

Article

A User Study of a Prototype of a Spatial Augmented Reality System for Education and Interaction with Geographic Data

Gabriel Henrique de A. Pereira ^{1,*} , João Vitor M. Bravo ²  and Jorge A. S. Centeno ¹

¹ Department of Geomatics, Federal University of Paraná, Curitiba, PR 81530-900, Brazil; centeno@ufpr.br

² Institute of Geography, Federal University of Uberlândia, Monte Carmelo, MG 38.500-000, Brazil; jvmbravo@gmail.com

* Correspondence: pereira.gha@hotmail.com; Tel.: +55-41-985-249-360

Received: 10 July 2018; Accepted: 31 July 2018; Published: 1 August 2018



Abstract: Recent technological advancements in many areas have changed the way that individuals interact with the world. Some daily tasks require visualization skills, especially when in a map-reading context. Augmented Reality systems could provide substantial improvement to geovisualization once it enhances a real scene with virtual information. However, relatively little research has worked on assessing the effective contribution of such systems during map reading. So, this research aims to provide a first look into the usability of an Augmented Reality system prototype for interaction with geoinformation. For this purpose, we have designed an activity with volunteers in order to assess the system prototype usability. We have interviewed 14 users (three experts and 11 non-experts), where experts were subjects with the following characteristics: a professor; with a PhD degree in Cartography, GIS, Geography, or Environmental Sciences/Water Resources; and with experience treating spatial information related to water resources. The activity aimed to detect where the system really helps the user to interpret a hydrographic map and how the users were helped by the Augmented Reality system prototype. We may conclude that the Augmented Reality system was helpful to the users during the map reading, as well as allowing the construction of spatial knowledge within the proposed scenario.

Keywords: map-reading tasks; knowledge construction; Spatial Augmented Reality system

1. Introduction

Augmented Reality (AR) is a technology that enhances the perception of the real environment by adding virtual information [1]. An AR system supplements the real world with virtual objects that appear to coexist in the same space—the real world [2]. Azuma et al. [2] also define an AR system to have the following properties: combines real and virtual objects in a real environment; runs interactively and in real time; and registers (aligns) real and virtual objects with each other. Therefore, it enhances the user's interaction and experience in both real and virtual environments [3]. Medicine, industry, military, entertainment, and other fields have used AR in order to facilitate several tasks [1,4]. Azuma [1] already pointed out that there are several challenges that are still open in this field and there are many unexplored options of new devices, making the AR subject a vibrant area of research. His statement remains valid today, as one may see in Carbonell-Carrera et al. [5] and Carbonell-Carrera et al. [6].

According to [3,7], map users can interact intuitively and directly with a paper map, in a natural and familiar way, like all other things in the real environment [5,6]. However, printed maps are static and offer poor interactive tools [4,7]. On the other hand, virtual maps offer high update potential while

representing dynamic phenomena, as well as being easily adapted to a map-reading task. Virtual maps support analyses that are not possible when dealing with printed maps and they can also provide advantages for visualization [8].

The integration of printed maps and electronic devices combines their benefits and can be highly attractive in the map use context. AR can combine these characteristics (from real and virtual maps), enabling a user's interaction with the real environment (e.g., handling a printed map) and the potential of computer processing in real time [4,9]. The dynamic information of the 3D terrain, placement of virtual objects, animations, and interactivity are characteristics of the digital world that can be superimposed on a paper map [9,10] when AR techniques are applied. So, in other words, AR techniques can be used to complement paper maps digitally [5,6,10].

According to Paelke and Sester [8], applications of AR related to map reading are exciting as well as promising. It is expected that AR can increase interactivity with geographic data and therefore with the geographic space understanding, since it is able to provide a new learning environment. Asai et. al. and Arvanitis et. al. [7,11] report that the current efforts of technology-enhanced learning in various fields of science have improved the perspective of understanding the concepts by users. Also, according to Ternier et al. [12], the combination of AR features and educational situations offers a unique opportunity to experience and application contexts. Wu et al. [13] also stated that research has indicated that AR systems could help their users to develop skills and knowledge in a more effective way. Users using AR could virtually manipulate a variety of learning objects and handle the information in a novel and interactive way.

That is, with the ability to infuse digital information in the real world, AR could be very helpful for science education [14]. But also, as stated by Wu et al. [13], while AR offers new learning opportunities, it also creates new challenges for educators. So, this paper deals with assessing how AR can help users with geographic data interaction and in map-reading tasks [6]. Recently, Carbonell-Carrera et al. [6] have tested the potential contribution of an AR application for improving map-reading skills. These authors found interesting results: 3D technologies have significantly improved the map-reading skills of students, over a 2D relief representation. In this case, students have better interpreted landforms in the 3D maps, especially in the AR application.

In general, researchers [1–4,7–9,13,14] have argued that AR contributes positively to user performance when dealing with real situations, as it was empirically verified by Carbonell-Carrera et al. [5]. But just a few studies have been designed for a real evaluation of how it enhances visual perception for the users [5,6,15]. Therefore, this research aims to assess the effective contribution of an AR System prototype for map-reading tasks. Therefore, in this paper, we discuss the contribution of an AR system for handling geographic data, based on a User-Centered Design point of view [16]. Thus, this research was divided into two main steps: (1) build a prototype of AR for map-reading purposes; and (2) evaluate how the user takes advantage of its use, applying an activity based on a set of tasks and scenarios, in order to obtain a framework of its practical utility in the construction of the spatial knowledge. Based on the results found by Carbonell-Carrera et al. [5,6], the hypothesis we argued was that the AR system would help users to create and/or recreate concepts about the geographic space in an attractive way, with a positive “cost-benefit” relation. The users would be able to modify their previous knowledge while using a new interactive 3D tool for visualizing geographic data.

