An Embodied Instrumentation Approach for Spatial Thinking development using Geospatial technology

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Abstract

From navigation and furniture assembly to understanding planetary motion and DNA structure, making sense of spatial representations is an essential skill. Despite a large number of studies consistently highlighting the importance of spatial thinking and its relation to academic success, the impact of spatial representations on spatial conceptualization has not yet been adequately studied, and research has not been able to provide researchers and educators with design principles for the integration of spatial training into formal education. At the same time the use of geotechnologies, like GPS, for educational purposes has sparked the interest in the field. In this design-based research, we use an embodied instrumentation approach aiming to understand what kind of spatial meanings 12-year-old children develop while using digital spatial representations during navigation. The findings of this study suggest that the integration of dynamic screen-based representations into real navigational activities offer a rich context for spatial thinking development.

Keywords: spatial thinking, spatial orientation, GPS, embodied instrumentation

Introduction

"Spatial ability", "spatial skill", "spatial sense" are only some of the terms that researchers use to describe the set of knowledge and skills related to the ways we think and reason about space. Even though there is no clear consensus on the terms and the definitions given in the literature, it is widely accepted that the ability to "think spatially" is a necessary asset even in domains that are not naturally connected with physical space (Newcombe & Frick, 2010). We use maps to find our way in unfamiliar places as well as timelines and diagrams to represent the chronological order of historical events and the causal linkages between them. The positive correlation of spatial thinking with problem solving abilities (Mulligan, 2015), mathematics (Lowrie et al., 2017) and success in STEM domains (Uttal et al., 2013) is well established, nevertheless, formal education neglects children's spatial development even in fields that are inherently tied to space, like mathematics or geography (Lane et al., 2019). Consequently, children as well as many adults face difficulties in using spatial representations and find challenging even simple daily tasks such as assembling furniture or using a building outline to find a location in a shopping mall (Newcombe & Frick, 2010).

At the same time, digital technology advances, now provide us with new ways to interact with physical and digital space, creating an uncharted context for spatial meaning construction. The widespread use of geotechnology applications, like GPS and Google Earth, have made new kinds of spatial representations available even in mobile devices supporting this way modern educational approaches for spatial learning (Kerski, 2015). Even though many researchers have emphasized their pedagogical potential (Palaigeorgiou et al., 2018), educational design principles for geotechnologies integration in educational practice have not

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been developed since most of the research in the field has not been conducted in connection with actual educational settings (Jarvis et al., 2017). In this context this design-based research proposes an embodied instrumentation approach (Shvarts et al., 2021) in spatial thinking development aiming to gain insights on the spatial meanings 12-year-old children develop when using screen based spatial representations in real navigation settings. Aiming to gain insights in the kinds of meanings and thinking processes that children develop, the research is driven by two research questions:

RR1: How children use digital spatial representations in order to understand spatial concepts?

RR2: What is the role of children's embodied experience in relation to the use of these representations?

Spatial Thinking and Geotechnologies

Spatial thinking is described by the literature as a multifaceted construct that consists of spatial concepts, processes of reasoning and use of spatial representations (Bednarz et al., 2022). The development of spatial concepts such as location, direction comes as a result of processes of reasoning, the cognitive mechanisms such as recognizing or synthesizing (Jo & Bednarz, 2009), by which learners develop spatial concepts using spatial representations. Reasoning processes and conceptualization heavily rely on the use of spatial representations, meaning that the kind of representations one uses determines the kind of spatial reasoning processes and thus concepts he/she develops (Atit et al., 2020).

Nowadays geotechnology applications have evolved the way people interact with space, providing rich opportunities for spatial thinking development (Lei et al., 2009). Google Earth and GPS applications offer dynamic spatial representations that can be directly manipulated by students, making them potential impactful learning tools (Hamdanah et al., 2020). Many studies conclude that the use of geotechnologies can support the development of spatial concepts like direction, distance, network, analogy (Xiang & Liu, 2017) as well as problem solving abilities (Bryant & Favier, 2015). While most of the studies in the field support that students can benefit from the integration of geospatial tools in educational practice, research on the field remains limited and sparce (Schulze, 2021). There are still questions about how children use these representations in order to develop and communicate their ideas about space (Jarvis et al., 2017) while at the same time most of the research in the field is not conducted in real educational settings (Schulze, 2021) failing this way to provide design principles for geotechnologies integration into pedagogically designed learning activities.

