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Geotechnology-based Spatial Learning: The Effects on Spatial Abilities and Sketch Maps in an Inter-Cultural Study

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Abstract. GIS have been coined as a support to thinking and learning spatially. In particular spatial learning in real environments can be supported by Geotechnologies as location-based games. We investigate how the use of a custom map-based geocaching game influences the individual development of spatial abilities and sketch mapping. We present a cross-cultural study with primary school children consisting of two spatial ability tests and a sketch map task in a pre- and post-test setting. Improvements were found in mental rotation and sketch map perspective, individual differences in culture and gender decreased for the experimental group. We conclude with a discussion of prospects and problems of integrating this type of GIS into education and learning.

Keywords. Spatial Learning, Spatial Thinking, Spatial Abilities, Geogames, Location based games, Education

1 Introduction

Geoinformation and geospatial technologies have made their way to the general public. Despite their potential for education (Baker and White, 2003; Favier and van der Schee, 2009; Vogler et al., 2010) studies reveal low levels of digital geomedia integration in educational contexts (Höhnle et al., 2010; Kerski, 2009).

Learning with geoinformation in K-12 education possesses the potential to support the development of spatial skills and competences (Bartoschek et al., 2017). Other researchers proposed geographic information systems (GIS) to train spatial thinking (Committee on the Support for the Thinking Spatially, National Research Council, 2006) and "Minimal GIS" for primary schools, in which a pedagogic goal of grade-appropriate concept understanding becomes the driving force behind the GIS (Marsh et al., 2007). However, classical GIS were not developed for teaching spatial learning and are not accepted by most educators. Both is mostly due to the complexity of the software and its interfaces (Höhnle et al., 2011). Furthermore, spatial learning and map reading can best be practised outside in the real environment which is not supported by the typical GIS.

Curriculum designers all over the world have already recognized the relevance and potential of learning with geoinformation and spatial technologies to foster competences like spatial orientation and have therefore developed new strategies to implement the use of geoinformation as an integral part in their curricula (Bartoschek et al., 2010; Milson et al., 2012). While the integration into the educational standards, curricula and even workbooks in geography education mostly took place between 2000 – 2010 (German Geographical Society, 2014) the teacher education and especially the factual use of GIS in K-12 education did not arise substantially in the same period (Höhnle et al., 2010; Kerski, 2009). In the following decade a successful integration of GIS in school education could only be observed in countries with well-established teacher training programs (Kholoshyn et al., 2021).

"Spatial thinking is the knowledge, skills, and habits of mind to use concepts of space, tools of representation like maps and graphs, and processes of reasoning to organize and solve problems." (Committee on the Support for the Thinking Spatially, National Research Council, 2006). Human navigation and orientation are fundamental spatial competences involving spatial problem solving, as well as the selection, utilization, and creation of spatial representations. The competences comprise cognitive skills (e.g., relating spatial information derived from maps to spatial relations in real environments) and spatial strategies (e.g., selecting appropriate tools and representations for the orientation task at hand).

Education of navigation and orientation contribute to the education of spatial thinking. Although it is expected that children learn to find their way and read maps (through the sixth grade in German school education for example), actual skill acquisition appears to be unsystematic and depends largely on learning opportunities outside the classroom. This results in large individual differences in spatial learning and orientation competence in early adulthood (Münzer et al., 2012).

Spatial technologies are pervasive today, and they are widely utilized for navigation purposes. Flexible, interactive map-based representations and mobile assistance for navigation in the real-world support spatial problem solving, route planning and guidance for navigation. In an educational context, technology should play a supportive role for the acquisition of human spatial competence.

The present study examines a particular approach for such a support system for spatial learning.

2 Related Work

We think spatially to orient ourselves, to find our way effectively to our destinations, to experience our surroundings, to interpret maps and other geographic information displays (Montello et al., 2014). Referring to position, determining distance, direction, or orientation are spatial concepts relevant for thinking spatially. Particularly, the ability to orient oneself spatially in different ways is therefore an important spatial skill, going well beyond the possession of basic topographic knowledge and serving as the foundation for the development of further geographical competences (German Geographical Society, 2014). Already more than 15 years ago Goodchild (2006) suggested that education in „numbers, text and logic" should be broadened to include reasoning with „maps, pictures and spatial data". This reasoning, or visualizing spatial relationships then representing and manipulating those relationships to perform cognitive tasks (Hegarty and Waller, 2005; Kastens and Ishikawa, 2006) encompasses competencies that humans have developed as we evolved (Tversky, 2003). Spatial orientation as a very specific area of these competences in geography education consists of the ability to orientate oneself in space (topographical orientation, map-reading competence, orientation in real spaces and reflection upon spatial perceptions). This competence can be found in most educational standards or curricula for geography on primary school level (Bartoschek et al., 2017).

