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The FingerTrips approach

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Touching and traveling on 3D augmented tangible maps for learning geography

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Abstract

Purpose – Tangible physical maps which are enhanced by new digital forms of interaction can become an invaluable asset for learning geography in an embodied way. The purpose of this work is to evaluate an interactive augmented three-dimensional (3D) tangible map on which students interact and travel with their fingers.

Design/methodology/approach – A total of 58 fourth-grade students from eight elementary schools participated in the study. The participants played with the FingerTrips environment in 24 sessions and in groups of two or three. Each session lasted for about 20-25 min. After completing the interactive game, the students answered a questionnaire concerning their attitudes toward the tangible environment and participated in a short interview.

Findings – Students' responses revealed that FingerTrips managed to transform the experience of meeting new places, understanding spatial relations and learning geography. Students supported that such an approach is closer to their interactive experiences and expectations, and exploits embodied learning affordances to achieve enjoyable learning. Students identified their finger-based trips as an effective and intriguing static haptic guidance that helped them learn more effectively.

Originality/value – The specific approach has two distinctive characteristics. First, a new interaction style on the map is suggested, the use of trips with fingers. Students have to follow predefined engraved paths on the 3D terrain to sense distances and changes in altitude and "touch" the topology asked to understand and explore. Second, it is examined whether a low fidelity interactive 3D terrain, which can be easily reconstructed and reprogrammed by primary school students, can become a useful canvas for learning geography.

Keywords Embodied learning, Geography, Augmented map, Mixed reality environments, Tangible interfaces, Tangible map

Paper type Research paper

Introduction

Several national organizations recognize the significance of promoting geographic literacy in the early grades. As Catling (1993) suggested, geographical exploration is a natural part of child's development; children are natural geographers. Information and communication

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technology has managed to address their needs by making geography activities more authentic, by offering interactive navigation on enormous geographical visual data resources, by simulating geographical systems and environments and by allowing more time for observation, discussion, and analysis. Several different technologies such as geographical information systems, GPS, digital photography, simulations, Web 2.0, augmented reality and tablets have been exploited and researched in the context of making geography teaching more effective and pleasant (Walczak and Taylor, 2018; Riihelä and Mäki, 2015; Kerski *et al.*, 2013; Rød *et al.*, 2010). The aims are mostly the same, to improve spatial awareness and spatial thinking, to explore the sense of the place and location, to provide knowledge of the different people of the world and the interdependence of mankind, to develop respect for students' own culture and the cultures of other people, to encourage travel and to develop an understanding of basic concepts, principles and theories relating to geographical phenomena.

Maps either in the form of paper, or digital images, simulations or virtual globes are vibrant tools for teachers and can greatly enrich geographical understanding by becoming a canvas to display and analyze information about people and environments. Recent studies have indicated that both paper maps and their electronic counterparts have advantages and limitations in regard to students' spatial thinking skill acquisition (Collins, 2017). However, the spatial topography of paper and electronic maps is inherently limited and abstracted, as the maps are projected into two dimensions. In that way, tasks about height judgment, natural limitations or visibility assertions of locations are difficult to accomplish, as learners have to reconstruct and reason for them mentally (Li *et al.*, 2017). Another form of maps, tangible 3D physical maps, have also played and continue to play a major role in contemporary cartography (Buchanan and Tschida, 2015; Petrasova *et al.*, 2015). Tangible physical maps based on the traditions in cartography and enhanced by new digital forms of interaction complement and advance digital cartography presented in screens. Though, tangible maps can also become an invaluable asset for learning geography in an embodied way.

In this paper, we will present FingerTrips for geography, a tangible environment that aims to transform the experience of learning geography by offering students journeys with their fingers over a three-dimensional (3D) augmented tangible map. We aimed to explore the learning effectiveness of a tangible interface constructed with low-cost rapid prototyping hardware and which can be easily recreated and extended by students and teachers by themselves.

