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The Cartographic Journal

The World of Mapping

ISSN: 0008-7041 (Print) 1743-2774 (Online) Journal homepage: http://www.tandfonline.com/loi/ycaj20

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The Cartographic Journal *Vol. 54 No. 4* *pp. 313–321* *2017*

REFEREED PAPER

Augmented Reality and Maps: New Possibilities for Engaging with Geographic Data

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Among the systems that aim to help users to perform map reading tasks, augmented reality (AR) is one of the most promising. However, the impact of this new technology in terms of acceptance, motivation and improvement of the learning process has still not been sufficiently explored. This study aims to assess the contribution of an AR system for map reading and for improving users' understanding of geographic data. Landscape and census data from New Zealand were used to evaluate the performance of an AR system in an experiment involving 60 participants. Differences in the participants' backgrounds were reflected in the way they completed the task for both printed maps and the AR system and 90% of the participants preferred to work with the AR system rather than with traditional printed maps. Users that had previous experience of the geographical dataset provided performed the task better using only the printed maps, while those without that experience performed better with the AR system.

Keywords: geographical space; 3D relief; computer systems; mobile devices; teaching and learning process; interactive environment; augmented reality

INTRODUCTION

Augmented reality (AR) is a technology that enhances the perception of the real environment by adding virtual information (Azuma, 1997). According to Bobrich and Otto (2002), AR enhances users' interaction and experience in real and virtual environments, and the information transmitted by the virtual objects can help the user to perform real-world tasks. Olsson *et al*. (2012) state that AR is an emerging interactive technology that has gained increasing interest in recent years, making contextually relevant information easily available and enabling new possibilities for interaction with information.

Medicine, industry, entertainment, and other fields have used AR in order to facilitate several tasks (Azuma, 1997; Bobrich, 2003; Cheng and Tsai, 2013; Paelke and Sester, 2010). Yet Azuma's (1997) assertion that the technology presents several challenges because of the many unexplored options and new devices being developed still holds true today.

Alternatively, there are printed maps, with which users can interact intuitively and directly in a natural and familiar way, in the same way as they do with other objects in a real environment (Asai *et al*., 2008; Bobrich and Otto, 2002). However, where printed maps are static and provide limited interactivity, virtual maps are easier to update, can include dynamic content, and may be adapted to suit the needs of particular users more easily. Virtual maps, therefore, support analyses that are not possible with printed maps and also provide advantages for visualization, allowing map users to see more than the printed features (Paelke and Sester, 2010).

The integration of the properties of printed maps with virtual information thus combines the best of both worlds and can be highly attractive. AR enables user interaction with the real environment – e.g. handling a printed map, a smartphone or tablet, for example – and the potential of computer processing in real time to interact with the virtual information (Adithya *et al*., 2010; Bobrich, 2003). The dynamic representation of 3D terrain, location of virtual objects, animations and interactivity are characteristics of the digital world that can be superimposed on a printed map (Adithya *et al*., 2010). Put another way, AR techniques can be used to 'boost' paper maps digitally. As Reilly *et al*. (2006) have asserted, enhancing paper maps by combining virtual data is appealing because the maps by themselves are artefacts from the real world that are already a source of information. Paelke and Sester (2010) have also emphasized that using AR and paper maps together show features in an interactive

DOI: 10.1080/00087041.2017.1411417

visualization, and open up some interesting possibilities that need to be further explored.

Azuma (1997) recognizes that AR is a promising field for psychophysical studies and points out the need to conduct psychological experiments that explore performance issues concerning questions about perception. He also states that enhancing a user's understanding is the purpose to be achieved by an AR system, but it is necessary to determine whether AR is a truly cost-effective solution for a proposed application (Azuma, 1997). Later, Azuma *et al.* (2001) states that research concerning human factors – as well as cognitive and perception studies – can help to guide the development of AR systems and that the ultimate challenge of an AR system is social acceptance, but less attention has been paid to these fundamental issues. Indeed, concerning user-testing and AR, Wang *et al.* (2013) provide a review of the state-of-the-art of research published between 2005 and 2011, in a survey involving 120 papers. The authors found, however, that only 22.5% (27 articles) involved a considerable practical analysis of human factors.