While there is evidence that some individuals are inherently better at spatial literacy than others, research confirms that where people lack spatial competencies, they can, and should, compensate with spatial training (Hartley and Burgess, 2002; Hegarty et al., 2006). Having developed mostly paper-and-pencil tests for mental rotation, 2D/3D transformations, pattern recognition, and manipulation of shapes/volumes (Wakabayashi and Ishikawa, 2011), these measures of small-scale spatial ability are not wholly applicable to processes of spatial thinking over large-scale geographic space (Hegarty et al., 2006).

Nowadays, through various developments in technology, many alternatives to the paper map exist, that can assist individuals in spatial thinking. Geographic Information Systems (GIS), 3D representations of buildings, online mapping services, navigation systems all represent tools that can support spatial thinking (Lobben, 2004). Lobben (2004) encourages the use of maps to supplement spatial thinking, reasoning that “maps are more than tools", they are powerful models of display requiring a variety of human cognitive processes to read and interpret.

According to Klippel et al. (2010)'s analysis of You-Are-Here (YAH) maps, their broad uses and types can play a significant role in fostering spatial awareness. Schmid et al. (2010) introduce route aware maps where the context of environmental information necessary for the reader is available at different scales of the map, enabling the map reader to more easily relate the spatial surroundings to the route. Bilge and Taylor (2010) explore how learning environments by exploring them is more effective in small-scale spaces, whereas large-scale environments were much better learned from a map. Liben et al. (2010) advocate for the improvement of map reading education.

Gersmehl and Gersmehl (2007) developed “Teaching Geography", a collection of multimedia teaching resources for spatial thinking within world geography lessons. Marsh et al., (2007) argues that avoiding complex software packages is important to teaching younger school children spatial thinking, and Newcombe (2010) emphasizes that playing computer games improves spatial thinking as well. Wakabayashi and Ishikawa (2011) argue that for teaching younger children spatial thinking should be taught with GIS encouraging children to participate with geospatial information. Thus, teaching through maps, games, and practical interactive methods are ideal for spatial literacy education for children and led to our further developments.

3 The Spatial Learning Activity

Following the postulation “to design systems with spatial education as their goal, not simply shoehorning generic systems into this purpose” (Montello et al., 2014) we proposed a spatial learning activity. Given the availability of a widely distributed XO-Laptop from the One Laptop

Per Child Project in our study region Rwanda, we chose XO-Laptops as technology for our application. The activities's concept is applicable to any kind of mobile device as tablets or smartphones. The activity aims at providing a game activity for primary school children to support spatial thinking, especially in the domains of orientation and map reading.

We inquire, what educational aspects might be appropriate for the target group and discuss how the activity can deal with increasing ambitions of elder children. This didactical approach is combined with the cognitive view of the development of spatial competencies.

The display is comparable to a 10-inch tablet. The application allows only portrait format. Based on previous research and studies, we point out basic spatial concepts, the Geo activity shall provide. It is not intended to give an exhaustive list of possibilities, but rather to give a baseline to choose appropriate concepts.

Our didactical approach can be found in between constructionism and instructionism: children learn by doing and explore and discover instead of consuming prechewed knowledge (Papert and Harel, 1991). However, we are aware that an integration into educational practice, particularly curricula is key for the success.