Literature review

A common denominator of most educational technology tools for learning geography is the protagonists' journeys or tours. For example, GeoStories (Buchanan and Tschida, 2015) is an online resource bank of slideshows with maps, videos and narratives from places around the world or on specific topics. In GeoStories, once students locate the tour of their choice, they simply click to navigate the photos and videos or text information, and together with print or digital maps, they can discover places or regions featured in the stories to explore additional geography themes. Similarly, Global Trek enables students to make virtual trips to 35 locations around the globe and meet people to understand the local experience (Buchanan and Tschida, 2015). The second common element of all geography learning tools is the representation type of spatial data and the way it is exploited to nurture spatial skills. Geospatial technologies are considered as an alternative to the traditional mapping methods, and seem to play a positive role in fostering spatial thinking (Liu, *et al.*, 2012). Google Earth, either as a virtual globe on which one can "fly" above or with its functionality involving animated maps, photos placing and placemarks, has been identified as a promising platform for geography education and spatial thinking skills acquisition (Xiang and Liu, 2017; Demirci *et al.*, 2013; Bodzin, 2011). Finally, the effect of the modality of the spatial representation has also been studied. Walczak and Taylor (2018) supported that there are no significant differences between teaching traditionally or with touchscreen tablet technology when teaching land shapes and location to second graders.

Tangible interfaces seem to offer a new perspective on geography learning, as they reduce the modality on the interface, promote sensory engagement which is the natural way students learn, facilitate spatial tasks, offer opportunities for coupling the control of the physical object and the manipulation of its digital representation and encourage group learning by providing an inherently social interface (Mpiladeri *et al.*, 2016; Antle and Wise, 2013; Bakker *et al.*, 2012; Manches *et al.*, 2010). Augmented tangible interfaces couple the physical and the digital through a feedback loop and enable direct interaction with physical data. They also offer a vivid and immersive audiovisual interface for eliciting body activity (Lindgren *et al.*, 2016; Lindgren and Johnson-Glenberg, 2013). In essence, such approaches allow students to become part of the system they are trying to understand, giving them an insider perspective on the critical mechanisms and relationships that define the domain (Lindgren *et al.*, 2016). As Li *et al.* (2017) showed, learners seem to be more relaxed, comfortable and confident when interacting with 3D terrain models than using two-dimensional topographic maps. Under the umbrella of terms like embodied interaction, full-body interaction, motion-based interaction, gesture-based interaction, tangible interaction, bodily interaction and kinesthetic interaction, several tangible learning environments based on novel interaction modalities have been developed. The new mediated environments seem to increase learner engagement, as body-based experiences are more perceptually immersive and learners may feel that they are in a more authentic and meaningful educational space (Dede, 2009).

There have been proposed several tangible user interfaces for geography with continuous shape displays (Petrasova *et al.*, 2015) to be of special interest. In continues shape displays, a continuous physical model is coupled with a digital model through a cycle of sculpting, 3D scanning, computation and projection (Petrasova *et al.*, 2015; Ishii, 2008; Ishii *et al.*, 2004). Users can sculpt the display with their hands and then they can see the re-estimated computation projected onto the model in near real time. The feedback is usually visual (Petrasova *et al.*, 2015). Such shape displays are passive and cannot alter their form dynamically. Similar models can be built of a malleable, continuous material such as sand or clay that can be sculpted with preciseness and can represent different kinds of forms such as landscapes (Ishii *et al.*, 2004; Ishii, 2008).

The first example of continuous shape display was illuminating clay (Piper *et al.*, 2002), in which landscape models were constructed using clay support. The 3D geometry was analyzed in real time using a laser scanner and it was easy to recognize changes such as shadow casting and land erosion. The results of the analysis were used to project back onto the clay model an updated digital enhancement of the landscape. The authors (Piper *et al.*, 2002) mentioned an instructional scenario of exploiting illuminating clay for learning, in which a geoscience professor with his student may sit around the clay model of a landscape and the students can watch the direction of water flow in different regions of the model. As the teacher flattens a hill or digs the ground, the student can observe how the drain direction changes on the model.

TanGeoMS (Tateosian *et al.*, 2010) is also a similar geospatial modeling visualization system that combines a laser scanner, a projector and a flexible physical 3D model with a geospatial information system to create a tangible user interface for terrain data. TanGeoMS displays an image of real-world data onto a physical terrain model, and users can alter the landscape by modifying the clay surface or by placing additional objects on the surface. The modified model is recognized by a laser scanner and then it is imported into a geographical information system (GIS) for analysis. Then, the results are projected back onto the surface of the model.