In general, contributions such as Azuma (1997); Asai *et al.* (2008); Bobrich and Otto (2002); Bobrich (2003); Paelke and Sester (2010) and Adithya *et al.* (2010), argue that AR contributes positively to user performance when dealing with real situations. This paper addresses the question of whether an AR application can help users during the map-reading and data-learning process. The hypothesis is as follows: if AR is a more effective visualization process, the user will be able to solve map-reading tasks more easily and with more interactivity and efficiency. A related question is that of whether the user's previous experience with geographic data influences in some way the contribution that AR makes to the user's experience. This study therefore describes the construction and evaluation of an AR system prototype for map-reading tasks to determine whether AR provides any real improvement in helping users to solve geographical problems.

BACKGROUND

Milgram *et al.* (1994) explain that the transition from real to virtual environments can be described as a continuum, where AR is a part of mixed reality (MR) (see Figure 1). Virtual Reality technologies completely immerse users inside a virtual and synthetic environment, and, once immersed, users cannot see the real world around them. In contrast, AR systems enhance the real world with virtual objects, producing a mixed scene where real world and virtual objects are combined (Azuma *et al.*, 2001). Or, as Nilsson and Johansson (2008) have stated, the main characteristic of AR interfaces is the 'fusion of worlds', in which virtual information is added to the real world. The co-existence of virtual

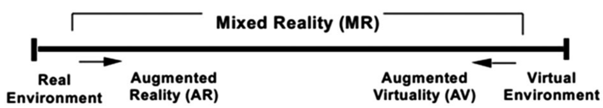


Figure 1. The reality-virtuality continuum (Source: Milgram *et al.*, 1994)

objects and the real environment constitutes a MR, where users can interact with the environment and virtual information from appropriate systems and in real-time (Arvanitis *et al.*, 2009).

Huynh *et al.* (2009) state that, over the past few years, advances in the capabilities of 3D graphics processing and display technologies in smartphones have made these devices attractive platforms for mobile AR. Olsson and Salo (2011) complement this view, saying that mobile devices such as smartphones and tablets are becoming popular tools and are reasonably priced, and it is expected that the number of potential uses of AR applications will increase significantly over the next few years.

According to Ternier *et al.* (2012), the combination of mobile AR resources and educational situations offer a unique opportunity for joining experimental and practical contexts in the real world. Arvanitis *et al.* (2009) report that the current efforts of technology-enhanced learning, in various fields of science, have improved the prospect of understanding concepts amongst its users. In other words, with the ability to infuse digital information in the real world, AR could help to advance science education (Cheng and Tsai, 2013).

By extension, the application of AR to mapping can increase the interactivity of geographic visualization, since the tool is able to provide a learning environment where the user perceives virtual information overlaid on geographical areas. The combination of a printed map and computer graphics creates a tool for an interactive learning environment, where the user sees enhanced geographical information mixed with the real map (Asai *et al.*, 2008).

There are many examples of the combination of AR and maps for both desktop or mobile platforms, including Billinghurst *et al.* (2001), Bobrich and Otto (2002), Bobrich (2003), Hedley (2003), Reitmayr *et al.* (2005), Reilly *et al.* (2006), Schöning *et al.* (2006), Morrison *et al.* (2009), Paelke and Sester (2010), Grammenos *et al.* (2011), Morrison *et al.* (2011) and Low and Lee (2014). More specifically, the contribution of Halik and Medyńska-Gulij (2017) focuses on graphic variables in AR, aiming to better understand how the public (e.g. pedestrians in the city) perceive cartographic symbols in a mobile AR system.

Although AR has been used with maps and geographic data by these authors, sometimes to evaluate how much it improves users' ability to complete their tasks or the level of the users' acceptance of the new technology, there remain many questions to be answered in this emerging field. Thus, in this paper we discuss the contribution of an AR system from a map-reading point of view.