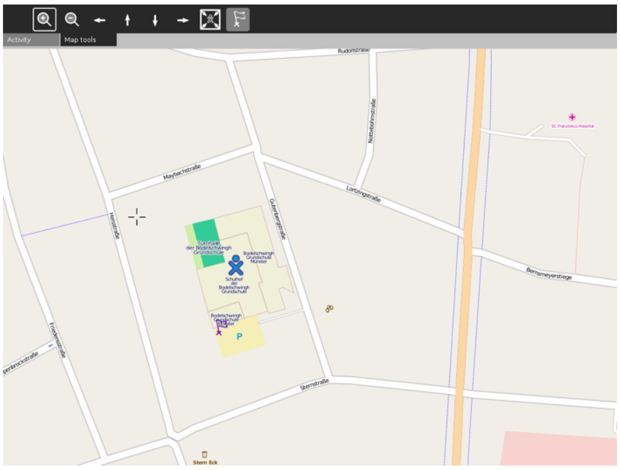

Figure 1. Interface of Geo Activity showing player's position and treasure

In a nutshell, an application incorporating the concepts of orientation and locomotion and the use of spatial representations such as maps can support/improve children's spatial thinking throughout the target age. In their study, Battersby et al. (2006) and Marsh et al. (2007) propose a minimal GIS for all grade levels at school, when particular spatial concepts were incidentally used. We believe, however, that such concepts are intrinsically used in human's environment, so a minimal GIS would make sense, anyway. Our activity can be used to provide spatial concepts in a gaming environment. No spatial analysis functionality is planned to be implemented, to reduce the educational content to the basic concepts, though, the activity could be considered as a minimal GIS, introducing simple spatial concepts to children. In an adaption of the GPS-based game "Geocaching" the player must find a treasure on the school ground. They have support through a base map, the display of the player's position on the map and a symbol marking the treasure on the map (s. Figure 1).

4 Experiment

4.1 Subjects

Subjects were 189 children, 101 males and 88 females, from Germany, Rwanda and Brazil. Their average age was 10.51 (S.D.=2.20). In Germany the children were in the fourth grade of the primary school, in Rwanda and Brazil the children were in the fifth grade. The children from Rwanda were between 10 and 16 years old, due to the irregular school attendance. The children participated in the study voluntarily, but during regular school time; their parents had been asked for permission in advance.

4.2 Materials

The materials consisted of two paper-and-pencil spatial-ability tests, which had been proven to be appropriate for children at this age (Quaiser-Pohl et al., 2004). The tests were supposed to measure the children's abilities in terms of mental rotation and spatial orientation. Additionally, the subjects were asked to draw a sketch map of the school ground and its neighbourhood, showing all the places that are of a relevance to them. These sketch maps were used as indicators of children's spatial representations of the study area.

Mental rotation is defined as the ability to mentally rotate three-dimensional objects (Linn and Petersen, 1985). Spatial Orientation is a factor proposed to measure the ability to imagine the appearance of objects from different orientations (perspectives) of the observer (McGee, 1979).

Spatial perception was measured by the mental-rotation ability was measured by the Mental Rotations Test and spatial orientation was measured by the Spatial Orientation / Perspective Taking test.

(1) Mental Rotation Test. A simplified version of the Mental Rotations Test (Shepard and Metzler, 1971; Vandenberg and Kuse, 1978) was used, based on the positive experience of Quaiser-Pohl et. al (2004). It consisted of eight standardized items, each showing a criterion and an

alternative figure. The figures were either identical, only seen from different angles and transferable into each other by mental rotation, or the alternative figure was a 'distractor', for example, a mirror image of the standard figure. In contrast to the original version of the Mental Rotations Test, there were no multiple choice answers: the subjects had to decide whether both drawings showed identical or different objects (see Fig. 2).

(2) Spatial Rotation / Perspective Taking Test (Hegarty and Waller, 2004; Kozhevnikov and Hegarty, 2001). According to the manual, this test is representative of the ability to imagine different perspectives or orientations in space. The test consists of an array of objects and an "arrow circle" with a question about the direction between some of the objects. The subject has to imagine standing at one object in the array, which is named in the centre of the circle, facing another object, named at the top of the circle and then to draw an arrow from the centre object showing the direction to a third object from this facing orientation (see. Fig. 3). Six arrays and questions were used in this version of the test instead of 12 in the original version to make the test more applicable for children.

(3) Sketch map. The subjects were asked to draw a sketch map of the school ground and its surroundings on a blank A4-sheet of paper using a pencil. Sketch maps represent the sketchers conceptual structure of the understanding of the sketched environment (Tversky, 2002).

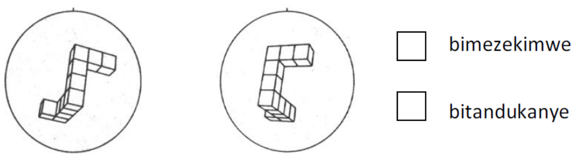

Figure 2. Adapted mental rotation test, based on Quaiser-Pohl et.al. (2004)

4.3 Procedure

In all three schools the testing took place in the classroom setting during regular school time. The participants were assigned randomly to the experimental and the control group. The study was divided into a pre- and a post-test and a variable in-between activity, consisting of playing the Geo activity for the experimental group and regular class activity for the control group.