An embodied Instrumentation design for spatial learning

Whereas technological advances have been bringing the role of tools and representations in the center of research attention, the role of one's body and senses on cognitive development has recently started to gain ground. Embodied cognition theory proposes that cognition "*is not considered an exclusively mental affair, but based on bodily experiences, that take place in interaction with the physical and social world*" (Ferrara & Sinclair, 2016). Thus, it is through embodied multimodal experiences that children create an understanding of the world while acting on it. In this context recent approaches in educational research reconsider the use of tools in learning contexts from an embodied perspective, emphasizing on the role of one's body and senses play on the meaning construction processes (Alberto et at, 2019).

Taking into account that spatial thinking development is naturally related to the way our bodies experience physical space, our educational design is based on so-called embodied instrumentation approach, where integration of digital tools into bodily educational experiences can support meaningful learning (Alberto et al., 2019). In this context the use of digital tools has impact on the practices and meanings the user develops (instrumentation process) and on the other hand these meanings affect the way the user uses or transforms a tool (instrumentalization) (Drijvers, 2019) in an action based embodied design where children tackle with a motor-control problems (Abrahamson et al., 2020). In this context, reasoning and concept development derives from the synchronization of their body movements in physical space and the according changes in digital representations (Duijzer et al., 2019).

Methodology

Aiming not only to contribute in related literature but also to provide a framework for action, proposing an innovative educational approach in learning spatial concepts linked to actual educational practice, this research follows the design-based research approach (Bakker & van Eerde, 2015), including the design of learning tools and activities and their implementation in reals educational settings. It is conducted in cycles of design-testing-evaluation. In this paper we refer to the 2nd cycle of implementation, where children participated in three navigational activities, that took place both outdoors and in the school's laboratory. In the first outdoors activity students were asked to choose a landmark to visit in their school's neighborhood. This could be another school, a church or the stadium. Childrens' paths were recorded using GPS Tracker application and were later saved as .kml files and in the next phase uploaded in Google Earth. The second activity was implemented in the school's lab where children worked in teams of three and used Google Earth and MaLT2, a logo programming environment where the user programs the movements of a digital entity, a hummingbird, in a 3D scene (Kynigos & Grizioti, 2018). In Google Earth they could see the map of their school's neighborhood, the landmarks of the neighborhood which were indicated with pin points of different colors and the paths they walked during the first phase (Figure 1). The MaLT2 microworld which we designed for the activity represented the landmarks of children's school neighborhood with pin points of the same colors as Google Earth map (Figure 1). In both environments children can change the view from 2D to 3D so that spatial relationships of the landmarks can be vied from different perspectives. Children were asked to recreate the paths they walked physically by moving the entity either by using simple logo commands like forward, left and right or by using the procedure "new flight" in the window of the editor (Figure 1). When they run the procedure, a green dot appears beneath the hummingbird. By clicking on this dot two sliders appear at the right bottom of the screen. The slider NS moves the entity on the axes North-South while the slider WE moves the entity on the axes East - West. When the entity reaches the target point a new pin appears that has the same color with the according pin on Google Earth map and the name of the landmark appears in the messages window of MaLt2 (Figure 1).

Data collection and Analysis

The data were collected from audio recordings of children's conversations during the activities, screen recordings from the mobile devices and computers used, activity sheets, children's digital artefacts and researcher's observations. The analysis was based in critical incidents approach (Angelides, 2001). Critical incidents are episodes that took place dusting the activity where children phase a problem and negotiate a solution. These episodes were categorized according to Bednarz et al. (2022) spatial thinking framework in order to identify

a) how children use the representations given in combination b) what kind of processes of reasoning they developed and c) what kind of spatial meanings they develop.