According to Board (1978) there are often mismatches between the purposes for which a map was conceived and how it is read. He describes the essential tasks needed to enable a person to extract information from a spatial representation of the environment (how to understand and to create knowledge from this), and divides what he calls map-reading tasks into three major segments: navigation, measurement and visualization tasks. The first two segments (navigation and measurement) are the best known. However, individuals rely upon the visualization tasks in order to understand geographic space and what is represented (Board, 1978; MacEachren, 1995; Ware, 2012). Therefore, this

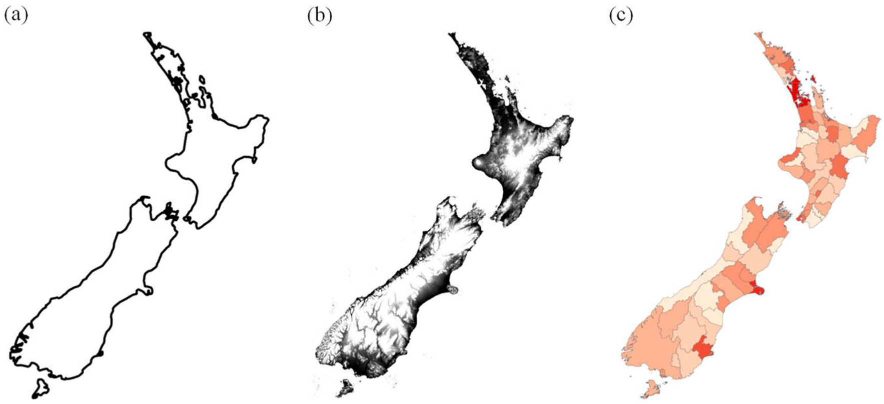


Figure 2. Printed maps used. (a) Outline; (b) altimetry (SRTM); (c) number of inhabitants from the 2013 census

paper aims to investigate the extent to which AR facilitates this map-reading and data-learning process, with especial focus on the role of visualization.

METHODOLOGY

The AR system

The AR system proposed in this study consists of overlaying virtual information over traditional, printed maps. A digital camera is used to capture the real environment information as an image, which is visualized on a screen. The system computes the user's orientation, movements and attitude relative to the physical hardcopy of the printed map (using real-time image processing) and superposes virtual data onto the image of this hardcopy map.

One of the main issues in AR is computing the relative position and attitude of the user within the real environment. Positioning systems, such as a global navigation satellite system (GNSS), gyroscopes, and/or image processing and computer vision algorithms, have aided the AR system developers to process and overlap the information in real time. GNSS and gyroscopes are normally used outdoors. Solutions based on image processing and computer vision – which can be used for indoor applications – compute the relative position and attitude based on the recognition of features in the real environment.

There are several image processing tools supporting the development of AR systems, such as the ARToolKit, which is a widely used library with rapid and relatively accurate tracking (He *et al.*, 2006). However, when using this library, there is the need to add markers on the map, as per Bobrich and Otto (2002), Bobrich (2003). These markers are normally square patterns that are recognized by the system and used to compute the user's position and orientation. As these markers are not natural elements of a map, they can disrupt the reading of the map, or even disturb the map's layout.

One way to solve this problem is to use alternative methods, where the map itself can be used as a known pattern to support the computation of the position and orientation of the user. For example, Qualcomm Vuforia is a library that enables such an approach. The AR system used in this study uses the Qualcomm Vuforia library in the Unity3D environment.

For this experiment, three printed maps were used, as shown in Figure 2. These printed maps comprise an outline of New Zealand (Figure 2(a)), altimetry information derived from Shuttle Radar Topography Mission (SRTM) data (Figure 2(b)), and population data using the most recent census (2013) of each territorial authority (Figure 2(c)). New Zealand was chosen as the subject area because one of the authors was very familiar with the datasets used in the study and these were unfamiliar to the participants interviewed, thereby avoiding the possibility of participants' previous knowledge influencing the results. The maps used are at 1:8,000,000 scale, which allows New Zealand to fit onto an A4 format (210 × 297 mm).

The virtual information used and presented on the AR system is shown in Figure 3. This comprises the terrain model in 3D (Figure 3(a)), the map of the number of inhabitants in 2D (Figure 3(b)), and the map of the number of inhabitants on the terrain model in 3D (Figure 3(c)).

The interviews

According to Štěrba *et al.* (2015), research into usability of cartographic products may be divided into two main areas: the usability of individual maps as forms of representation and the usability of complex geographic information systems; which include both cartographic representation and the overall technological approach. The first area focuses on the evaluation of various cartographic methods in terms of the purpose of the resulting visualizations (in accordance with the context) and a target group of participants. The second area includes the usability of tools for manipulation and interaction with cartographic products or geographic information systems. Given that our focus is on the way in which the user works with an AR system and the functions and control tools she or he uses, this second approach is adopted for this study.