On the first day of the study the two spatial-ability tests and the drawing of the sketch map of the school ground were administered in the following order: Mental Rotations Test, Spatial Rotation / Perspective Taking Test, Sketch map. The children completed the two tests without a time constraint, to not push any pressure and class-test atmosphere on them. To draw the sketch map, the children had a fixed time frame of ten minutes.

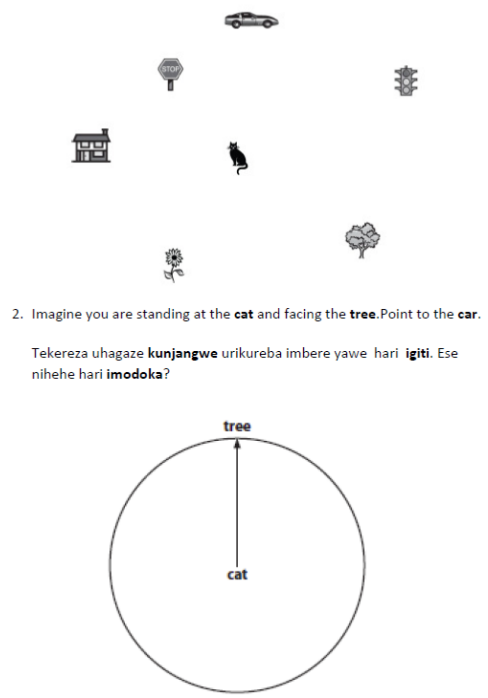

Figure 3. Spatial Rotation / Perspective Taking Test by Hegarty and Waller (2004)

On days 2 to 4 of the study the children performed the in-between activity. One group worked outdoor with the XO laptop (s. Figure 4) on the map-based geocaching-like activity. A control group was continuing typical indoor class work.

On the last day of the study all subjects performed the post-test in the same way as the pre-test on day 1.

Figure 4. XO-Laptop being used during field work

4.4 Scoring

For the Mental Rotations Test the correct items were counted and a sum score was calculated (α =0.62).

For The Spatial Rotation / Perspective Taking Test according to Kozhevnikov & Hegarty (2001) the score for each item was the absolute deviation in degrees between the participant's response and the correct direction to the target (absolute directional error). A participant's total score was the average deviation across all items. If a participant did not point to any target direction, a score of 90º was assigned for that item (i.e., chance performance, since the absolute angular deviation can range from 0º to 180º). The lower the score (smaller deviation) was, the better was the performance. To allow comparable statistical models we decided to code the score, by subtracting it from 180 as higher scores mean better performance in all other variables.

The sketch maps were categorized according to Siegel and White (1975) and Hart and Moore (1973) in terms of the stage and the quality of the underlying cognitive map. A cognitive map is ‘‘that body of knowledge of a large-scale environment that is acquired by integrating observations gathered over time and is used to find routes and determine the relative positions of places’’ (Kuipers, 1982, p. 203). Cognitive mapping is the process ‘‘by which an individual acquires, stores, recalls, and decodes information about the relative locations and attributes of the phenomena in his everyday spatial environment’’ (Downs and Stea, 1973, p.7).

First, the number of landmarks and route sections in each map was counted. Landmarks were all the salient objects, buildings, and places on the sketch maps, for example, the school building, sports places, or a playground. Routes were the connections between the landmarks, and route sections were the links from one crossing to another. Afterwards, the maps were categorized, first, if they were based on an egocentric (1), a fixed (2) or a coordinated (3) frame of reference according to Hart and Moore (1973) (Score name: SMP), and, second, if they were landmark maps (1), route maps (2) or survey maps (3) according to Siegel and White (1975) (Score name: SML). Both categorization are closely related to the different strategies that people use in large-scale orientation (e.g. Lawton et al., 1996). Some prefer a ‘‘landmark strategy’’ and retrace the route by walking from one landmark to the other. Others rely on ‘‘Euclidean strategies’’ based on configurational knowledge and use cardinal reference points, such as north and south, for wayfinding. Additionally for each study area the most prominent (most mapped) object was chosen, and a topology analysis was performed. The topology to other features in the real world was described using the RCC-8 model. Then the topology was compared to the topology of other sketched objects (Score name: SMT).