2. Materials and Methods

In this research, we assessed the contribution of a Spatial Augmented Reality system for education, especially for geographic data interaction and map-reading tasks. Therefore, this research consists of three major stages: the first being the creation of the prototype of the AR system; the second being the investigation of the effective contribution of the developed system for map reading with a user's activities; and the third stage was the analysis of a user's answers, as well as their evaluation of the AR prototype.

2.1. The Augmented Reality System Development

He et al. [17] stated that one of the hardest tasks when developing an AR system is to precisely compute the point of view of the user in real time. Real time computation of the user's point of view can be performed by using computer vision techniques such as the ARToolKit library. This library computes the position and attitude of the camera/user based on the recognition of specific simple markers [17–19].

The process behind the ARToolKit library can be described as follows. A video camera is used to capture images from the point of view of the user. The images are binarized to speed up the process and the marker is searched in these images. Once the marker is detected, the transformation matrix can be computed, because the marker has a known size and orientation. The transformation matrix describes the position and attitude of the camera in relation to the marker, which can be later transformed into the world coordinates system [3].

According to Adithya et al. [9], when using ARToolKit (ARToolworks, Seattle, US), two coordinates system transforms are needed (Figure 1):

1. The Marker Coordinate System to the Camera Coordinate System (3D to 3D);
2. The Camera Coordinate System to the Screen Coordinate System (3D to 2D).

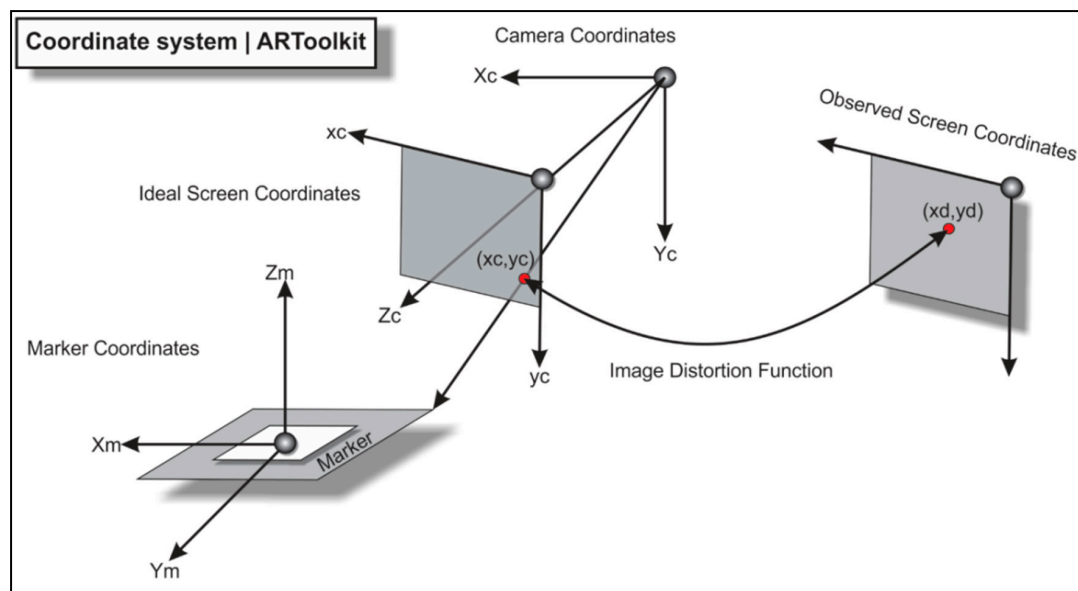


Figure 1. Coordinate systems used in processing with ARToolKit. (Developed by the authors).

The system calibration was conducted with four well-defined points in the frame and on the screen. When the image appeared, we marked the pixels' coordinates in the projection and set a simple transformation model, a first-degree polynomial transformation model to calibrate the coordinates system transforms.

In the case of using an AR system based on these fiducial markers, patterns can be understood as points for “geo-referencing” the artificial objects over the physical map, and so it can merge real and virtual information [3,4]. Therefore, the great advantage in using a system based on computer vision—and more specifically the ARToolKit library—is that only a video camera and a computer are required [3]. Thus, the ARToolKit was chosen for the implementation of this prototype because of its extensive presence in the literature and good processing efficiency reports [3,4,8,17,19].

For this work, the following were used: a whiteboard (where maps were fixed); a projector and a screen, where the AR scene was displayed; an external webcam (that could be moved by the users) to capture and record the maps; and a notebook for processing and generation of the AR scene.

This kind of AR system developed can be defined as a Spatially Augmented Reality (SAR) system. This AR developed uses a projector to display the information over a flat white board, differently to the ones that are developed to be used in mobile devices such as tablets and smartphones or HMD (Head Mounted Displays). According to Raskar, Welch, and Fuchs [20] in Spatial Augmented Reality (SAR), the user's physical environment is augmented with images that are integrated directly in the user's environment, not simply in their visual field. For example, the images could be projected onto real objects using digital light projectors, or embedded directly in the environment with flat panel displays. While the approach has certain restrictions, it offers an interesting new method for realizing compelling illusions of virtual objects coexisting with the real world [5,6].

Thus, the AR system developed projects the virtual layers through a projector, and uses a PC with Windows OS, the ARToolKit library, and the Processing programming language to compute and generate the AR information.

2.2. A First Look into the Usability of the Spatial Augmented Reality System

Slocum et al. [21] argued that several cognitive issues need to be considered within the geoinformation system evaluation [22]. These authors stated that Geospatial Virtual Environments (GeoVEs) have changed the traditional way of acquiring spatial knowledge [23–25]. They considered the AR systems as one of those GeoVEs applications where we have a virtual world supplementing the real world with additional information. These new dynamic systems allow knowledge construction differently, and that is a good point to establish a research challenge [5,6,21].

