A Learning Environment for Geography and History Using Mixed Reality, Tangible Interfaces and Educational Robotics

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Abstract. Integrating ICT technologies in history and geography teaching may promote critical thinking and bridge the gap between unconstructive information accumulation and an explorative and critical learning approach. The aim of this study was to design, deploy and evaluate a low cost and easy-to-use mixed reality learning environment for interdisciplinary and embodied learning of geography, history and computational thinking. The proposed learning environment is comprised of an augmented 3D-tangible model of southern Europe where students interacted using their fingers, and a second treasure hunt augmented interactive floor depicting historical sites, where students performed tasks with Mindstorms EV3 robots. Students swapped between finger-based and robot-based journeys in Europe in two pairs until the end of the game. In order to evaluate our proposal, six groups of four undergraduate participants played with the environment in 6 sessions and for approximately 45 min. Data were collected with a pre and post knowledge test, an attitudes questionnaire and semi-formal group interviews. Students scored significantly higher in the post-tests and their answers in the questionnaires revealed that the multimodal environment enhanced their engagement and motivation, helped them orient themselves better around Europe's geophysical features, while the robotics treasure hunt consolidated their computational thinking skills, inducing a highly entertaining dimension. This approach better conforms to students' interactive experiences and expectations, gamifies learning and exploits embodied learning opportunities. Students engaged in the two augmented spaces in a perceptually immersive experience which became a more authentic and meaningful educational space.

Keywords: Mixed reality · Tangible interfaces · Educational robotics · Geography learning · History learning

1 Introduction

History provides students with past-to-present anchors and knowledge that can be used to develop a deeper understanding of current society and status quo, but also enables them to make informed decisions about their own social life. While a fascinating subject, learning about history was mostly deemed by students as an uninteresting and boring activity, owed to the fact that up until recently, teaching of history included

M. E. Auer and T. Tsiatsos (Eds.): ICL 2018, AISC 917, pp. 106–117, 2019.
https://doi.org/10.1007/978-3-030-11935-5_11

mainly the endless recitation of dates, facts and events. Students have always had trouble developing their historical understanding, limiting it to just the presented facts, and misinterpreting them out of historical context [1]. Learning history, nowadays, involves actual research and evaluation of historical sources and letting students reach conclusions based on accumulated evidence [2].

Geography on the other hand provides the essential spatial—in counterpoint to history's temporal-dimension, so that neither history nor geography are intelligible without each other [3]. Promoting geographical literacy as early as possible is seen as a highly significant endeavor for early education. The integration of ICT into school curricula has managed to evolve geography teaching by making related activities much more appealing and authentic to students, who are now able to use features such as interactive navigation on 2- or 3D data or access huge databases of geophysical data. ICT offers the opportunity to have more immersive geographical experiences and more time for observation, discussion and analysis [4].

The current research focus is to promote interdisciplinary teaching methods that combine History with Geography (and Maths, Art, Music) which can prove to be instrumental in increasing student motivation and learning effectiveness on all related domains [5]. In this frame of reference, tangible physical maps can play a major role in the development of novel teaching scenarios. Tangible physical maps complement and advance digital cartography (usually represented in screens) and become an invaluable tool for teaching geography in an embodied way. Tangible interfaces promote a sensory engagement of the student and the facilitation of spatial tasks while actively manipulating a digital representation of physical objects [4, 6]. On the other hand, a virtual "fingertrip" over an interactive augmented tangible environment representing historical sites seems to motivate students to engage deeper into the study of historical content [7].

Robotics can also add value to mixed reality tangible interfaces in a "shared reality" concept [8] where the robots act as an extra tangible interface to the mixed reality landscape and function as an agent to the virtual world. Beyond the physicality of the robot, the addition of robotics in a mixed reality scenario enhances the children's computational thinking skills [9]. The integration of robotics in learning environments facilitates the development of high order thinking processes (decomposition, abstraction, pattern recognition, algorithm design) and enables students to improve their problem solving skills [10]. Moreover, educational robotics provide a rich potential for team building and social skills development, enabling students to experiment and create on their own.

In this article, we present a two-layered tangible environment integrating two mixed reality environments that aim to enhance and improve the experience of learning geography, history and practicing computational thinking tasks. The environment offers two interactive surfaces, one table-top and one floor-based. The two tracks depict a journey performed by students via touching a 3d augmented tangible map, coupled with a robotics track where students perform a "Treasure Hunt" with a robotic companion. The goal of the study was to explore the efficacy of this multimodal tangible interface, which was constructed with low-cost and easy-to-find hardware, and which teachers and students can easily reproduce and transform to fit into multiple teaching scenarios.