5 Results

The goal of the analyses was to estimate the contributions of experimental conditions and individual and cross-cultural differences for the prediction of performance in various spatial abilities.

The cross-cultural study was planned to be conducted with 4th or 5th grade children aged 9-12. The participants in Germany and Brazil fitted this interval, but in Rwanda participants from the 5th grade were 10-16 years old, due to irregular attendance of school (e.g., attending only every second year, due to homework). The dataset was tested if age is influencing any of the variables beforehand, based on the pre-test results. As various analyses did not show any significant effects of age on the variables, we decided to use the full dataset (n = 189) for further analyses, although the groups were inhomogeneous in terms of age. Since the children in Rwanda spent a similar amount of time in school, we assume that spatial abilities that might be practiced in school may be developed at the same level.

Table 1. Initial scores in spatial abilities tests

Country	**Sex**	**pre/post score diff. (SD)**	
		MRT	PTSOT
RW	F (n = 37)	3,70 (1,37)	71,96 (21, 74)
	M (n = 37)	3,81 (1,85)	78,80 (24,39)
BRA	F (n = 28)	4,69 (1,42)	57,93 (17,98)
	M (n = 33)	4,82 (1,59)	72,74 (21,59)
GER	F (n = 25)	5,48 (1,36)	111,14 (29,31)
	M (n = 29)	5,45 (1,45)	110,97 (33,37)

The cross-cultural data showed major differences in the descriptive analysis. Cross-cultural differences were found in the results of the spatial abilities tests (based on the pre-test only). While German children performed well in the Mental Rotation Test (Mean 5,46, SD 1,41) and the Perspective Taking / Spatial Orientation Test (Mean 111,03, SD 31,11), the children from Brazil and Rwanda showed a much worse performance (s. Table 1). The gender comparison shows that German boys and girls performed nearly similarly, while boys in Rwanda and Brasil performed much better than girls in all spatial ability tests (s. Table 1), e.g., significantly for Brazilian children in the Perspective Taking / Spatial Orientation Test (p = .004) (s. Figure 6).

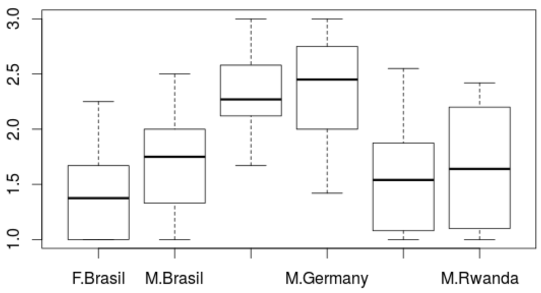

Figure 6. Box-plot of gender comparison in Perspective Taking / Spatial Orientation Test

The experiment condition of using the laptop and performing the geocaching game outdoors had effects on some of the test scores. We compared the difference of the pre- and post-test score to see any increase or decrease in the spatial ability. Overall, there was an increase in all the scores for all groups (Country / experiment condition – control group) besides in the Perspective Taking / Spatial Orientation Test. On a first glance there seems to be a strong effect of the experiment condition in the Mental Rotation Test (s. Table 2), in the Sketch Map Perspective measure and the amount of Sketch Map landmarks (s. Table 3).

Table 2. Pre/post scores in spatial abilities tests

Country	group	pre/post score diff. (SD)	
		MRT (Score 0-8)	PTSOT (Score 0-180)
RW	Laptop (n = 36)	**1,14 (1,59)**	-4,92 (20,78)
	Control (n=38)	**0,42 (1,99)**	5,48 (33,33)
BRA	Laptop (n=34)	**1,00 (1,60)**	1,43 (12,26)
	Control (n=27)	**0,67 (1,04)**	-3,99 (9,06)
GER	Laptop (n=11)	**0,64 (0,81)**	5,82 (12,08)
	Control (n=43)	**0,16 (1,59)**	-3,16 (20,00)

Based on the first findings, differences in the pre- and post-score that might be attributed to country, age, gender and group (experiment condition or control group) were further investigated using Analysis of variance (ANOVA) and linear regression models respectively.