Also, for knowledge construction and spatial reasoning studies, it is necessary to define the way that the people read maps and acquire (or develop) geographic knowledge. This topic has been popular in research since the 1960's [21,26,27]. Maps depict visual information and are dependent on the cartographer's abstraction, as well as the background knowledge of its reader [28]. It means that maps are graphical representations of knowledge, depicting features or phenomena that are seen or occur in the real world [20]. Because maps are considered a kind of knowledge representation [28,29], the knowledge construction might be evaluated in terms of how the cartographer has perceived, processed, and represented the information about the world; and how the map reader has perceived, processed, and represented—mentally—the information depicted on a map [26,30]. In both cases, the knowledge construction might be assessed by means of detecting changes in the individual's conceptions about the phenomena or about the space represented.

In order to achieve our goal, we have designed activities with individuals that agreed to participate, voluntarily. We have evaluated the results based on the Tversky and Hemenway [31] structures of reasoning, and Rosch [32] levels of abstraction [33]. While observing these variables, we have tried to identify the knowledge construction by analyzing the users' responses, comparing the results with their background knowledge. In the next section, we present the methods we have used to design this research.

2.2.1. Participants

Slocum et al. [21] stated that “one of the keys in conducting a usability study is specifying the users and the tasks that they need to perform”. The choice of “who is going to attend our activity” was based on several other researches whose interest lie in testing the usability of a geoinformation system [2,21,26,34,35], because we understand that this research could benefit from the methods applied to this sort of study. Therefore, individuals with and without education in Cartography and GIS were selected, because they could show us differences in the usability parameters that are going to be analyzed [35]. In this context, two groups of interest were determined: experts and non-experts.

To define the user groups, we have used the criteria presented in Table 1. It has allowed us to distinguish the users considering their experience and background, separating the experts from the non-experts.

Table 1. Definition of the users' profile.

Class	Requirements
Experts	Professor, with a PhD degree in Cartography, GIS, Geography, or Environmental Sciences/Water Resources, with experience treating spatial information related to water resources.
Non-experts	Individuals who have not been classified as an expert.

To perform the activities, 14 volunteers were interviewed and they were distributed in the classes of interest. Three users were considered experts and had PhD degrees in specific areas of interest. All the other participants were considered non-experts.

2.2.2. Activity Design & Basic Procedures

For designing the activities, we have used a qualitative approach [36]. A qualitative approach is appropriate for research whose efforts are made in order to generate and then modify initial research concepts [36,37]. Suchan and Brewer [36] indicated general methods to observe phenomena while developing qualitative researches. The methods are: Questionnaires, Interviews, Verbal Protocols, Ethnography, and Document Analysis. They comprise a rich source of data because they give the first findings related to the subject assessed. Roth, Ross, and MacEachren [16] indicate that there are several investigations on GIS usability that have used this approach. Ooms, De Meyer, and Fack [38] showed that the users must be listened to while testing geoinformation products. Based on these investigations [16,38,39], we have proposed and designed the activities that we have applied.

Also, Wu et al. [10] classified three categories of AR approaches that emphasize the “roles”, “tasks”, and “locations”. In this work, we focus on the task and problem-solving approaches. It is commonly accepted by researchers (like [16,36–38]) that experiments can be designed by using specific scenarios where individuals are going to perform tasks. The tasks need to be defined under specific conditions and these conditions are going to demonstrate the limitations of the findings [38]. In this research, we have created scenarios where individuals performed map-reading tasks [39]. Map-reading tasks are those related to the use of maps in a pre-defined map use context [38]. The map-reading task is any action that individuals perform using maps. It is used to understand the map use in Cartography research. Also, the “pre-defined map use context” is the map use context we have delimited by the scenarios presented to the users [38,39].

Therefore, the activities were designed to allow users to answer the question: “Where are the best places to locate a dam at Paraná State—Brazil?”. For this, the data used in this activity are from SRTM (Shuttle Radar Topography Mission) in a raster format (30 m spatial resolution), as well as the vector data related to the boundaries of Brazil and the Paraná State and hydrography (scale 1:50,000, from IBGE—Brazilian Institute of Geography and Statistics). There were three steps taken to answer this final question. The details about how the activity was set up, as well as the procedures, are presented below.

The first stage was an introductory step where the AR system was presented. This step was necessary to enable the user to have first contact with the AR system. The users were asked to perform a simple task: locate the Paraná State within the map of Brazil. This stage is described in Table 2 and represented in Figure 2.

Table 2. First Stage Tasks.

	Task	Goal
1	Given the printed map with the Brazil's boundaries, draw the boundaries of Paraná State.	Instigate cognitive and perceptual reasoning processes.
	After this, we turned on the system and projected the Paraná State boundaries (Figure 3b).	
2	Once the system is presented, would you change your first representation? Why?	Instigate the parallel of knowledge between what is presented and what the subject knows, aiming to allow a new boundary delimitation.
3	Does the system help in the proposed task?	Verify the system contribution for the spatial knowledge construction.

The second stage was considered more complex since the number of tasks to be done and layers of information provided by the system are significantly higher. At this step, the users should interact with the Paraná State map, solving problems related to the Paraná State relief, rivers' location, and flow directions. These steps are described in Table 3 and illustrated in Figure 3.