2 Literature Review

The embodied cognition theory framework, postulates that acting and thinking are intertwined. The way we perceive objects or spaces is affected by the way we engage or explore them tangibly. Our mental representations are directly influenced by the physical world through our body. A variety of theoretical frameworks propose that full-body interaction potentially supports learning by involving users at different levels (affective factors, cognitive aspects, sensorimotor experience). Students create conceptual anchors on which new knowledge is built, by acting out and "physicalizing" processes, relationships etc. [11]. Thus, new interaction technologies provide us with the ability to deploy embodied learning interventions that serve as conceptual leverage. New modalities are constantly being developed, following the precepts of embodied interaction. These environments aim to facilitate embodied experiences of specific concepts, represent abstractions as concrete instances or express specific content via the operalization of actions. The use of educational robotics, mixed reality applications and tangible interfaces offers learning opportunities that need to be explored and exploited, since designing learning activities for such complex environments is an emerging and not yet systematized area of research.

Three research domains constitute the pillars of this study: a. Geography learning and tangible maps b. History learning and ICT and c. Tangible interfaces and educational robotics

Regarding tangible maps, recent studies have indicated that both paper and electronic maps have advantages and limitations in regards to students' spatial thinking skill acquisition [12]. However, the spatial topography of maps is inherently limited since the maps are projected into two dimensions. In that way, tasks about natural limitations or visibility assertions of locations are difficult to accomplish since learners have to reconstruct and reason for them mentally [13]. Tangible 3D physical maps enhanced by new digital forms of interaction, play a major role in contemporary cartography [14] and become an invaluable asset for learning geography in an embodied way [4]. Continuous shape displays, where a digital model is coupled with a physical one through a cycle of sculpting, 3D scanning and computation provide a continuous feedback loop through which the student interacts directly and very naturally with geophysical bodies, are being proposed as tangible interfaces for learning and are of special interest. The FingerTrips approach for teaching geography [4] has been shown to have positive results in altering the learning experience, making it more interactive, facilitating understanding of geographical spatial and geophysical relations.

Examining history learning, several studies have suggested that the use of ICT may motivate students and help them develop historical thinking skills [15] and contribute to the transformation of history learning to an explorative and constructive approach [16]. Apps such as timelines and simulations of historical events allow participants to better understand the concept of time, the successions of historical events and to capture how knowledge was discovered [17]. Museums and public installations are increasingly incorporating digitally-enhanced interactive experiences that provide visitors with a 'multimodal' engagement with the past [18]. There are few examples of embodied learning with tangible interfaces concerning history subjects. Recently, there is a trend to bring closer the classroom with historical installations through affordable and easily reconstructible augmented and embodied learning environments such as the FingerTrips approach, which apart from its geography application has also been used in the context of history teaching [7].

Educational robotics seem to enable educators to implement a wide range of educational approaches to classrooms: discovery learning [19], collaborative learning [20], problem solving [21, 22] competition based learning [23] and compulsory learning [24]. Although educational robotics are usually related to computational thinking [25], the potential for multidisciplinary learning is strong i.e. students can create a catapult as a prop for a tangible re-enactment of a historical battle or a water dam in the area the students inhabit [26]. Robotics have been successfully used in conjunction with drones in out-of-class teaching approaches [27] as well as with wearables and mixed/augmented reality environments in primary education classes [28]. Teaching scenarios integrating robotics with tangibles and mixed reality applications in a gamified context have been described in literature in multiple forms, highlighting the precepts of experiential learning in authentic contexts [29].

Mixed Reality (MR) environments merge the digital with the physical and offer a vivid and immersive audiovisual interface for eliciting body activity. In these environments, authentic and expressive physical activity can be augmented with digital displays that emphasize the metaphor and tools for feedback and reflection [30]. Mixed reality technologies allow students to become part of the system they are trying to familiarize with, and give them the advantage of the insider who can monitor and evaluate the mechanisms and relationships of the domain [30]. Mixed reality environments can function as an umbrella under which multiple technologies can be combined.

3 The Learning Environment

In this study we tried to create a learning scenario for history, geography and computational thinking which combines the following design principles:

1. Exploits embodied interaction with tangible objects.
2. Creates an immersive mixed reality environment in an authentic context where history and geography are intertwined with problem solving activities that also facilitate computational thinking and team work.
3. Creates a differentiated chain of activities which trigger two different modalities (FingerTrips and Robotics) and motivates students to interact with them.