Table 3. Pre/post scores in sketch map tests

Country	Group	pre/post score difference (SD)		
		SMP (Score 1-4)	SML (open scale)	SMT (Score %)
RW	Laptop (n = 36)	**2,00 (0,78)**	**1,64 (2,16)**	0,08 (0,12)
	Control (n=38)	**1,41 (1,02)**	**0,79 (1,50)**	0,06 (0,19)
BRA	Laptop (n=34)	**1,32 (1,12)**	**1,94 (2,57)**	0,04 (0,10)
	Control (n=27)	**0,70 (0,78)**	**0,59 (1,47)**	0,03 (0,10)
GER	Laptop (n=11)	**0,73 (0,65)**	**1,64 (1,96)**	0,09 (0,10)
	Control (n=43)	**0,60 (0,82)**	**1,28 (1,80)**	0,04 (0,10)

Results of ANOVA revealed a statistically significant effect of the laptop condition in the Mental Rotation Test, $F(1,180) = 6,720$, $p = .01$, as summarized in Table 4.

Table 4. ANOVA of Mental Rotation Test

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Laptop	1	17.0	16.972	6.720	0.0103
Country	2	4.9	2.448	0.969	0.3813
Age	1	1.5	1.546	0.612	0.4350
Sex	1	0.9	0.855	0.339	0.5614
Residuals	180	454.6	2.526		

A closer look on the linear regression model on the influence of the experiment condition on the Mental Rotation Test Score Difference reveals even a stronger significance of $p< .001$, see Table 5.

Table 5. Linear Regression Laptop Condition on MRT

	Estimate	Std. Error	t value	Pr(>ltl)
(Intercept)	0.3796	0.1520	2.498	0.01335*
Laptop	0.6327	0.2321	2.726	0.00703**

Similar results were found using ANOVA, respective a linear regression model on the influence of the experiment condition on the Sketchmap Perspective Score Difference and the Sketchmap Amount of Landmarks Difference. The influence of the experiment condition on all other variables (Perspective Taking / Spatial Orientation Test, Sketchmap Topologies) were not significant, see Table 6.

Table 6. ANOVA Effect of Country on SMP (Sketch Map Perspective)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Laptop	1	16.11	16.115	20.02	1.43e-05 ***
Country	2	25.05	12.525	15.56	6.55e-07 ***
Age	1	4.73	4.726	5.87	0.0165 *
Residuals	163	131.23	0.805		

Additionally, a main effect of country on the Sketch Map Perspective Score difference was detected to be strongly significant $p<0.0001$.

6 Discussion of Results and Relation to Other Studies

The present study was an attempt to assess the impact of the use of a digital map-based geocaching game on a mobile laptop on various spatial abilities of children independent of their cultural or educational background.

We have found no effects of the age of the children (9 – 16) on any of the variables tested. This was not what we have expected based on the (rather outdated) ideas of developmental stages and based on more recent work by Newcombe and Huttenlocher (2003). But this result gave us the possibility to work with the whole sample of 189 subjects.

The initial analysis of spatial abilities with Mental Rotation Test and Perspective Taking / Spatial Orientation Test, before the experiment gave us some insights into cross-cultural differences. German subjects performed significantly better than Brazilian and Rwandan children in all three tests. For the Mental Rotation Task this result is consistent with previous researchers' findings in a similar comparison study between German and Cambodian children (Janssen and Geiser, 2012), where German children outperformed the Cambodian participants. This result might be an effect of schooling, which has a strong impact on spatial abilities as shown in various studies (e.g., Bisanz et al., 1995; Huttenlocher et al., 1998). German children attended 4-5 years of school at the time of the study and were exposed to maps from the early years. German primary school curricula (grades 1-4) contain the training of spatial competencies and the use of maps in early stages (Nordrhein-Westfalen, 2008). Most of the Rwandan participants (9-16 years old) did not attend school every year, due to the participations in home and field work, all of them where in their fourth school year. Also most of them were not exposed to maps during schooling due to missing material (e.g. maps) although the Rwandan curriculum for social studies (Ministery of Education, Republic of Rwanda, National Curriculum Development Centre, 2006). Brazilian children were exposed to a very different curriculum with a rather small focus on spatial abilities.