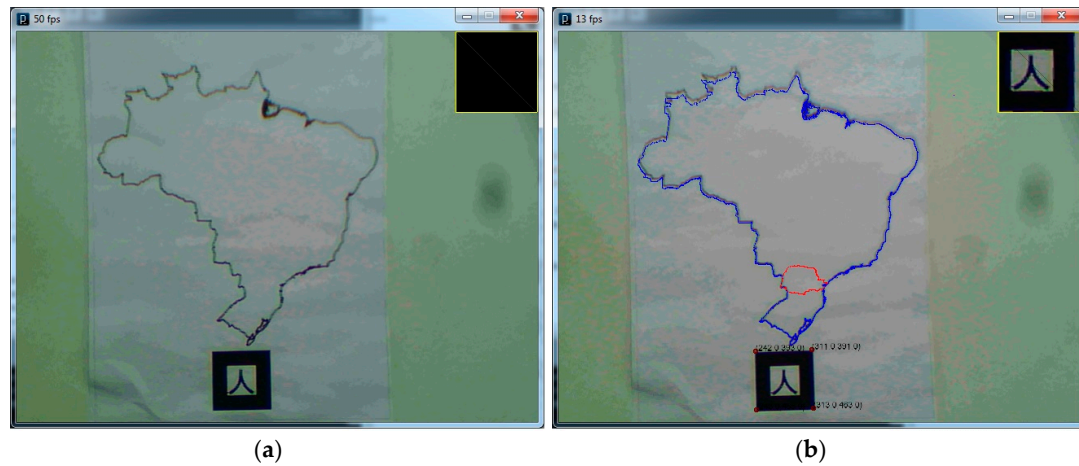


Figure 2. Layers of Information Shown in Step 1 by the AR System. (a) original printed map of Brazil's boundaries, and (b) map augmented with the addition of digital information and the outline of Brazil and the State of Paraná. (Developed by the authors).

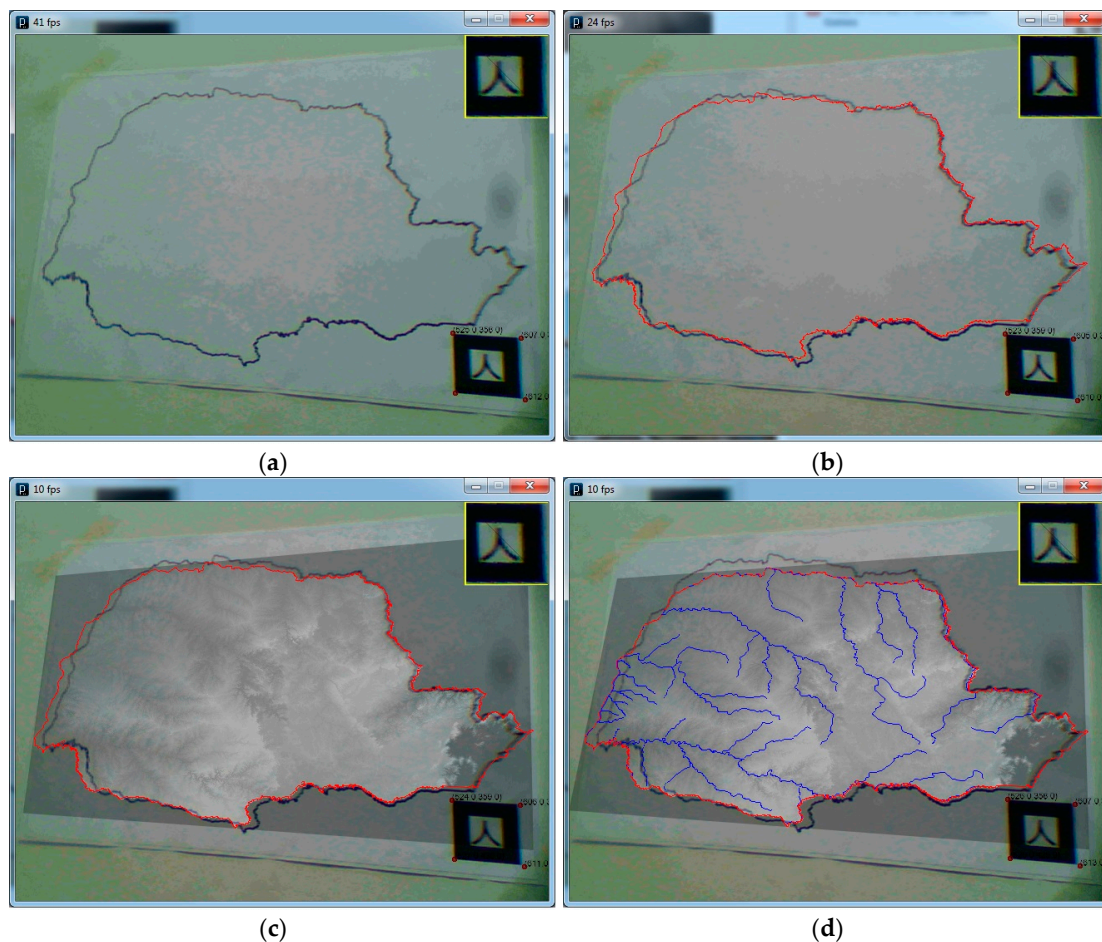
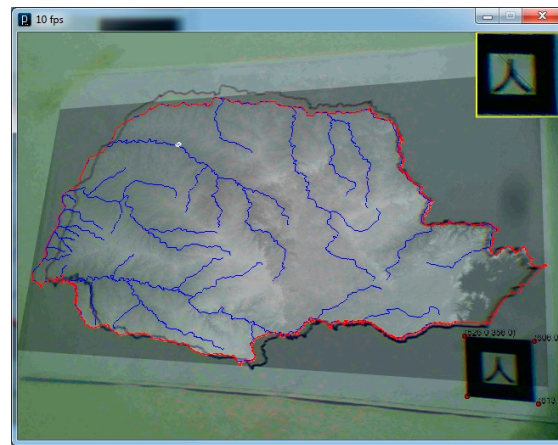


Figure 3. Cont.



(e)

Figure 3. Layers of Information Shown in Step 2 using the AR System. (a) original physical map of Paraná; (b) map augmented with the addition of digital information of the state of the Paraná boundary; (c) SRTM information added; (d) addition of the hydrographic information; and (e) with the addition of animation indicating the direction of flow of rivers. (Developed by the authors).

Table 3. Second Stage Tasks.