Since we are conducting an evaluation to verify whether an AR system facilitates map reading and data learning when compared with a conventional map reading process, we designed the experiment as a usability test. The reason for this is that users are required to interact with the system in order to accomplish the designated tasks. In usability

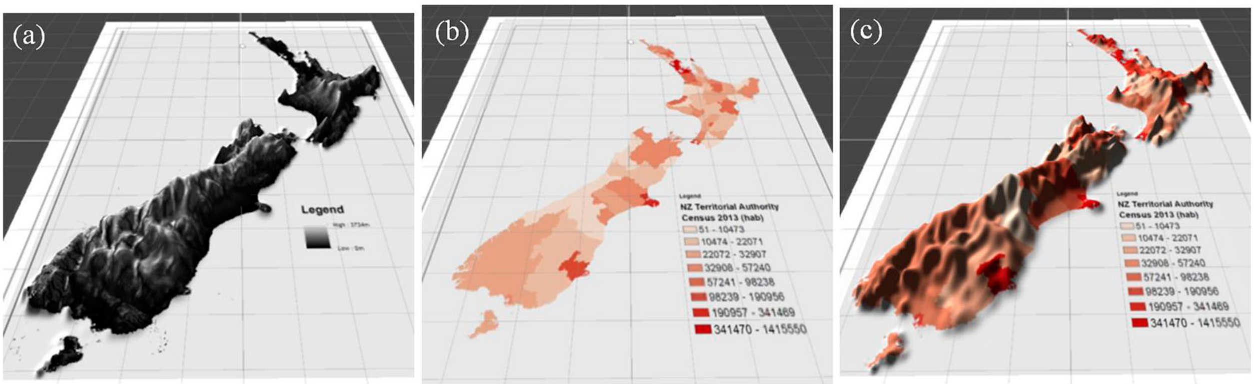


Figure 3. Virtual information presented by the AR system: (a) 3D landscape; (b) number of inhabitants from the 2013 census 2013 in 2D; (c) the number of inhabitants over the terrain, in 3D

experiments, a qualitative approach may be adopted, since we are more interested in evaluating the use of the system and how it can improve knowledge acquisition, rather than in the evaluation of static maps. Usability studies typically adopt a much smaller number of respondents than experiments for more general purposes, and thus we limit our sample size to a total of 60 (10 in each group), as 10 is a reasonable number for usability studies (Preece *et al.*, 2015). This approach was also used by Behrens *et al.* (2015) and Koletsis *et al.* (2017).

Interviews were conducted in order to ascertain the participants' backgrounds in using AR and map-reading tasks. All the participants were asked before the test to provide details of their academic degree and major subject and their level of knowledge and experience in GIS and AR, all by self-reporting and by a verbal description of their level of experience. We considered pre-testing to establish GIS and AR experience, but we preferred to use self-reporting in order to avoid any potential influence of pre-tests on the final results (since pre-tests would have resulted in respondents gaining some experience).

A total of 60 people were interviewed, according to the following categories: 4 geoinformatics professors, 27 undergraduate cartography students and 29 graduate geoinformatics students. The participants' experience was as follows:

- None of the undergraduate students had experience with GIS or AR systems (students from the first year of a Cartographic Engineering programme);
- All professors had experience with GIS, and two of them had experience with AR;
- Most of the graduate students had experience in using GIS (26 of 29), and one of them had familiarity with AR (1 of 29).

For the study, the groups were separated according to their GIS experience rather than their academic degree since the latter alone could not accurately reflect the knowledge of the participants' skill in reading, using and understanding the geographic data or maps. GIS experience, on the other hand, might better reflect the abilities of the user with maps and geographic data. It was found that some graduate participants had no previous experience at all with GIS or geographic data manipulation (some of them had just started their courses), which can cause them to be said to have the same ability to read and understand the map or geographic data as the undergraduate students. Thus, the experienced participants with GIS numbered 30, and those with no experience with GIS, 30.

The main question that the participants were asked was about the relationship between the landscape and the population of New Zealand. They were also asked to identify the location of the most populated districts and whether there was any relationship between the population density and the landscape. Specifically, the two questions were: (1) 'What is the relationship between the landscape and the population of New Zealand?'; and (2) 'Can you identify the locations of the most populated districts and whether there is any relationship between these and the landscape?'. We would consider correct any participants' answer that showed that they realized that the flat or coastal areas are more populated in New Zealand. It is important to report here that none of the participants had been to New Zealand before, or had prior knowledge of its population density or New Zealand's territorial authority divisions.