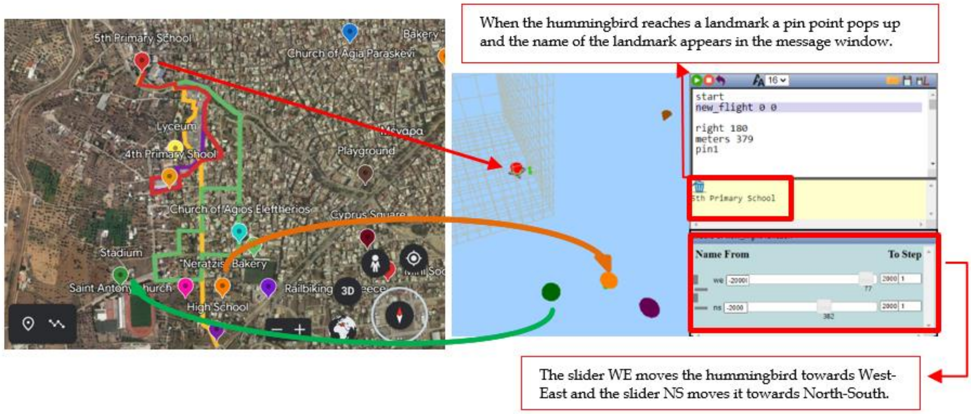

Figure 1: On the left the Google Earth map that students used. On the right the MaLT2 microworld. In both environments the landmarks children visited appear with pin points of the same color.

Results

This research aims to provide insights about the ways children use digital spatial representations in combination with their embodied experience in order to understand spatial concepts. In this section we present two critical incidents referring to our research questions:

RR1: The use of digital representations in spatial conceptualization

The variety of representations of the spatial environment children used enriched their thinking processes. In the first episode children have decided to use the procedure "new_flight" and move the entity using the sliders. The point the try to find is the Lyceum, which is indicated with a yellow pin point on the Google Earth map.

Episode 1:

C1: Where do I move now?

C2: Wait, so we are in the middle of the high school (purple pin point) and the stadium (green pin point) (Figure 2, 2)… (*opens Google Earth tab*) Now the Lyceum is here (*points on the Google map to the yellow point*). So, it is north…we have to go north…

C1: Ok so (opens MaLT2 tab) we use this slider (*clicks on the slider NS*)…

C2: But where is North?

C1: Wait, this is the Highschool (purple pin point) and this is the stadium (green pin point) ok? Look (*opens Google Earth tab*), the stadium is north of the high school… so (*opens MalT2 and changes the view*) (Figure 2, 1)…we move towards the stadium which is north…(*moves the slider so that the hummingbird moves towards the stadium and the yellow pin appears*). Yes! We found it (Figure 2, 3)!

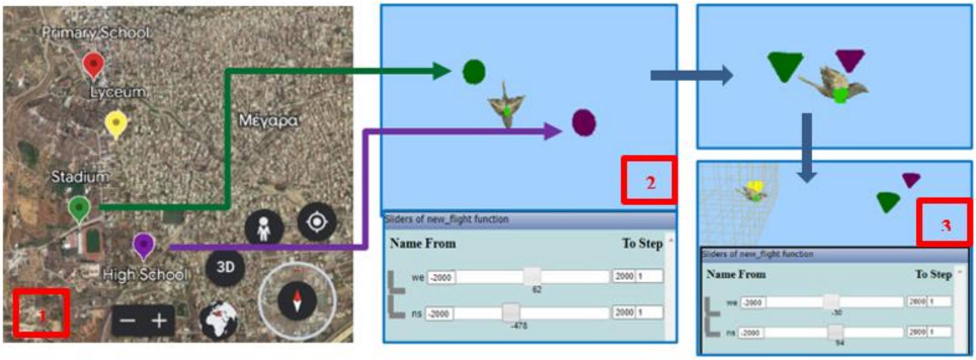

Figure 2: Students compare Google Earth map and MaLT2 environments in order to define which slider they have to move (1, 2). They then rotate the view in MaLT2 in order to identify which way they have to move the slider NS using the Stadium and Highschool spatial relationship (3).

The above episode is an example of how children used MaLT2 in order to identify north direction. C1 realized the spatial relationship of the two known landmarks, the Stadium (green pin point) and the Highschool (purple pin point). She though that the difference of these locations referring the north south axes would indicate the direction to the North. At this point she rotated the 3D camera in order to see the scene in a way that the spatial relationship between the two points would be more evident. Finally, she moves the entity towards the stadium (green pin point) because it is north of the high school and manages to reach the Lyceum (yellow pin point).