	Task	Goal
1	Given the map with the Paraná State's boundaries, draw four rivers you know or remember.	Instigate cognitive and perceptual reasoning processes.
	At this point, we connected the system and projected the SRTM image with the relief of the area (Figure 3c).	
2	Do you recognize this product (the SRTM image)? Does it help you in this task?	Instigate cognitive and perceptual reasoning processes.
3	Once presented to the system again, would you change your representation? Why?	Instigate the parallel of knowledge between what is presented and what the subject knows, aiming to allow a new river flow delimitation.
	At this point, we connected the system and projected the river flow vectors (Figure 3d). We looked forward 10 s and then turned off the SRTM layer.	
4	Do you recognize this product (the river flow vectors)? Does it help you in this task?	Instigate cognitive and perceptual reasoning processes.
5	Once presented to the system again, would you change your representation? Why?	Instigate the parallel of knowledge between what is presented and what the subject knows.
6	Does the system help in the proposed task?	Verify the system contribution for the spatial knowledge construction.
7	Based on your representations, draw arrows indicating the river flow direction.	Instigate cognitive and perceptual reasoning processes.
	At this moment, we connected the system and projected the river flow direction animation (Figure 3e).	
8	Do you recognize this product (the vectors and the animation)? Does it help you in this task?	Instigate cognitive and perceptual reasoning processes.
9	Once presented to the system again, would you change your representation? Why?	Instigate the parallel of knowledge between what is presented and what the subject knows.

The last stage consisted of a general review, where the AR system was not used; the aim was to detect if the AR system had triggered the construction of spatial knowledge during the former activities, as well as to evaluate the contributions of the system according to the users' background. The steps of this third part are shown in Table 4.

Table 4. Third Stage Tasks.

	Task	Goal
1	Based on your representations, draw optimal points for dams by means of traces, as well as its reservoir by a polygon.	To instigate cognitive and perceptual reasoning processes.
2	Does the system help in the proposed task?	To verify the system contribution for the spatial knowledge construction.

2.3. Describing and Analyzing the Results

2.3.1. Answer Transcriptions

The individuals explained—during the entire process—the way that they were performing the map-reading tasks. We have used the think aloud protocol [36,38] to guide the activity session, as well as to record the responses. After the activities, we analyzed the participants' discourse. We also applied direct observation during the activities [36].

2.3.2. Trends and Users' Evaluation

The participants were also invited to give us feedback about possible applications of the AR tool. This last and fundamental step was defined to guide us on developing the new perspectives, given by the “end-users”. The results from this step are guiding us while developing new versions of the system prototype.

3. Results and Discussion

In this section, firstly, we describe the results of development of the AR system and subsequently the results obtained by applying the activities. We have presented the discussion in the results section.

We have analyzed the results by interpreting the user's performance from a cognitive point of view. That means we have discussed the type of reasoning and abstraction [31–33] used by the participants during the activities, aiming to understand if the system prototype allowed, somehow, spatial knowledge construction [40]. We also considered evaluating the answers depending on their professional skills/level of knowledge.

3.1. Analysis of Results from User's Activities

First, it is important to report that Figures 2 and 3 show the information layers used by the AR system in the first two steps. It is possible to identify the sequence of information that was presented to the users—supported on the map of Brazil and on the map of the Paraná State. It is possible to see details in the images, such as the video frame rate (fps), in the upper left corner, and the identification of the fiducial markers. It was possible to verify that the frame rate decreased from 50 to 40 and even to 10 fps when the markers were recognized and the virtual data displayed. This decrease was proportional to the amount of virtual data being displayed.

In the first step, the users only worked with the printed map of Brazil. The users were encouraged to draw the boundary of the State of Paraná. It was noted that all individuals were looking for landmarks on the Brazilian map that could help them recognize the shape of the state of Paraná. For example, experts 01 and 03 recognized the “Edge of the State of Paraná” (as the expert 01 said), referring to the extreme southwest point of the Paraná State, which lies close to the Itaipu hydroelectric power plant. These individuals also sought “the shape of the coastline”—as explained by expert 03—corresponding to the Paranaguá bay. This shows a more complex knowledge obtained by previous experience working with spatial data or the territory. Non-expert users also sought landmarks; however, their analyses were conducted in a less complex manner.

When the AR system was turned on—and the layers of information representing the outline of Brazil and the state of Paraná were displayed—all the reactions from the users (experts and non-experts) were similar—normally with a smile. The experts recognized the information displayed by the system and admitted the inaccuracy of their drawings. On the other side, non-experts showed disappointment with their representation or even found their answer “funny” when they were completely wrong in their drawings. When asked if they would like to modify their drawings, all users wanted to make improvements according to the information displayed by the AR system. The users were unanimous in using the AR system to correct the drawing in real time, always looking at the system while making modifications. As the system was working in real time over the map, they could look through the

layers displayed by the system and were able to correct their drawings. They agreed in saying that the presentation of the data layer was a great help to validate their drawings.

In the second step, users had to draw at least four rivers in the state of Paraná. For this purpose, a printed map with the outline of the state of Paraná was set on the whiteboard. The aim was to encourage cognitive processes that remind users of the hydrography of Paraná State. As expected, the expert users performed this task very accurately. Their reaction indicates confidence in their knowledge about the location of the rivers. Even not knowing the exact position of the features, the expert users divided the space to help them to complete the task. For example, expert 03 designed mentally geographic regions, such as the Paraná plateaus. Such a complex relationship allowed the experts to achieve a better performance and greater confidence in their representations. When the system was turned on, the expert users used the AR system only occasionally, making just a few changes to their drawings.

On the other hand, non-expert users relied on a simpler logic to draw the features while the system was turned off. Many of them tried to draw the rivers based on the boundary of the state. This reasoning is marked by a common knowledge of the Brazilian reality, where many state or municipal boundaries are based on geographical elements such as rivers or mountains. Some non-experts even risked representing rivers randomly—like non-expert 10, who said: “I do not know well the Paraná State, so I’ll do it anywhere”. Then, when the AR system was turned on, non-expert users proceeded to make changes in their representations based on the displayed information. Non-expert users made more changes in their drawings than the experts, as one may see in Figure 4.