To answer the questions, the participants were randomly divided into three scenarios, according to the available material they were given. The first scenario (S01) had to perform the task using only the printed maps (Figure 4(a)). The second scenario (S02) was instructed to perform the task using only the printed map with the outline of New Zealand and the AR system (Figure 4(b)). The third scenario (S03) could use the AR system and/or any physical printed maps (Figure 4(c)). Thus:

- Scenario 01: Used only the physical printed maps;
- Scenario 02: Used only the outline map and the AR system;
- Scenario 03: Could use all the physical printed maps and the AR system.

The scenarios were therefore designed to allow a comparison of the different approaches. While the AR system offers the option to see the layers separately or with overlaid terrain and population information, the display of both datasets on the same, flat paper map made interpretation very difficult, as the shaded and coloured areas conflicted with one

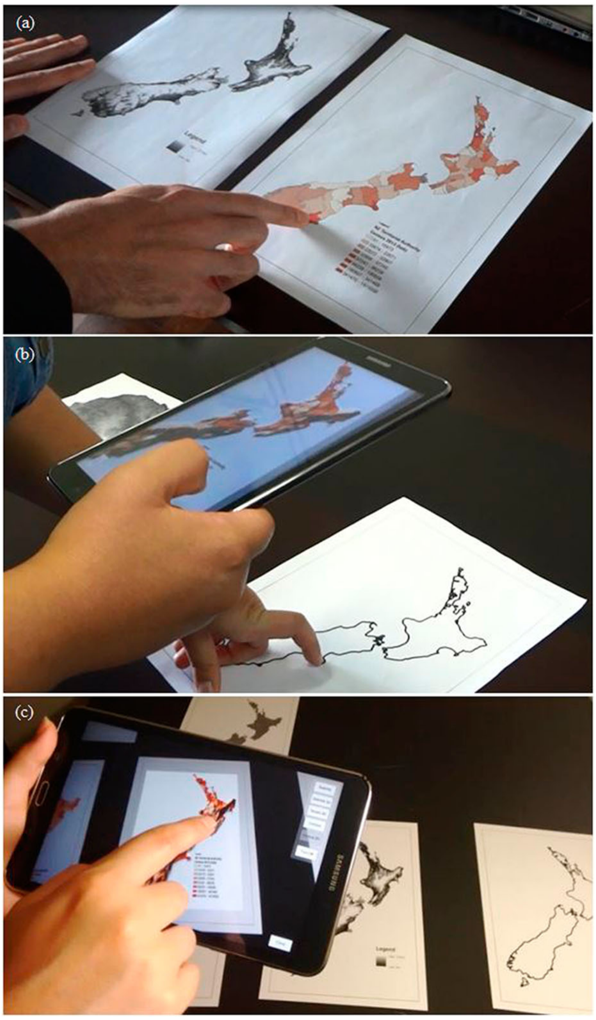


Figure 4. Performing the tasks according to each scenario: (a) Scenario 01 (only the printed maps); (b) Scenario 02 (contour map and the AR system); (c) Scenario 03 (all printed maps and the AR system)

another. Although this may have affected the results, since for the paper maps people had to do more interpretation work and so experienced a greater cognitive load than for the AR, this does reflect the real situation when maps are used rather than AR. It is more difficult to visualize complex and overlapping data on flat paper maps. Furthermore, it could also be argued that users of the AR system had a greater cognitive load in that they had to learn to use a new technology.

Hence, in this study, the participants were distinguished by two groups (i.e. with or without experience in GIS) and completed one of the three scenarios (S01, S02 or S03). The participants were selected randomly for the scenarios, with the same distribution between the groups. The number of participants in each scenario can be seen in Table 1 and an example of each scenario used in the test is presented in Figure 4.

The participants were not told that the time taken for them to provide their answers would be recorded, in order to ensure that they did not feel under pressure to respond quickly or to make rapid decisions. All interactions were

Table 1. The number of participants in each scenario

Scenario	S01	S02	S03	Total
Experienced	10	10	10	30
Not experienced	10	10	10	30
Total	20	20	20	60

recorded in order to measure the time taken for each participant's response, the subsequent verification of the response, and the way that each participant chose to answer. The recording of audio and video for the tests was made using a smartphone.

