Effectiveness of a WebGIS-based project on high school students' spatial thinking skills

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Abstract

This study aims at developing a learning environment for school education based on the Web-GIS Technology using the Project-Based Learning (PBL) methodology. In this framework, 3 projects were designed and implemented with Project 1 and 2 combining and incorporating fieldwork with GIS while pertaining to local community problems, and Project 3 being conducted indoors, in the computer lab only with web-based data.

With the view to exploring the effectiveness of such an environment on students' Spatial Thinking Skills on qualitative basis, a quasi-experimental research on a sample of 58 students, 10^{th}, and 11^{th} grade of High School, was carried out. Two research groups were created, the first one for the realization of Project 1 και 2 (GIS1) and the second for realization of Project 3 (GIS2). A pre-test was conducted in advance and a post-test upon concluding all three Projects. The study found significant improvement in students' Spatial Thinking Skills. There is no obvious differentiation between genders while Spatial Thinking Skills are further boosted and enhanced when field work is applied in order to address local community issues.

Keywords 1

WebGIS, Spatial Skills, Spatial Thinking, Project-Based Learning, GIS-Based Project

1. Introduction

The formation of geospatially literate citizens, who have spatial thinking skills and are able to understand and process geoinformation from the physical world around them, is extremely important. This becomes apparent when looking at issues such as climate change, migration, urbanization, environmental pollution, epidemics, the globalization of the economy, the loss of biodiversity and the natural hazards growing on a global scale. All the above-mentioned issues have a spatial component, and hence addressing them requires a spatially literate population. According to [1], Spatial Thinking is defined as "collection of cognitive skills comprised of knowing concepts of space, using tools of representation, and reasoning process". Spatial thinking is universal and useful in a wide variety of academic disciplines and everyday problem-solving situations and should be taught at all levels of education, especially in scientific education [2, 1, 3]. The National Research Center (NRC) [1] recognizes that GIS has a well-established value as a high-technology support system for spatial thinking. Furthermore, geospatial technologies, which include GIS, have been included in the 25 most important developments that have affected the way of life in the 20th century [4]. Geographic Information Systems (GIS) are integrated computing systems responsible for collecting, storing,

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analyzing, visualizing, and presenting spatial data and the related descriptive information [5, 6]. WebGIS is a GIS based on the web technology and can be implemented with cloud technology.

The potential positive effects of integrating GIS into the educational process have been the subject of much study and discussion in the international scientific community. According to numerous studies, the integration of GIS in the educational curriculum promotes creativity, innovation, and collaborative learning. Furthermore, it enhances critical thinking and learning engagement and helps develop spatial-thinking, decision-making, and practical problem-solving skills [7, 8, 9, 10, 11, 12, 13, 1].

Despite the widespread use of GIS in higher education, the same does not, unfortunately, occur in school education due to a number of obstacles - at least until recently [14, 15, 13, 16]. However, the new opportunities and workflows that WebGIS provides, the free distribution of online geospatial data, mobile devices, the emphasis on spatial thinking, an educational emphasis on practical problem solving, the professional development of teachers and schools with modern laboratories, are gradually lowering barriers and are positioning GIS as a valuable tool for schools around the world [17, 18]. Aptly, Van der Schee and Scholten [19] argue that "It goes without saying that GIS is part of the education of the future. The question is not whether GIS should be used in education, but how".

Therefore, the research agenda should look for the most appropriate ways to use GIS in the curriculum and the environments in which they can be effective [7, 18]. It is accepted by the vast majority of the educational community that a Project-Based Learning (PBL) methodology is particularly effective in achieving learning objectives. GIS, as a technologically powerful tool, can be easily integrated into the PBL method as such technologically advanced tools have data collection, storage, analysis and visualisation as their main functions. A new framework to utilise GIS in school education can be created by adding the spatial dimension through GIS technology to the design and implementation of a PBL project related to local community issues, aiming to cultivate spatial thinking skills. As a testament to the above, the specific field of research regarding the connection which students develop with their communities as well as the pedagogical benefits they gain as a result of conducting GIS-Based Projects, were recognized by Baker et al. [7] as one of the six research gaps related to GIS in education.

2. Methodology

The present study aims at developing a school-education learning environment, based on WebGIS Technology using the Project-Based Learning (PBL) methodology. In this framework, 3 projects were designed and implemented related to real-world issues. Project 1 and 2 examined local community issues and both included authentic field data collection using smartphones and GPS while project 3 was related to a global issue and it was conducted only in the computer lab based on web data.

2.1. Sample Analysis

With the view to investigating the impact of such a learning environment on students' spatial thinking skills, a quasi-experimental research on 58 senior high school students (Lyceum of Vrachnaiika) was conducted during the school year 2019-2020. Two work groups were created, one for the realization of Project 1 and 2 (GIS1) and the second for Project 2 (GIS2). The two groups were tested in isolation (GIS1 vs GIS2) and as a whole group (GIS All) (Table 1).