In this second step, users were also asked to represent the flow direction of the rivers that they had drawn. As happened in the previous step, experts marked the flow direction using complex cognitive relationships. For example, expert 01—who mentally divided the State of Paraná into larger and smaller basins—assumed that small rivers flow into larger ones. This behavior was also adopted by other experts, who also used the shape of rivers, plateaus, contributions from tributaries, and other previous knowledge. An animation of the flow directions of the rivers was later displayed by the AR system (Figure 3e). Although the experts did not make any changes to their drawings, all of them waited for the animation to end. They said that the animation was only necessary to validate the results of the flow direction they drew, but they recognized that it is definitely an interesting tool. Finally, the system was considered a “tool of great help for people who have no or just a few knowledges about this subject”, a representative statement made by expert 02, similar to those made by the other users during the activities. The experts also stated that they would use the AR application in their classes, once it is an interesting tool to transfer knowledge in the teaching/learning process, as verified by Carbonell-Carrera et al. [5,6].

Unlike the experts—and agreeing with the behavior observed in the previous steps—some non-expert users drew the flow direction randomly. However, some of them properly performed this task relying on the knowledge acquired during the previous steps, based on the relief and contributions from tributaries rivers. When the non-experts saw the animation of the flow directions, they showed great enthusiasm. Even when they were sure about their answers, all of them waited for the animation to show the direction of the rivers they had drawn, proving that this would be a valid option to learn or validate the flow direction of the rivers.

The randomness of answers of some non-expert users confirmed the classification of these users as non-experts. This can be explained by the reaction that Lakoff [33] called “turn automatic on”. Lakoff [33] says that it is common to see individuals making random decisions when they do not have enough knowledge. This was clearly seen in the behavior of non-expert users 07 and 09, who had drawn the features randomly and waited for the “feedback of the system” (according to non-expert 07) or even to see “the right answer” (as expressed by non-expert 09). Such behavior confirms that these users trusted the system as a way to “better work on the map” (according to non-expert 07). So, this relationship between the AR system and the users—especially the non-experts—is an effective validation of the impact of the AR system on the performance of the users; also, if the users like and

trust the system to help them, they feel more comfortable to perform their tasks or engage in the decision-making process on a subject.

In the third and final task, the users had to mark places for the construction of hydroelectric power plants and water dams. This task was done without the AR system. This enabled an assessment of whether there was effective knowledge construction in the previous activities. The experts relied on prior knowledge—knowing the location of existing dams, as well as the approximate size of the reservoirs. Most non-experts did not know where the dams were located. Some of them only knew Itaipu (a famous hydroelectric power plant). However, based on the knowledge and the drawings they made in the previous steps, most of them converged to propose dams downstream of rivers' confluence, assuming that would be the place "where more water flows". So, by doing that, they demonstrated the construction of knowledge about the direction of the flow of rivers and detailing on the contribution of the tributary rivers.

Figure 4 is presented to illustrate the differences obtained in the activities between the expert and non-expert users. These images are the final maps developed by users in stages 2 and 3, over the Paraná State printed map. Both maps present the marker that was used by the AR system (ARToolKit library) to track the map-users-web cam position and attitude in real time. Figure 4a shows the results of an expert user, while Figure 4b is a map from a non-expert user. Besides the clear difference between the information on the maps, we highlight the use of many different colors in the representations. That happens because any correction users did in their drawings with the help of the AR system had to be made in a different pen color.



Figure 4. Comparison of the maps resulting from Steps 2 and 3. (a) Expert; (b) Non-expert. (Developed by the authors).

The expert user—Figure 4a—used fewer colors, showing that he did not make many changes during the process. However, it is possible to notice some changes, proving the contribution of the AR system, even for experts. Moreover, as previously reported, experts were even able to approximately identify the position and size of existing power plants, dams, and their reservoirs.

The map produced by the non-expert—Figure 4b—shows that the AR system helped to make significant corrections of the representation which is evident by the number of colors used. Note that the hydrography in the northwest region was first represented as a hatched blue area and then changed to an almost perpendicular position. It is also possible to verify the change of the arrows indicating the flow direction of two rivers. The polygons that represent the proposed hydroelectric plants and their reservoirs are located at the confluence of rivers or "at the end", where there would be "more water flowing", as previously reported. So, it is possible to realize that the AR system contributed to

improve the representations. In the experiment when the dams had to be located, the user had already created prior knowledge using (this time) a more complex reasoning for decision-making.

Expert users recognized the value of the sequence in which the information was presented as a way to help learning and/or in constructing knowledge within the context of the subject. For example, expert 01 indicated that “this sequence would be the strategy I would adopt to teach the hydrography of Paraná”. This was confirmed by expert 03, who stated that “to teach about the hydrography of Paraná I would show first the relief map and then the rivers, in the same order that it was presented to me”.

Sometimes, the interaction between the users and the AR system was verified by turning it off purposely without notification by the researchers during the activity. When it was done, the users stopped their modifications on the maps and usually asked to turn the AR system on and to display the information layer again. In some cases, users kept looking at the system. They seemed to be hoping or waiting for the information layer to be displayed again—even when they did not ask to turn the system on. This attitude proves the impact of the AR system on the users, where it is possible to say that they created a bond with the system, as they felt more confident in making their decisions or changes in the drawings when supported by the AR system.

Moreover, as stated by many of the non-expert users, the AR system allowed them to learn about this subject in a “more interactive way” (this is an expression used by non-experts 01 and 03). The users also stated that they worked with a new tool that they have not worked with before, where the layers of information were shown during the evolution of the tasks and especially where they can interact with the real map and geographic virtual information at the same time.