The learning environment is based on two augmented spaces and students have to continuously swap between them. The first space is a 3D augmented interactive map on which students have to perform “FingerTrips”, i.e. travel on the map by placing and moving their fingers on an embossed geomorphological path (i.e. the Alps, the Pyrenees, the Apennines etc.). While travelling with their fingers, students have to react to challenges/questions posed by the environment. Some of these challenges prompt them to move to the second augmented space—the interactive floor—in order to program their robots to perform specific tasks for a series of clue-finding missions. The Robotics track changes to a different city every time the students visited a different place with their finger trips. As soon as they perform their programming tasks, they come back to the first augmented space. The whole activity encompasses a "treasure hunt" scenario around Europe. The students—in two groups of two students—have to complete a variety of tasks of increasing difficulty, which ask them to recall and apply prior knowledge but also provide new information in a fun and embodied framework.

For the construction of the FingerTrip [4, 7] model we used a 50 × 75 cm MDF for the base and plasteline for recreating morphological characteristics of the 3D map. A map was then overlaid on the model using a projector as seen in Fig. 1. The game was implemented in Scratch and the interface along with the finger trip with a Makey-Makey board. On the floor, another projector was presenting images on the robotics tracks with dimensions of 1.5 m × 1.13 m as seen in Fig. 2. The robotics track interface was also implemented with Scratch and a second Makey Makey board for the touch-bases. In Fig. 3 the full setup of the environment is presented.

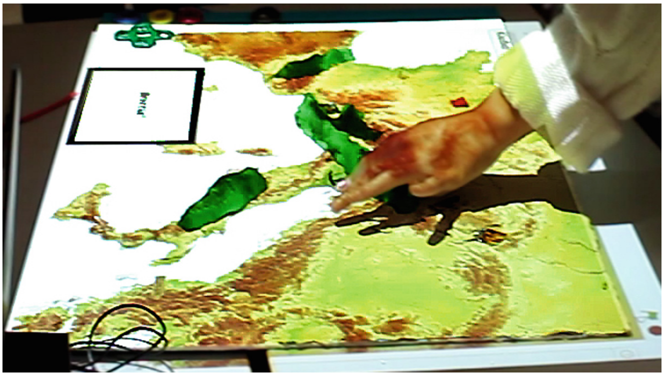

Fig. 1. FingerTrips Board

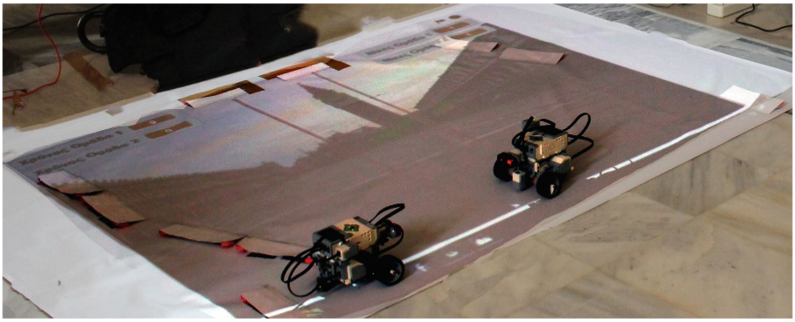

Fig. 2. Robotics track with EV3 explorers

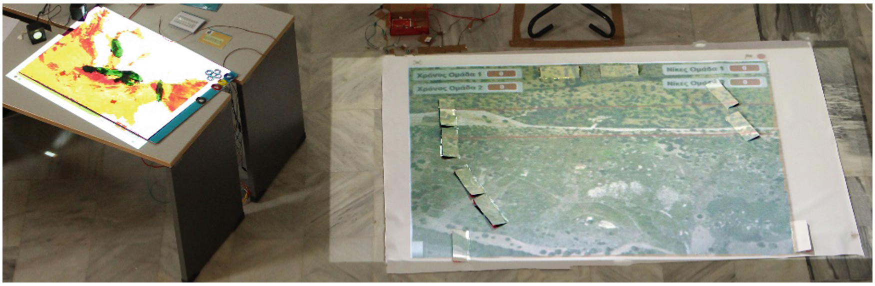

Fig. 3. Combined view

The game session begins at the augmented 3D map, where all participants play as one team. The journey begins from Corfu and passes through 6 major European cities, exploring the whole routes in between, answering to questions, learning about historical landmarks or geographical information, and finding "clues" that point to the next city. The game prompts questions which are answered (by all participants) via a tangible interface. As soon as the team arrives at a major destination, participants break down into two teams and "turn against each other" hunting for clues with their robots on the floor based track. Their robots take the role of competing "Explorers" who search for clues in historical sites across Europe (Valle dei Tempi in Sicily, the Colosseum and the baths of Caracalla, piazza San Marco in Venice, etc.). Students must follow in each city a projected route and perform specific tasks with their Robot explorers in order to be able to proceed. The interactive floor keeps the time each team needed to complete the robot missions and calculates the score. The programming tasks are evolving from introductory lessons of moving forward/backward, to more advanced uses using sensors, in 4 separate stages. The robotics track is equipped with cardboard "touch-bases" which detect whenever each robot reaches each destination. During all stages, programming instructions are provided to the students in the form of printed cards.