SandScape (Ishii *et al.*, 2004) shares the same architectural features with illuminating clay. However, in this case, the users could modify the form of the landscape model by working with sand, a much freer to use and shape material. Concurrently, the users could see the effects of their changes on the surface of the sand in real time. Similarly, the Augmented REality Sandtable (ARES) (Amburn *et al.*, 2015) is a sand-based research testbed that uses commercial cheap prototyping tools to create a low-cost method of geospatial terrain visualization together with a tangible user interface. The projection technology in ARES is combined with a Microsoft Kinect sensor, which uses an enhanced depth camera to recognize the 3D geometry of the landscape. ARES has been used as an enhancement to traditional military sand tables.

Projection-based city atlas (Rossi *et al.*, 2014) is a low-cost exhibit of a projection-based city atlas. The exhibit could be replicated and reconfigured by the size of the mock-up and the spatial arrangement of the place where it will be located. Based on the description of events occurring over time, the interactive virtual tour aims to highlight how the urban fabric has changed throughout the historical and political periods that have affected the city.

All previous approaches take advantage of our natural ability to understand and manipulate physical forms while still harnessing the power of augmenting these forms with useful digital representations. However, there are also tabletops with the potential to provide novel and innovative learning environments for mapping applications.

The technological basis of the collaborative design platform (Schubert *et al.*, 2015) is a large-format multi-touch table with real-time 3D object recognition. Collaborative design platform obviates the needs for markers in the physical model, making it possible to flexibly and freely alter the model as desired and to have these changes reflected immediately in the digital reconstruction. OrMiS (Bortolaso *et al.*, 2013) supports collaborative analysis, planning and interaction around digital maps. TerraGuide (Oskamp *et al.*, 2015) is a multi-surface environment for exploratory terrain analysis. TerraGuide provides three tightly coupled displays including a real-time viewshed, a 3D panoramic view and a helicopter view controlled by an optically tracked tablet. GeoTUI (Couture *et al.*, 2008) is a system designed for geophysicists that provides props on a tabletop vision-projection system for the selection of cutting planes on a geographical map of a subsoil model.

Most of these proposals lack comprehensive evaluation in regard to specific learning objectives, whereas a minority of them can be recreated by students in secondary education, and their functionality is difficult to be altered.

Fingertrips for geography

Being able to interact more naturally with digital enriched spaces enhances our spatial thinking, encouraging creativity, analytical exploration and learning. The interaction in tangible interfaces is mostly done by touch. However, as Elo (2012) supported:

> "[. . .]insofar as digital interface design aims at haptic realism it conceives of the sense of touch in terms of narcissistic feedback and thus tends to conceal the pathic moment of touching"

Elo (2012) continued by indicating that the finger has been given the status of a switch hut now it seems to be dragging the whole body along. In this manuscript, we also support that touch is not only a computational input device but also a human sense, which is overly underestimated as a learning means.

The objective of this study was to create and evaluate an easily constructible 3D tangible map for students who will be able to travel with their fingers, feel the distances and the altitude differences and interact with cultural information at several places of their journey. Few studies have sought to examine whether physical spatial data representations affect learning. Researchers usually assume that it will be easier for students to learn, as the cognitive load during map-related tasks will be reduced (Buchroithner, 2012).

There are distinctive characteristics of our study, as mentioned below.

First, we suggest a *new interaction style* on the map, the use of trips with fingers. Students have to follow predefined engraved paths on the 3D terrain to sense distances, changes in altitude and "touch" the topology asked to understand and explore. The engraved paths on the maps function as natural static haptic guidance, provide spatial references, improve visual attention on the surface and advance terrain perception. We hypothesized that the directed "feeling" of the map will intrigue students and will help them learn relying both on visual and sensed information. In addition, as the system can recognize the exact position of users' finger, a variety of interactions were developed based on this specific type of interaction.