Table 1
Analysis of sample size

Group	N	Male	Female	Group Description	Projects
GIS1	38	23	15	Students from A1 & B2 class	1, 2
GIS2	20	12	8	Students from A3 class	3
GIS All	58	35	23	All students	1,2,3

2.2. Geographic survey area

Lyceum of Vrachnaiika is a 40-year-old public school with students of working class and farmer families mainly, coming from lots of surrounding areas/villages. The school is located in Vrachnaiika which is administratively part of the enlarged Municipality of Patras, by the sea, about 12 km from the center of Patras, has an altitude of 16 meters, a longitude of 21.6665260608 and a latitude of 38.1595322598 (Figure 1). According to the 2011 Greek national census, the survey area has a population of about 5,300 inhabitants. In the present study the above geographical area will be referred to as the "survey area" and concerns Project 1 and 2. Regarding Project 3, the survey area is the whole of Greece.

Figure 1. Geographic survey area of project 1 and 2

2.3. Spatial Thinking Skills Test

The data collection process involved having both groups take a pre- and post- Spatial Thinking Skills Test. This test was predominantly based on Spatial Thinking Ability Test (STAT) developed by [20] and consists of 16 multiple choice questions assessing 8 parameters of Spatial Thinking. The Spatial Thinking Skills Test used in this research adapted 7 suggestions of the STAT which were modified to suit senior high school students. An additional item was taken from Spatial Concepts and Skills Test (SCST) [21]and two more from Spatial Ability Test [22]. These 10 items combined are used to assess 5 components of Spatial Thinking (Table 2). The overall performance of the students was based on the total number of questions answered correctly, with each correct answer counting as 1 point, for a total of 10 points.

Table 2

Description of question types and spatial thinking components to evaluate

Item	Spatial Thinking Components
1,2	Overlaying and dissolving maps
3,4,5	Comprehending orientation and direction
6,7	Comprehending and utilizing geographic semiology (point, line, or polygon)
8,9	Choosing the best location based on several spatial factors
10	Spatial concepts

2.4. Statistical methodology

In order to assess the efficacy of the learning environment (Independent variable) on Spatial Thinking skills (dependent variable) t-tests were used, a p value less than 0.05 ($p \leq 0.05$) assumed to be statistically significant. Pre- and post-test scores were compared by taking a paired-samples t-test to understand whether students significantly improved their spatial thinking skills after they finished the WebGIS-Based Project (educational intervention). To compare the difference of the two score means between the genders, independent samples t-tests were conducted, pre- and post- the educational intervention. Lastly, to measure the Effect Size of the educational intervention on students' spatial thinking skills, Cohen's d was calculated. The calculation involves taking the score mean difference between two groups and divide the result by the pooled standard deviation. Some typical Cohen's d values are referenced in Table 3.

Table 3
Effect Size Scale Cohen's d [23]

	Small Effect	Medium Effect	Large Effect
Cohen's d	0.20	0.50	0.80

2.5. Description of WebGIS-Based Projects

In order to determine the students' research interest, those who make up the GIS1 group were asked to explore the main social, environmental, and economic problems of the local community and to formulate respective research-project topics that will assist in designing solutions to these problems. Various project topics were discussed in the initial meetings and after evaluating factors such as the actual connection of the topic with local community, the availability of data and equipment, the required time, the level of knowledge of students, school limitations etc. [8], the three most suitable projects were selected (Table 4). The first two were conducted both indoors, in the school computer lab, and outdoors, in the survey field, and the third which was related to a current global socio-economic health crisis, was conducted only in the computer lab, based on web data, and is an example of an internal GIS-Based Project.

Table 4
Description of GIS-Based Projects

	Topic of GIS-Based Projects	Class Group	Duration	Place
1	Sidewalk inventory of the survey area	A1 GIS1	1 School Year	Computer Lab & Research Field
2	Recycling and Waste bin inventory of the survey area	B2 GIS1		
3	Creation of an interactive application that maps the geographical distribution of the recorded confirmed cases and deaths of Covid-19 in Greece.	A3 GIS2	1 Semester	Computer Lab

Before starting the planning of the activities, the teacher, following the directives of Demirci et al.; Kotsopoulos; and Favier [8, 24, 25] which state that students should first learn to how to use GIS tools and then use them so as to learn with them, conducted a series of workshops on the basic functions of the ArcGIS Online platform. It should be noted that throughout the implementation of the projects, there was further targeted training of students on the applications of the ArcGIS Online platform

(ArcGIS Survey123, ArcGIS Collector, ArcGIS Insights, ArcGIS Story Maps) related to the planned activities of the projects.

In brief, Table 5 presents in a coded manner all the activities carried out during the implementation of the three research projects.