The hardware that participants used to complete all tasks was a Samsung Galaxy Tab4 (tablet). This device was selected because it presents a good screen size (7′) and resolution (1280 × 800 pixels) and has enough memory (1.5 GB RAM) and processing capability (1.2 GHz, quad core) for the AR application (app) to perform well. As the AR app runs on any Android device (including smartphones), further tests could be done in future using newer, faster or bigger tablets, or on devices with smaller screen sizes.

After finishing the experiment, the tasks performed under the other two scenarios were explained and presented to participants, and they were asked whether they would prefer to use the method of another scenario or if they thought that another scenario had advantages in terms of the available material.

RESULTS

Participants with GIS experience

First, we present an analysis of the time used to solve the task amongst participants with GIS experience. It is important to mention that, although the working time varied according to the participant, all those with GIS experience answered the question correctly. The variation in time taken to answer the question of each scenario (S01, S02 and S03) was computed and is shown in the whisker plot in Figure 5.

According to Figure 5, the participants with GIS experience that only used the printed maps (Scenario 01) were faster than the others. Scenario 03, where participants were allowed to use all the available information (i.e. AR system and all printed maps), was slower. However, the fastest answer was recorded in Scenario 02, just taking 9 s. This can be explained by the fact that the participant that answered faster than all the others was a professor with both GIS and AR experience.

Although Scenarios 02 and 03 (i.e. those that used the AR system) were slower, almost all participants preferred to work in the AR scenarios, as shown in Table 2. Just two participants preferred to work in the traditional way, using the printed maps. Nine participants preferred Scenario 03, saying that having more information available to consult is better, even though a minority of the participants in Scenario 03 had consulted the printed maps during the task – normally the participants in Scenario 03 had just consulted the AR system. Eleven participants preferred

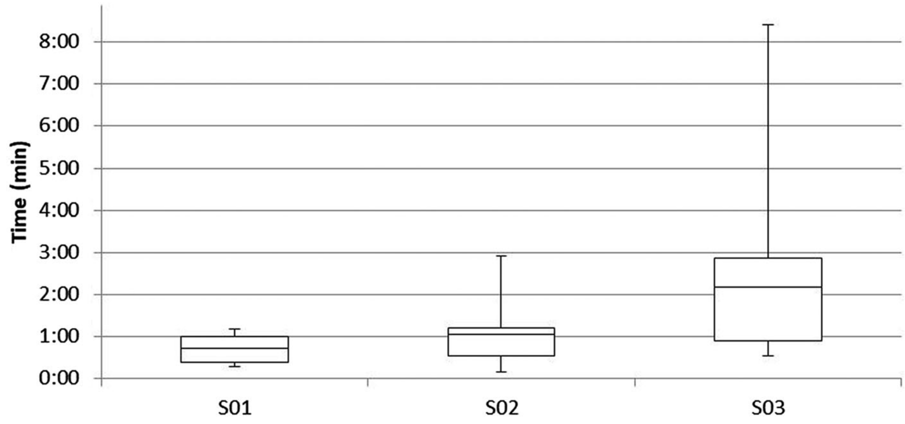


Figure 5. The time taken to answer the question of each scenario for the participants with GIS experience

Table 2. Preference of scenario for the participants with GIS experience

Preference by participants with experience with GIS	S01	S02	S03	S02-S03	Total
Quantity	02	11	09	08	30

Scenario 02, saying that if they have the AR system, they did not need additional information on the map. Eight participants said that they preferred either of the scenarios that uses the AR system.

Nevertheless, one participant reported the need of at least one map, which could be the outline map, to serve as spatial reference in the geographic space. They reported that the task could not be achieved by using another symbol (representation) instead of the map. Therefore, if there is just one symbol to be used by the AR system, such as a square, it could make users lose their spatial reference. The background map enables a geographic reference, which would not be possible if just a marker or square were used.

Despite taking part in Scenario 03 (which provided the AR system and all the printed maps) only one participant used just the printed maps to solve the problem. Only after finishing the test did they begin to play with the AR system to see how it works. The participant stated that for them it was easier to use the map because they had spent many years working directly with maps.