A look on gender differences shows that German boys and girls performed nearly similarly in all tests, while boys in Rwanda and Brazil performed much better than girls in all initial spatial ability tests. In the Perspective Taking / Spatial Orientation Test Brazilian boys performed significantly better than girls. The absence of significant gender differences prior to training in Germany contrasts earlier findings in the literature highlighting male advantage over females especially in mental rotation for children of different ages (Carroll, 1993; Halpern, 2000; Linn and Petersen, 1985). A cross-cultural study by Sorby et al (1999) also found male students outperforming female in Mental Rotation and other spatial abilities. Similar findings to the one in our study were made by Rafi and Samsudin (2010) and Samsudin et al (2011) with secondary school children (15-16 years old) from Malaysia. A deeper look into gender differences would be necessary to understand these results, but this was not the focus of this study.

The main results of our study are the improvements in Mental Rotation, Sketchmap Perspective and Amount of Landmarks on the Sketchmaps after the experiment condition. The pre/post difference of the scores in these three tests is notable higher for the children that used the laptop with the map-based geocaching game in comparison to the control group. The significant increase of mental rotation abilities is consistent with findings by Okagaki and Frensch (1996), also in a comparable experiment condition, where the contact of a spatial training task with a video game was very short (6hr).

Baenninger and Newcombe (1989) found out that the effectiveness of spatial training is a function of the similarity between the training task and the testing task. That's why we have expected an improvement in the Perspective Taking / Spatial Orientation Test, as our experiment task (outdoor geocaching/orientation game, with the support of a digital map on a mobile laptop) was very similar to the testing task. Our results did not confirm this hypothesis. Only German and Brazilian subjects from the experimental group slightly improved in the PTSOT test, while the control group's score has decreased. Rwandan subject groups behaved contrary. The training effects may change, if the spatial training would not only a one-time contact, but having a medium duration as defined by Baenninger and Newcombe (1989) with several contacts in a period longer than three weeks. This medium duration had a largest combined effect size with control groups in a training meta-analysis (Baenninger and Newcombe, 1989). In another study the PTSOT was applied on a group of adult university students and a medium duration of training with a GIS. A statistically significant increase of the score was found amongst the whole population (Carbonell Carrera et al., 2011). Unfortunately, a medium duration of training was not applicable in our cross-cultural study setting. The PTSOT was successfully used by Lin et al., (2014) in a pre- and post-test setup and a similar training task (treasure hunting game) in a short training condition (1h) showing a significant improvement of the orientation ability. The training task was settled in a complete virtual environment, which was not the case in our study.

7 Conclusion and Future Work

In the presented work we introduced a motivation for the use of mobile and minimal GIS in education to support spatial learning and gave theoretical background on spatial abilities and competencies related to geotechnologies. We presented a custom map-based geocaching game on a mobile laptop and a cross-cultural study in Brasil, Germany and Rwanda assessing the impact of the game's use on various spatial abilities of children independent of their cultural or educational background. Based on the present results, we can conclude that the use of the game, even for a very short period of time (one hour), had a positive impact on the children's mental rotation abilities, independent of their cultural background. Also, the abilities to draw sketch maps of the study area (school ground and surroundings) improved significantly in terms of the drawing perspective and the amount of landmarks drawn, especially for the children in Rwanda.

A new finding was that male children outperformed females in the initial tests in Brazil and Rwanda while in Germany male and female participants performed nearly equally. This is a contrast to former studies (Carroll, 1993; Halpern, 2000; Linn and Petersen, 1985).

We also have found large cross-cultural differences in the initial tests of spatial abilities. German participants outperformed participants from Brazil and Rwanda in all tested spatial abilities. Both the cross-cultural and the gender differences were significantly smaller after the experiment condition.

These results support the initial hypothesis that the use of a mobile minimal GIS of this kind can support spatial learning. A promising result is that even a very short contact to such technologies has positive influences on the gain of various spatial abilities. This would allow the introduction of this kind of technologies into primary school curricula at different stages and different points of the curriculum. As educational systems usually are focused on short-termed interventions (45-90min classes), it may be difficult to find systems that can be reasonably used in such a context, giving an added value and supporting the development of spatial abilities. In times when ICT are being widely spread and used in education there is lack of useful systems, that really support learning in a short-termed use.

This study was focused on children in the age of 10-12, but other target groups of younger or older ages should be addressed in future studies.

Also, in further studies, we will refine the concepts of the software to better suite to the gain of spatial abilities and restructure the test design with an experimental intervention with a medium duration as successfully implemented by Baenninger and Newcombe (1989).

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