Thus, the intervention included a continuous exchange of activities, from traveling around Europe with Fingertrips to traveling in places with robots.

4 The Study

In order to evaluate the proposed environment, a study was conducted targeting pre-service school teachers.

4.1 Participants

Twenty-four (24) students from a Primary Education Department, 13 males and 11 females, participated in the study. The participants played with the FingerTrips and the augmented interactive floor environment in 6 (six) groups of 4 students. Each session lasted about 45 min.

4.2 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. Pre and post knowledge tests were given immediately before and after the intervention. At the end of each session, students were also asked to complete an online questionnaire about their experience. All students afterwards, participated in brief group interview.

4.3 Research Instrument

Data collection was based on pre/post tests, an attitudes questionnaire and a semi-formal group interview. Pre and post-tests were identical and were consisted of twelve questions for spatial relations (i.e., *Paris and the Alps are equidistant to the Equator*) and eight questions for information recall questions about geography and history (i.e., *To which mountain range does Mont Blanc belong?*).

The attitudes questionnaire consisted of 25 7-point Likert questions and evaluated the tangible environment in regards to its usability and attractiveness. Some of the questionnaires' items were derived from AttrakDiff [31] and Flow State Scale [32] and composed the following variables:

- *Ease of Use* (3 questions): Measure how easy to use the system is and its learnability;
- *Autotelic experience* (3 questions): Measures the extent to which the system offers internal user satisfaction;
- *Perceived learning* (3 questions): Measures students' perceptions on the educational value of the system;
- *User Focus* (3 questions): Measures the concentration during the use of the system;
- *The learning environment for practicing educational robotics* (3 questions): Measures students' attitudes towards the learning environment as canvas for practicing educational robotics development skills;
- *Pragmatic Quality* (4 questions): Measures the extent to which the system allows a user to achieve his goals;
- *Hedonic Quality-Stimulation* (3 questions): Measures the extent to which the system meets the user's need for innovation and whether it is of interest;
- *Hedonic Quality-Identity* (3 questions): Measures the extent to which the system allows the user to identify with it.

All variables can be considered as consistent since they had satisfactory Cronbach's a as seen in Table 2.

The semi-formal interviews took place immediately after the end of each session and aimed at extracting the qualitative assessments of the students and at allowing them to describe in their own words their experience with the FingerTrips and Robotics virtual space. The questions were focused on what students liked and disliked and their perceptions in regards to the learning effectiveness and efficiency of the environment. All audio-recorded interviews were transcribed and then encoded and compared within and between cases.

5 Findings

5.1 Questionnaires Results

Pre and post scores followed a normal distribution according to Shapiro-Wilk normality test ($p > 0.05$). Paired samples t-test were conducted and the results are presented in Table 1. The students scored significantly higher in the post-test both in spatial relation questions and in information recall questions as seen in Table 1. Hence, we can support that the learning environment had provoked significant learning outcomes.

Table 1. Pre/Post test results

	Pre test mean (SD)	Post test mean (SD)	t	Sig
Information recall	7.09 (1.70)	9.00 (1.98)	−4.757	0.001
Spatial relations	5.57 (1.65)	7.35 (1.07)	−4.229	0.001
Total score	12.65 (2.84)	16.35 (2.56)	−5.334	0.001

Students' answers to the attitudes questionnaire (see Table 2) show that the environment can address the problem of engagement with the historical and geographical content. However, students were also positive in regards to the learning efficiency of the environment and the possibility of exploiting it further for other university courses. They claimed that the environment made learning easier and more intriguing than with traditional teaching methods and that the environment helped them to remain focused on the learning activities.