It was also noted that some participants needed more time when dealing with the AR system, because they were playing with the system before answering the question, moving the tablet to see the virtual model, walking around the printed map, tilting the AR system almost 90° in relation to the printed map just to see the landscape in perspective, or taking the hardcopy maps off the tablet's field of view to see how the system would react. Also, some participants were trying to understand how the system works – if the virtual information were registered over the hardcopy maps – before answering the question.

In summary, for this experiment, it is possible to see that participants with GIS experience worked better with the traditional printed maps, although the majority preferred the scenarios that could use the AR system.

Participants without GIS experience

The results were different for the class of participants without GIS experience. Firstly, it is important to state that three participants in this group did not answer the question or answered it incorrectly. Given that one of these participants was in each scenario, it is not possible to confirm whether the AR system or the printed map was the source of difficulty they encountered in solving the task. Their time was not measured.

The variation in the time taken to answer the question in each scenario for the group of participants without GIS experience is presented in Figure 6. The slower scenario was the one that used just the printed maps (Scenario 01). Scenarios 02 and 03 performed very similarly, but Scenario 02 had the fastest answer of all.

For this group of participants and this experiment, it is possible to see that using the printed maps required more time because the participants had to interpret and combine the information; an action that requires some cognitive processing. On the other hand, when the participants used the AR system, the information was easily available; especially when they needed to combine the census data with the relief. According to some participants, they 'saw the information in an easier way than merging the information of the printed maps'. So, it is possible to conclude that using the AR system reduced the participants' effort to combine the information from different maps, making the problem easier to solve. Also, some participants reported that seeing the information in 3D using the AR app (the terrain layer and the census data over the terrain) helped them to understand the relationship between these layers. One user reported 'by seeing the information in 3D, it was easier to read and realize the data, which is more difficult to read from a flat paper map.'

Regarding the preference of these participants, more than 90% of them preferred the scenarios that could use the AR system. The results about the preference of the participants are synthetized in Table 3. Just two participants preferred working with the printed maps. Five preferred Scenario 02, i.e. with the AR system and the outline map. Eight participants answered that they prefer any Scenario that includes the AR system; they could therefore use just the outline map to solve the problem.

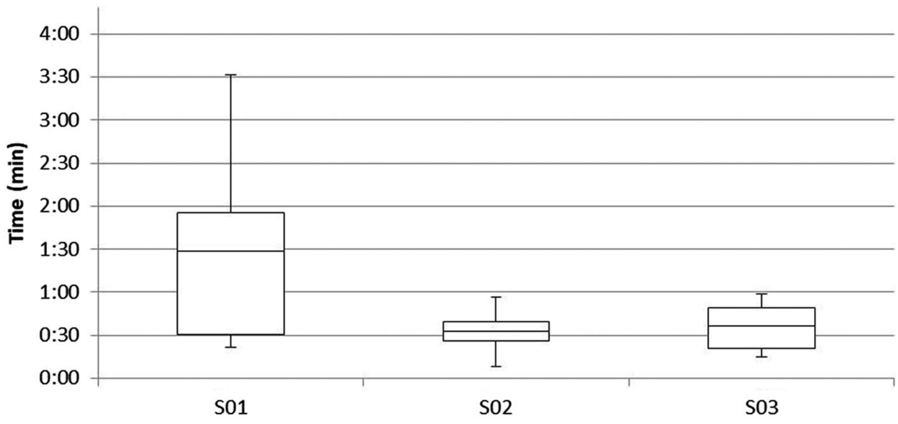


Figure 6. The time taken to answer the question of each scenario for the participants with no GIS experience

Table 3. Preference of scenario for the participants with no GIS experience

Preference by participants with no experience with GIS	S01	S02	S03	S02-S03	Total
Quantity	02	05	15	08	30

In addition, 15 participants said that they preferred to work with all the information together, the AR system and all the maps (Scenario 03). Nevertheless, in practice, almost all of them used just the information in AR system, and they used it over just one map (any map, normally the closest one). Just a few participants in Scenario 03 consulted the printed maps but most of them stayed with the AR system. They used the printed map merely as a reference in the real world, but they did not use the printed map as source of information to get the answer. It is possible to affirm that the behaviour of these participants was similar to those in Scenario 02, who used just the outline of New Zealand. They did not consult the maps as a source of information to solve the question, just to register the virtual information over a geographical reference.