RR2: The role of the embodied experience

In the above episode children relied on the movement of the 3D camera of MaLT2. However, in many cases their previous embodied experience navigating physically in their neighborhood proved to play an essential role in their reasoning. In the following episode children try to program the hummingbird to reach the 5th primary school which is indicated by a red pin point on the Google Earth map. They have decided to program simple direction commands to reach their target point and they discuss the direction the hummingbird need to head to before they move it forward:

Episode 2:

> C3: The primary school is not in this direction…(*means the direction the entity is heading to in MaLT2 scene*) (Figure). We have to go North (*shows on the Google Earth Map*) (Figure)…Now the hummingbird is heading to the stadium which is south.
>
> C4: So, we turn…turn right?
>
> C3: In order to go to the stadium, we went the opposite direction (*means the opposite from the one they took when they went to the primary school*). Think, in order to go to the stadium, we went that way. If you are like that and you look towards the stadium (Figure 4, 1), in order to go to the primary school, you turn like that (*rotates her body*) (Figure 4, 2).
>
> C4: 180 degrees turn! (*programs the entity to turn right 180 degrees and then 379 meters forward*). So now it looks north (Figure 4, 3)!
>
> C3: Good now put the meters and check it.

C4: Yes, it's there! (Figure 4, 3)

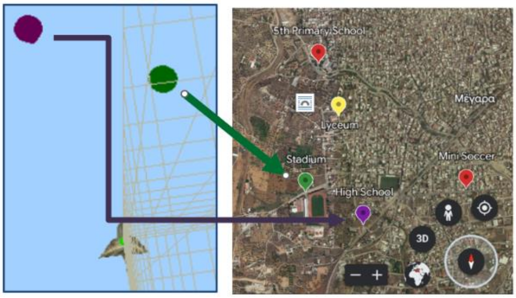

Figure 3: Children compare the digital representations and conclude that the direction the entity heads to is not the right one.

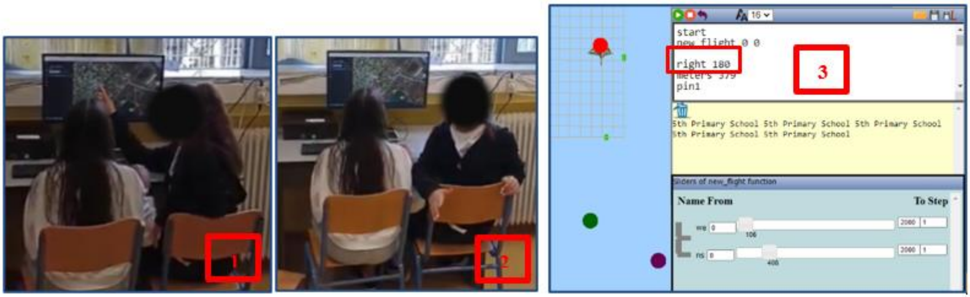

Figure 4: The girl recalls their walk and represents with her body the turn they would take if they were heading towards the stadium (1) and wanted to turn towards the 5th primary school (2). Her peer concludes that they have to program the entity to turn 180 degrees (3).

In the above episode previous embodied experience informed girl's reasoning as they tried to identify the spatial relationship between the target point and the points that appeared on the MaLT2 scene. Even if they realize from the Google Earth map that the direction the hummingbird needs to follow is the opposite one that it is heading to (Figure 3), this is not enough for them to conclude the turn they need to program the entity to do. For this reason, C3 represents with her body the movement the entity needs to make taking into account her embodied experience. She remembers that the way to the stadium is the opposite from the one that heads to the primary school so she makes with her body the movement she would do if she was physically heading to the stadium and wanted to head to the 5th primary school. Her movement is translated by her peer as a 180 degree turn as watching her, she realizes that the entity has to do an about turn.

Concluding remarks

The results of the study indicate that the combination of different kind of spatial representations that children can manipulate in combination with their embodied experience supported them in developing spatial thinking processes and thus spatial meanings, such as location and direction. On one hand the combination of Google Earth and MaLT2 dynamic representations enabled them to develop meanings about spatial relationships of known landmarks. On the other hand, their embodied experience supported children's reasoning. It has been supported that the concept of location and the conceptualization of spatial relations starts with reference to locations that students are familiar with, thus it is tightly linked to students' personal experiences (Schulze, 2021). This study confirms that children use familiar landmarks as reference points for determining spatial relations, thus concluding spatial meanings, even when interacting with digital representations that are linked to their personal experience, such as Google Earth maps. Therefore, children used their body and perception as means with which their conceptual thinking emerged, and evolved (Harris & Logan, 2021). Concluding the findings of the study show that there is a lot of potential in integrating dynamic digital representations into embodied educational experiences in order to develop spatial thinking and conceptualization.

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