Second, we examine whether *a low fidelity interactive 3D terrain* which can be easily reconstructed and reprogrammed by primary school students can become a useful learning canvas for the students. 3D terrain models are usually considered hard to construct, move and manipulate, and they remained popular only as interactive installations in museums and visitor centers. However, the uprising trend of arts and crafts fairs, tinkering and inventing and the lowering cost of construction materials and prototyping boards have made similar models accessible to anyone. Students' interactions on the map were supported by two Makey Makey boards, whose inputs were embedded into students' journey path while the interactions were programmed with MIT's Scratch. That way, students can take control over the proposed setting; can reprogram it to address their perception, interests and views; and can take the ownership of the finger journey experience.

For the construction of the FingerTrip model, we sought to exploit accessible and cheap materials; thus for our study, we used medium density fiberboard for the base and clay for recreating the 3D map with dimensions of 1.40 × 1.05 Plate 1. A map was projected into the clay model with the use of a notebook and a projector.

We aimed to offer collaborative interaction on the map in a gamified environment and, therefore, there was also need to find an appropriate and effective teaching context for use. The young students were the protagonists of a game in which they were invited to discover

Plate 1.
Part of the clay model with some of the interaction points through the engraved path

and unlock a hidden treasure by finding seven keys during their trip. The students were guided by 19 printed cards that led them to different activities. Students had to complete each activity to be able to continue to the next steps.

More specifically, the students started from Corfu in Greece and traveled to Italy and the island of Sicily, and then by touching the Apennines, they visited the Roman Coliseum and Venice. They crossed and experienced the mountains of the Alps to reach the highest mountain in Europe, Mont Blanc. They continued their journey to Spain through the Pyrenees, crossed the Loire River in France and visited the Eiffel Tower. Their next destination was Switzerland, where they interacted with Lake Geneva and touched other high mountains of the Alps, such as Eiger and Piz Bernini to complete their journey in Austria, reaching up to the Danube River.

During their trip, the students used various means, such as ship, car, plane and train. For their journeys by ship and airplane, there was a navigation panel (Figure 1) for guiding them on the model, whereas for car and train travels, they used their index finger over a path that was smoothly engraved on the model Plate 2. In the course of their finger or while traveling with other means, in unexpected points, more information for their position was unveiled (e.g. either acoustically or by superimposing images next to where they were). So, the journey was an endless combination of activities, movements of the players and tracking of

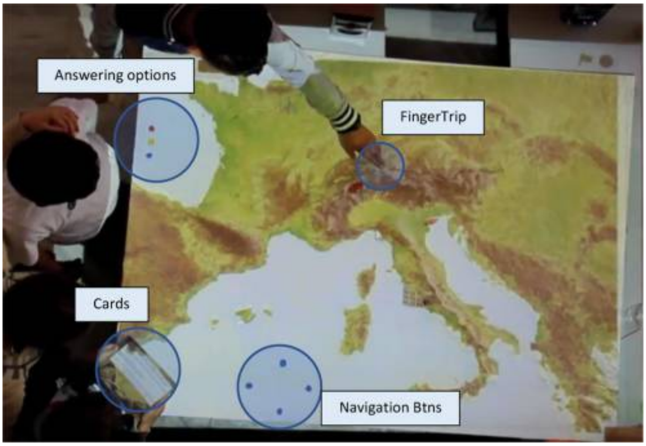

Figure 1.
The augmented tangible 3D map

Plate 2.
Fingertrips: the student just arrived at Rome and Colosseum appeared

contextual information. To maintain the alertness and the interest of the students at certain points of the route, questions were presented in different occasions and locations which had to be answered by using the answering options, shown on Figure 1. The interface can support the cooperation of two to four students by assigning different roles that alternate during the game (e.g. finger trip, card reading, answering questions and navigating ship or airplane).

The study

Participants

A total of 58 fourth-grade students from eight elementary schools participated in the study, 30 girls and 28 boys. The participants played with the FingerTrips environment in 24 sessions and in groups of two or three. Each session lasted for about 20-25 min. The intervention was conducted in the context of an interactive exhibition related to tangible and mixed reality interfaces for elementary schools. Students have not been taught in their schools the geography knowledge under consideration.

