the specific visual thinking of motivated and informed analysts.

In the selection of the different research methods to be employed to build the 'bridge' we are constrained by a number of influences. One of our research questions requires us to test the appropriateness of specific displays of numeric data within 3D virtual environments. Such a test typically calls for a controlled psychophysical experiment with a large number of users and generalisable results derived through quantitative methods. However, while the results of such a controlled experiment may be generalisable to a larger population of informed users they are not directly applicable to real world application as the experimental setting has to exclude or control many influences that are important aspects in applied settings. Consequently, other research questions require us to explore the utility of this geovisualization technique in real world settings. However, to do this we first need to know if the chosen display method (bar charts) is basically suitable for the display of numeric data within virtual 3D environments. Such an answer can be expected from the controlled experimental setting. Further, as we need to rely on rare data and task experts for the evaluation of the real world settings we are restricted to using case studies involving a few selected real world users and applications. Qualitative case study methods are most appropriate in these circumstances. To bridge the obvious gap between these two sides we employ two more methodological settings. Changes in the characteristics of each of these research settings are driven by increasing context, data and task complexity but minimised to ensure comparability of the results along the 'bridge'. Additionally, the interaction with display and data needs special attention. While most interaction taxonomies (see Yi et al. 2007 for a compilation of interaction taxonomies) combine navigation, data display manipulation and task, we try to separate. The navigational aspect of interaction is kept as standard as possible. Data manipulation is not possible. Tasks are designed using Andrienko et al.'s (2006) functional data and task view which allows a structured evaluation of the results. Focusing on a single data display technique (bar heights in our case) and evaluating with informed users or experts in all research settings gives a broad impression of the responses to this technique from experimental to applied settings that allows for combined and complementary inferences and findings. Research that relies upon related evidence is perhaps less profound in relation to any single aspect of a study than an in-depth analysis of one such aspect in isolation, but it is more holistic and leads to useable results quickly given that it stays focussed and is lead by the proposed research questions. With the ever-increasing amount of data to be analysed and the rapid development and adaptation of visualization techniques it is pragmatic and appropriate to focus on holistic approaches in their evaluation. We argue that the methodological knowledge from this study, in which a mixed methods approach is used to 'bridge' between two common and complimentary means of studying geovisualization users (controlled experiments and case studies), is applicable to other geovisualization design evaluations. It may help them benefit from this complimentarity and overcome some of the known weaknesses associated with each of the individual methods when used in isolation.

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