Table 2. Attitudes questionnaire answers

	Min	Max	Mean	SD	Cronbach's a
Easiness	5.33	7.00	6.28	0.55	0.73
Focus	4.33	7.00	6.19	0.78	0.83
Autotelic experience	5.67	7.00	6.72	0.40	0.75
Learning preference	5.00	7.00	6.57	0.56	0.86
As a platform for learning robotics	4.67	7.00	6.33	0.63	0.76
Pragmatic quality	5.00	7.00	6.13	0.58	0.71
Hedonic identity	5.00	7.00	6.54	0.57	0.82
Hedonic stimulation	4.67	7.00	6.62	0.59	0.72

Students' answers in the mini AttrakDiff questionnaire validated that they considered the functions of the environments as appropriate to achieve the goal of understanding the geographical features and historical information presented (pragmatic quality). Moreover, the variable hedonic quality, which is a measure of pleasure (fun, original, engaging) and avoidance of boredom and discomfort had very high scores. Students' answers indicate that the environment made them identify themselves with it (Hedonic Quality-Identity) and believed that it offered inspiring and novel functions and interactions (Hedonic Quality-Stimulation). Finally, the students stated a strong agreement towards the use of the platform as a canvas for learning robotics ($M = 6.33$, $SD = 63$).

5.2 Interview Results

In accordance to the answers in the questionnaires, students were particularly positive about the intervention and characterized the proposed environment as attractive, fun, playful, pleasant, and creative. Such forms of activity are more suited to their technological expectations and create a more authentic and meaningful learning environment.

> It is a game that we will always be interested in playing.
> It is not a boring thing. Children learn much more easily.

Most students compared the environment with the typical geography and history teaching environments and commented that the new proposal is very different, more interesting and more motivating than typical teaching.

> I think it is a different experience to approach geography in this meaningful way, rather than simply looking at a map, a book or even a computer.
> It is much more different than traditional teaching and I would have preferred it 100%.

The finger-based style of interaction on the map was vivid, real, pleasant or helpful. Students considered the 3D finger trip as an interactive and intriguing experience and claimed that it helped them

(a) understand better the details of the geomorphology of the map,
(b) understand better the relative geographical positions of the different sites,
(c) acquire an overall orientation on the specific map.

FingerTrips gave meaning to the map and the presented narration and brought the students closer to the sites of the scenario.

> It is like going through it [the journey] empirically, it's not just like watching the map, with the finger trip you can feel walking along the mountain ranges.
> I was troubled for example about the geographical location of Rome in relation to Corfu but with the help of the game I understood something I was not sure about
> [Fingertrips are important] because if the map was flat we would not have to touch it with our fingers. We could not understand the morphology. Now, we were in contact with the mountains and the geographical relief.
> It helped us to understand the spatial relations.
> It also helped us in orienting ourselves around Europe.

The students also felt that the mixed reality environment for performing robotic missions was more interesting as a learning canvas than what usually happened in the laboratory course, where robots performed tasks on desks with artificial obstacles. The robots missions were integrated in the overall scenario, while movement seemed to be taking place inside a real physical space. The fact that the interactive model recognized the success of the assigned task for each team, changed the score and the context of use and gave appropriate assistance to the two different groups created a competitive climate that kept the students active and engaged.

> The robotics floor is interesting and more active, like an actual game.
> It certainly helps, in the lab we did everything on a desk, it was not the same in our thinking, the way we perceived it
> The augmented robotics map gives the illusion of a real space
> I loved that it kept score and measuring wins and losses. It was highly competitive and kept us active.

6 Conclusions

Our pilot study indicated that the proposed scenario of integrating a multimodal tangible environment managed to alter the experience of learning European geography and history while it also promoted computational thinking tasks. This approach is highly differentiated from traditional learning approaches, closer to the students' routine environment—which is highly technological and interactive—, gamifies learning and exploits embodied affordances to improve the learning process by making it more effective while keeping it fun and enjoyable. We should underline that students evaluated positively the instructional framework and not only the interaction affordances themselves.

Our intervention consisted of an affordable, reconstructable and easy to make 3D augmented map and an equally affordable and reconstructable robotics track, which gave life to geography and history and offered an enhanced participatory experience to students. Both teachers and students may follow this approach, since they can easily design, develop and build interactive landscapes and tracks for course material of their own. Scratch and Makey Makey board facilitate both teachers and learners to easily deploy such interventions over augmented maps.

The competitive part of our intervention, where students performed robotics tasks on the second augmented environment, added an extra dimension of originality while spurring them to action. Students stated vehemently that the usual laboratory robotics course would be much improved if the learning tasks were also performed on augmented tracks in the form of competition between teams.

We do acknowledge several limitations of our study, first and foremost the small number of participants, or the lack of analysis of the underlying embodied mechanism for learning. More detailed and expanded studies must be done to further explore whether similar multimodal, multi-technologies environment can address students' needs and desires.

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