Procedure

At the beginning of the game, brief instructions were given to each group, to help students become familiar with the concept of interacting with the 3D model before starting their FingerTrip game. The researchers offered guidance whenever the participants requested for. At the end of each session, students were asked to complete an online questionnaire about their experience and the knowledge acquired. Afterward, all students participated in a brief group interview in a separate, quieter place.

Research instruments

After completing the game, the students answered a questionnaire that assessed their attitudes toward the tangible environment through nine 5-point Likert-Type scale items. The questionnaire tried to identify whether the environment was easy to use, was effective and efficient and whether it was preferable in comparison to traditional learning. In addition, the students answered a brief questionnaire regarding the knowledge acquired, which consisted of seven recall questions.

A short interview was also conducted to let students express their assessment in their own words. The interview included questions aiming at extracting the qualitative assessments of the students and at allowing them to describe in their own words their experience with the FingerTrips environment (e.g. Did the setting help you to learn about the geography? Do you think you would learn faster with similar games? Would you like to learn about the Geography this way?). All audio-recorded interviews were transcribed and then encoded and compared within and between cases. Afterward, the three researchers collaborated to reach consensus on the commonly identified issues.

Results

Quantitative results

Students' answers revealed their positive attitudes toward the FingerTrips learning setting and underlined that they found the interface very pleasant and easy to use. However, what is more interesting is that the students thought that FingerTrips promote efficient and effective learning and argued that the setting helped them to learn faster ($M = 4.6$, $SD = 0.67$) and to learn more things than with the traditional means ($M = 1.88$, $SD = 1.04$ – inverted) and with easiness that overcame the previous learning experiences ($M = 4.05$, $SD = 0.83$). All students agreed that they would like their teachers to provide them with similar interfaces and learning experiences (M = 4.46, SD = 0.88). It is also interesting that students did not find the interface quite innovative (M = 3.58, SD = 0.99) and that, in combination with the previous observations, means that they are ready for and expect similar interactive learning experiences. Moreover, most students supported that they would like to be in a position to create similar environments by themselves (M = 4.05, SD = 0.83). This validates the pervasiveness of the maker culture and that students are ready and want to create their own interactive learning tools. Students' answers are presented in Table I.

Qualitative results

Students' comments in the interviews were in agreement with the questionnaire responses. They claimed that the FingerTrips environment was more fun and less tedious than traditional learning, as the specific type of learning interactions is closer to their technological expectancies. Students also supported that the active participation, the cooperation and the use of their body activated their learning processes more than the inertia provoked from their school desks.

> It is more useful and more fun. It becomes an easier lesson to follow.

> In a short time, we are making a trip around the world, while in the class we need a whole lesson for one place.

> We would have liked more this environment, instead of sitting at a desk over a book. We touch the path with our finger. We hear and see more things in comparison to reading the book.

Students were very positive toward the learning efficiency of this approach. They underlined both the extent of the content learned and the improved speed of learning.

> We would learn faster with this environment [in the classroom]. We wouldn't spend one and a half hour to learn the same things in geography, as we do in the class and we would not be tired. It would be more fun, and we would learn more easily.

> [we learn] definitely faster, because it is fun. This way will make us more attentive in the classroom. This approach is closer to us, so we can learn.

> We learned many more things. This approach gave us a lot more than a book.

Table I. Attitudes questionnaire

Question	AVG	SD
The tangible interface is pleasant to use and I enjoyed interacting with it.	4.58	0.67
The tangible interface helps me learn faster.	4.60	0.56
The use of the interface was difficult.	1.54	0.68
The interface provides an easy way of learning that is difficult to achieve in the classroom with the traditional media.	4.05	0.83
The interface allows me to make mistakes and gives appropriate feedback to correct them	3.84	0.97
I prefer the traditional way of learning, I learn better that way	1.88	1.04
The interface is innovative, I have not seen anything like this in the past.	3.58	0.99
I want my teachers to deliver similar interfaces for learning purposes	4.46	0.88
I would like to be able to create similar interfaces by myself	4.00	1.03

They repetitively compared their experience with the experience of studying a book about geography without having been asked for something alike. As expected, printed books were considered as passive means with limited expressive power in comparison to the vivid experience offered by the interactive augmented 3D map.