3.2. General Review and Potential of Augmented Reality Systems According to the Interviewed Users

At the end of the interview, the users of both classes were asked to evaluate the AR system. The responses were positive, in terms of how helpful the AR application was for accomplishing the given tasks. The users mentioned adjectives such as “attractive” and “interactive” for describing their experience of handling an AR application for interacting with geographic data. This result is similar to that found by Carbonell-Carrera et al. [5,6]. When asked to describe the system advantages or disadvantages in terms of “cost-benefit”, all the users gave a positive response, once they considered the AR application a tool that saves space and physical resources. In this way, it does not require large spaces for storing maps, such as in map libraries, and is a fresh and adaptable tool, which motivates map-reading for both experts and non-experts, or even children and adults.

4. Conclusions

This research was designed to demonstrate the development of an AR application, as well as to evaluate its contributions for supporting the interaction with geographic data and map-reading tasks. The tasks performed by the users were supported by information layers presented by the AR system that allowed users to handle the real environment and virtual objects simultaneously. An activity was performed to assess the effectiveness of this application prototype as a basis to guide us in further developments.

It was noticed that the Augmented Reality system improved the map-reading ability of non-experts, and helped the experts to validate their understandings. The users felt comfortable during the completion of the tasks using the AR system, as well as asking to use it when it was turned off. The users showed that they had learned about the hydrography from the previous steps and were able to solve the task in the end, even without the AR system. These results indicate a positive relation in terms of contribution of the AR system developed when the subject is the user’s learning process about the geographic space. There was also a positive response in terms of the interaction between the users and the AR system, once the users had no difficulties in operating the system while accomplishing the given tasks.

Future researchers may reproduce this research with a large number of users, adapting the scenarios to other circumstances. Researchers engaged in this task could benefit from selecting equal groups—in number—of experts and non-experts, and adopting Psychobiological protocols for testing the participants' previous knowledge. Besides that, researchers could improve their analyses by using tools such as the Likert scale for counting results, as well as Cronbach Alpha to verify the reliability of the overall activity design. Further studies should also be focused on developing strategies to connect real and virtual scenes. The system sometimes experienced some difficulty in performing an exact spatial match between the virtual information and the maps. This problem was perceived by some users, but none of them reported that such a fact hindered the development of the proposed tasks. The same problem was detected by Paelke and Sester [8], who reported that the position of the user using the ARToolKit library was not very accurate, but good enough to validate the general concept of work.

Therefore, it is possible to conclude that the Augmented Reality application we have developed could be a valuable input for users whose interest lies in exploring the geographic space under a 3D computational interface, mixing reality with virtual objects. Moreover, the AR systems can promote a more interactive environment which can especially help in the teaching and learning process.

Author Contributions: G.H.d.A.P. wrote the manuscript, J.V.M.B. reviewed and edited the manuscript, and J.A.S.C. supervised the entire process.

Funding: This research was funded by the National Council for Scientific and Technological Development (CNPq).

Acknowledgments: The authors would like to give thanks for the anonymous reviewers that improved this paper, and for the participants that provided us their feedbacks during the activities.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Azuma, R.T. A survey of augmented reality. *Presence* **1997**, *6*, 355–385. [\[CrossRef\]](#)
2. Azuma, R.; Baillot, Y.; Behringer, R.; Feiner, S.; Julier, S.; Macintyre, B. Recent advances in augmented reality. *IEEE Comput. Graph. Appl.* **2001**, *21*, 34–47. [\[CrossRef\]](#)
3. Bobrich, J.; Otto, S. Augmented maps. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2002**, *34*, 502–505.
4. Bobrich, J. An Immersive Environment Based on Paper Maps. In Proceedings of the 21st ICC 2003, Durban, South Africa, 10–16 August 2003.
5. Carbonell-Carrera, C.; Avarvarei, B.V.; Chelariu, E.L.; Draghia, L.; Avarvarei, S.C. Map-Reading Skill Development with 3D Technologies. *J. Geogr.* **2017**, *116*, 197–205. [\[CrossRef\]](#)
6. Carbonell-Carrera, C.; Saorin-Perez, J.L.; Torre-Cantero, J. Teaching with AR as a tool for relief visualization: Usability and motivation study. *Int. Res. Geogr. Environ. Educ.* **2017**, *27*, 69–84. [\[CrossRef\]](#)
7. Asai, K.; Kondo, T.; Kobayashi, H.; Mizuki, A. A geographic surface browsing tool using map-based augmented reality. In Proceedings of the 2008 International Conference Visualisation, London, UK, 9–11 July 2008; pp. 93–98.
8. Paelke, V.; Sester, M. Augmented paper maps: Exploring the design space of a mixed reality system. *ISPRS J. Photogramm. Remote. Sens.* **2010**, *65*, 256–265. [\[CrossRef\]](#)
9. Adithya, C.; Kowsik, K.; Namrata, D.; Nageli, V.S.; Shrivastava, S.; Rakshit, S. Augmented reality approach for paper map visualization. In Proceedings of the 2010 International Conference on Communication and Computational Intelligence (INCOCCI), Erode, India, 27–29 December 2010; pp. 352–356.
10. Morrison, A.; Oulasvirta, A.; Peltonen, P.; Lemmela, S.; Jacucci, G.; Reitmayr, G.; Näsänen, J.; Juustila, A. Like bees around the hive: A comparative study of a mobile augmented reality map. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, MA, USA, 4–9 April 2009; pp. 1889–1898.
11. Arvanitis, T.N.; Petrou, A.; Knight, J.F.; Savas, S.; Sotiriou, S.; Gargalakos, M.; Gialouri, E. Human factors and qualitative pedagogical evaluation of a mobile augmented reality system for science education used by learners with physical disabilities. *Pers. Ubiquitous Comput.* **2009**, *13*, 243–250. [\[CrossRef\]](#)