Several of the participants who did not have any GIS and AR experience prior to the test showed enthusiasm when the AR system was turned on. When they first realized that the app responded to their movements they smiled and some used positive expressions (e.g. 'Cool!' and 'Awesome!'). At the end of the test, a few of these participants showed interest in discussing what else could be done with AR and whether it could be applied in other fields, data, formats, places, and so on. This response was unexpected and thus was not included as a variable in the initial analysis, but it was clear that they were more motivated when working with the AR system.

Overview

In an overall analysis, it is therefore possible to conclude from this study that the participants who had experience with maps and geographic data (i.e. those with GIS experience) performed the task faster using the printed maps, and those ones without previous experience performed faster using the AR system. However, we should point out that the participants with GIS experience sometimes 'lost' time playing with the system, trying to understand it more deeply before answering the question, which may have artificially extended the measured duration of the task. This interaction between the users and the system should not be considered a 'waste' of time, as it indicates that participants were enjoying the experience and trying to explore the map, data, and system. Yet, as time was a variable analysed in this study, participants took more time to answer the question, thus increasing the overall time for their scenario.

With respect to the participants' preferences, just four preferred to work with the printed maps (less than 10% of the participants interviewed). More than 90% preferred to work with the AR system over the printed maps.

Twenty-four participants reported that they would prefer to work with all the maps and the AR system (Scenario 03), explaining that they prefer the scenario with more information. However, while some participants were working in Scenario 03, they used just one printed map, only to support the AR system. Therefore, it is possible to conclude that while they liked to have many options to consult, they really used only one map to act solely as a spatial reference. So, we conclude that these participants could be added to those in Scenario 02, since they would use AR to solve the proposed problem using the printed map just as a spatial reference.

Sixteen participants preferred any Scenario that could use the AR system. It is possible to assume that they are interested more in the virtual layers and possibilities of the AR system rather than the printed map. Hence, these participants probably would use the printed map just as a reference and just the outline map would be enough. Moreover, some of them preferred Scenario 02, saying that the outline map could be enough as long as they have all the information offered by the AR system.

Despite of this comparison between the participants' experience, the scenarios, AR system, and methodology proposed, it is possible to claim that some of the results found in this study are similar to those found by others. For example, Grammenos *et al.* (2011) found similar evaluation results with an AR prototype, where the overall opinion of the users ranged from positive to enthusiastic. Also, McGee *et al.* (2002) found that the participants preferred their prototype to their paper maps because they gained access to computing and did not have to give up what the paper maps had to offer.

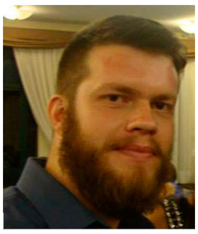
CONCLUSIONS

In this study, the performance of a sample of 60 participants has been analysed to evaluate the contribution of the AR system for reading and analysing maps and geographic data. Content specific to New Zealand was adapted to the platform, allowing participants to engage in visualizing and analysing spatial variables of the country. The study shows that the AR system helped participants to better understand the local topography and statistical data.

A comparison between the maps and the AR system developed revealed that the people we tested preferred to use the AR system to complete the task given. Those with some cartographic background were more efficient in dealing with printed maps, while those without previous experience were faster with the AR system. A common observation was that a base printed map is necessary and useful for orientation purposes and to provide a spatial reference in the real world.

Although more tests should be done to evaluate the AR system and users' attitudes more deeply, this research affirms that the AR system has clear efficiency benefits for inexperienced map users. Furthermore, participants of the test embraced it enthusiastically, with 93% preferring the AR system over printed maps. Overall, it was noticed that the AR system developed in this study helped the participants to solve their tasks, especially for those with no background in or experience with GIS and the professional manipulation of maps. Further tests should be conducted to compare the use of traditional printed maps, GIS, and AR systems as well as other forms of geographic data visualization including Virtual Reality and multimedia presentations, as well as to try to measure the increase in motivation, efficiency, accuracy and precision of users when dealing with these sources of information or technologies.

BIOGRAPHICAL NOTES



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ACKNOWLEDGEMENT

The authors would like to thank the participants that took part in the experiments as anonymous users.

FUNDING

The authors would like to thank the financial support of CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico)/Brazil – Process 459300/2014-8 (MCTI/CNPQ/Universal 2014), 401264/2014-9 (MEC/MCTI/CAPES/CNPQ/FAPS – Bolsa pesquisador visitante especial – PVE – 2014) and 301980/2014-4.

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