> It helped us tremendously. This method helps more students who cannot read Geography books and spend five-six hours over a book, and finally, they do not learn anything.

> [I liked] the fact that we could use our hands during the trip, while concurrently we were getting information. This way it's much easier to learn in comparison with the book, while you have the opportunity to travel and to learn about wherever place you want.

> We touch the map during the trip. We saw sights, we met various places through vibrant photos. These are things that cannot be done with books.

As also anticipated, students also pinpointed that the gamified learning activity grabbed their attention, motivated them to participate and have some fun while learning about geography. The inquiry approach and the gamified tasks assigned in the augmented terrain seem a good fit for geography learning. Once more, it was confirmed that games can attract and motivate students to the extent that formal education fails to do.

> It's better because the book is boring. With this game, we can learn but also have fun with our classmates.

> It is more interesting because there is an adventure when trying to find the keys. It is nicer because you cross the path by yourself and by touching the map.

> Yes, because it is more fun. You can learn and play simultaneously.

Students enjoyed driving the diverse means of transport over the augmented map with the navigational panel.

> We managed to fly by plane, we got on a train and a car.

> It was very nice to be able to control your own vehicle.

However, according to their comments, finger-based style of interaction on the map was the most remarkable component of their experience and had the greatest impact on their learning. Finger Trips were perceived as natural, real, pleasant or even "magical." The touch-based journey was interactive and surprised them by its easiness and the new type of interactions made possible. When students asked what they liked more in their experience, the majority indicated that the specific type of finger-based interaction was intriguing:

- The fact that we were in touch with the map and could travel with our hand from one place to another.
- The best part was once we start climbing the Alps.
- We can travel alone from one country to another, using our hand.
- It was magical to travel from one place to another using only your hand.
- It was very enjoyable to travel with the finger and follow the route as if you were there.
- It was perfect that we used our hand and, while traveling, the map was talking to us.

In the short knowledge questionnaire, students got an average score of 70 per cent, and that means that they recalled information for about five out of seven questions. If we consider the short duration of the interaction together with the rich pool of information presented, this is a satisfactory score. Because of its small size, students' answers could not reveal more info for relating the type of interactions with the knowledge acquired.

Conclusions

Our pilot study indicated that FingerTrips is a tangible environment that manages to transform the experience of meeting new places, understanding spatial relations and learning geography. Such an approach differs drastically from traditional means of learning, is closer to students' interactive experiences and expectations, gamifies learning and exploits embodied learning affordances to achieve efficient, effective and enjoyable learning. It is important to note that in such cases not only the interaction affordances but also the instructional framework which guides them are evaluated and that was also considered successful by the students.

Affordable augmented interactive 3D landscapes with FingerTrips can give life to geography and offer a participatory experience for students, a much-needed quality in geography learning. It is of equal importance that this approach can be followed by students and teachers by themselves, as they can design, develop and build interactive landscapes for the geographical areas of their own interest. The event-based programming of Scratch environment, together with the ability of Makey Makey to convert any conductive material to an interactive element, enables students and instructors to easily design and program FingerTrips with a variety of events and activities over an augmented map.

Static haptic guidance for learning is interesting because touch sensation is invisible and difficult to convey through verbal descriptions. Although touch is mainly considered as a computational input tool, it also seems to be an invaluable learning mean which can improve geography learning by providing spatial references and improving visual attention on the augmented terrains. Fingertrips have been proposed also for history learning (Triantafyllidou *et al.*, 2017) and our study is just an initial confirmation on the design routes that geography learning can take with tangible interactions. Both the 3D model can be enriched with more accurate and convincing representations (e.g. by adding real water in rivers) and the augmentation can be enhanced with more contextual multimodal feedback and more information semantics projected on the map.

Our study has several limitations, as we did not analyze the underlying embodied mechanism for learning and its learning effectiveness with detailed knowledge measures and learning analytics. We hypothesize that the FingerTrips provokes students to develop a significant number of gestures that help them codify and understand better the geospatial info. However, more detailed studies need to be done to explore similar hypothesis.

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