12. Ternier, S.; Klemke, R.; Kalz, M.; Van Ulzen, P.; Specht, M. ARLearn: Augmented Reality Meets Augmented Virtuality. *J. UCS* **2012**, *18*, 2143–2164.
13. Wu, H.K.; Lee, S.W.Y.; Chang, H.Y.; Liang, J.C. Current status, opportunities and challenges of augmented reality in education. *Comput. Educ.* **2013**, *62*, 41–49. [[CrossRef](#)]
14. Cheng, K.H.; Tsai, C.C. Affordances of augmented reality in science learning: Suggestions for future research. *J. Sci. Educ. Technol.* **2013**, *22*, 449–462. [[CrossRef](#)]
15. Carbonell-Carrera, C.; Medler, S.H. Spatial Orientation Skill Improvement with Geospatial Applications: Report of a Multi-Year Study. *ISPRS Int. J. Geo-Inf.* **2017**, *6*, 278. [[CrossRef](#)]
16. Roth, R.E.; Ross, K.S.; Maceachren, A.M. User-Centered Design for Interactive Maps: A case Study in Crime Analysis. *ISPRS Int. J. Geo-Inf.* **2015**, *4*, 262–301. [[CrossRef](#)]
17. He, Z.; Xia, Z.; Chang, Y.; Chen, W.; Hu, J.; Wei, X. Research on underground pipeline augmented reality system based on ARToolKit. In Proceedings of the Geoinformatics 2006: Geospatial Information Technology, Wuhan, China, 28–29 October 2006; Volume 6421.
18. Fiala, M. Comparing artag and artoolkit plus fiducial marker systems. In Proceedings of the IEEE International Workshop on Haptic Audio Visual Environments and Their Applications, Ottawa, ON, Canada, 1 October 2005; p. 6.
19. Schöning, J.; Krüger, A.; Müller, H.J. Interaction of mobile camera devices with physical maps. In Proceedings of the Fourth International Conference on Pervasive Computing, Dublin, Ireland, 7–10 May 2006; pp. 121–124.
20. Raskar, R.; Welch, G.; Fuchs, H. Spatially augmented reality. In Proceedings of the First IEEE Workshop on Augmented Reality (IWAR'98), San Francisco, CA, USA, 1 November 1998.
21. Slocum, T.A.; Blok, C.; Jiang, B.; Koussoulakou, A.; Montello, D.R.; Fuhrmann, S.; Hedley, N.R. Cognitive and Usability issues in Geovisualization. *Cartogr. Geogr. Inf. Sci.* **2001**, *28*, 61–75. [[CrossRef](#)]
22. Fabrikant, S.I.; Lobben, A. Introduction: Cognitive Issues in Geographic Information Visualization. *Cartographica* **2009**, *44*, 139–143. [[CrossRef](#)]
23. Sommerville, I. *Software Engineering*, 4th ed.; Addison-Wesley: Wokingham, UK, 1992; p. 649.
24. Van Elzakker, C.P.J.M. The Use of Maps in the Exploration of Geographic Data. Ph.D. Thesis, ITC, Utrecht/Enschede, The Netherlands, 2004.
25. Board, C. Map reading tasks appropriate in experimental studies in cartographic communication. *Cartographica* **1978**, *15*, 1–12. [[CrossRef](#)]
26. Maceachren, A.M. *How Maps Work: Representation, Visualization, and Design*; The Guilford Press: New York, NY, USA, 1995.
27. Slocum, T.A.; McMaster, R.B.; Kessler, F.C.; Howard, H.H. *Thematic Cartography and Geovisualization*, 3rd ed.; Pearson Prentice Hall: Upper Saddle River, NJ, USA, 2009.
28. Arnheim, R.T. The perception of maps. *Am. Cartogr.* **1976**, *3*, 5–10. [[CrossRef](#)]
29. Akhtar, M. Communication and retrieval of spatial information from thematic maps. *Natl. Geogr.* **1989**, *24*, 51–65.
30. Maceachren, A.M. The role of maps in spatial knowledge acquisition. *Cartogr. J.* **1991**, *28*, 152–162. [[CrossRef](#)]
31. Tversky, B.; Hemenway, K. Objects, Parts, and Categories. *J. Exp. Psychol. Gen.* **1984**, *113*, 169–193. [[CrossRef](#)] [[PubMed](#)]
32. Rosch, E.; Mervis, C.; Gray, W.; Johnson, D.; Boyes-Braem, P. Basic objects in natural categories. *Cogn. Psychol.* **1976**, *8*, 382–439. [[CrossRef](#)]
33. Lakoff, G. *Woman, Fire, and Dangerous Things: What Categories Reveal about the Mind*; University of Chicago Press: Chicago, IL, USA, 1987.
34. Maceachren, A.M.; Kraak, M.J. Research Challenges in geovisualization. *Cartogr. Geogr. Inf. Sci.* **2001**, *28*, 3–12. [[CrossRef](#)]
35. Koua, E.L.; Maceachren, A.M.; Kraak, M.J. Evaluating the usability of visualization methods in an exploratory geovisualization environment. *Int. J. Geogr. Inf. Sci.* **2006**, *20*, 425–448. [[CrossRef](#)]
36. Suchan, T.A.; Brewer, C.A. Qualitative methods for research on mapmaking and map use. *Prof. Geogr.* **2000**, *52*, 145–154. [[CrossRef](#)]
37. Patton, M.Q. *Qualitative Research and Evaluation Methods*, 3rd ed.; Sage: London, UK, 2002; p. 127.
38. Ooms, K.; De Meyer, P.; Fack, V. Listen to the Map User: Cognition, Memory, and Expertise. *Cartogr. J.* **2015**, *52*, 3–19. [[CrossRef](#)]

39. Roth, R.E.; Harrower, M. Addressing Map Interface Usability: Learning from the Lakeshore Nature Preserve Interactive Map. *Cartogr. Perspect.* **2008**, *60*, 46–66. [[CrossRef](#)]
40. Kulhavy, R.W.; Stock, W.A. How Cognitive Maps are Learned and Remembered. *Ann. Assoc. Am. Geogr.* **1996**, *86*, 123–145. [[CrossRef](#)]



© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).