Table 5
Activities carried out during the implementation of the research projects

	Group GIS1		Group GIS2
Project Activities	Project 1	Project 2	Project 3
Fieldwork	V	V	X
Field data collection	V	V	X
GPS use	V	V	X
Smartphone use for data collection	V	V	X
Web-Based data collection	V	V	V
Using Google Street View			
Activities related to ArcGIS Online platform			
Getting acquainted with basic features of the platform	V	V	V
Web Map Creation	V	V	V
Adding existing feature layers to the Web Map	V	V	V
Styles and pop-ups configuration in Web Map	V	V	V
Date Base creation	V	V	X
Using "Split" tool	V	X	X
Using Survey123 app for field data collection	V	V	X
Using Collector for ArcGIS app	V	X	X
Data Analysis using Insights for ArcGIS	V	V	V
Story Map Creation	V	V	V

3. Results

Statistical analysis performed presented in this section in two discrete directions: statistical analysis by student group (sub-section 3.1) and by gender (sub-section 3.2).

3.1. Results by student group

As seen by the following deductive and statistical metrics (Table 6), the Spatial Thinking Skills of all students were significantly improved (Group GIS All), indicated by the statistically very significant difference between the pre- and post- means (MD= 0.76, p= 0.001). The measurement of effect size of the independent variable on the dependent variable, measured by Cohen's d, was small to medium (Cohen's d = 0.46)

Table 6
A comparison of pre- and post-Test scores by group (Paired samples T-test)

		Pre-Test		Post-Test				
Group	N	Mean	SD	Mean	SD	MD	P value	Cohen's *d*
GIS1	38	5.95	1.66	6.79	134	0.84	0.003	0.52
GIS2	20	5.10	1.59	5.70	1.53	0.80	0.150	0.34
GIS All	58	5.66	1.68	6.41	1.49	0.76	0.001	0.46

As demonstrated in Table 6, it becomes apparent there is a statistical difference between group GIS1 and GIS2. The results indicated that Spatial Thinking Skills only for group GIS1 improved significantly since a statistically significant difference existed in the scores of pre- and post-test, as indicated by both p-value ($p=0.001<0.05$) as well as the effect size which as seen by Cohen's d (Cohen's d = 0.52) was medium. Group GIS2 showed some improvement of Spatial Thinking Skills (MD=0.80), however there was not statistically significant improvement between the scores of pre- and post-test (p= 0.150).

This study to find out whether there was a statistical significance in the mean value of the test between groups GIS1 and GIS2 prior to the educational intervention. In order to correctly assess that, an Independence Samples test was used, with Table 7 showcasing the results of the test. Examining Table 7, no statistically significant difference can be noted between the two groups ($p>0.05$), hence it can be concluded that the two groups were at a similar Spatial Thinking Skills level prior to the educational intervention. Conducting the Independence Samples test after the educational intervention can be seen to substantially affect the Spatial Thinking Skills, as p-value=$0.007<0.05$, with GIS1 group being the one most in benefit of the educational intervention (Table 7). This finding also further confirms the findings of the paired samples test (Table 6).

Table 7

A comparison of pre- and post-Test scores by group (Independent Samples Test)

	GIS1 (N=38)		GIS2 (N=20)		Score difference	P value
	MT	TA	MT	TA		
Pre-Test	5.95	1.66	5.10	1.59	0.85	0.066
Post-Test	6.79	1.34	5.70	1.53	1.09	0.007

The author will now conduct a quantitative descriptive analysis to understand which questions contributed the most to the improvement of the test scores between the two groups by comparing the mean value of each test item pre and post WebGIS-Based Project intervention (Table 8, Figure 2 and 3). Studying the data and the graphs, one can observe that GIS1 showed a greater improvement than GIS2 in most test items. Considering that each test item was designed to measure one or two components of spatial thinking (Table 2), it can be seen that the performance of both groups differs both per spatial thinking component and in item that evaluate the same component of spatial thinking. In particular, all groups found Q1 difficult to solve as it contains folding shapes, whereas Q2 was rather easy to solve as it contains a mental rotation of shapes, despite both questions assessing the same Spatial Thinking component, "overlaying and dissolving maps". A similar situation can be observed for questions Q3, Q4 and Q5, all examining Spatial Thinking component "comprehending orientation and direction", with students scoring well in Q3 & Q4 and mediocre in Q5. Q6 & Q7 assess Spatial Thinking component "comprehending and utilizing geographic semiology", in which students of GIS1 performed better than those of GIS2, given the nature of the research GIS1 conducted.

Table 8

Average score values of each item by group

		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
GIS All	Pre-Test	0.26	0.90	0.71	0.67	0.45	0.53	0.64	0.40	0.38	0.72
	Post-Test	0.33	0.86	0.74	0.74	0.57	0.76	0.74	0.45	0.50	0.72
GIS1	Pre-Test	0.32	0.92	0.76	0.66	0.45	0.58	0.68	0.45	0.39	0.76
	Post-Test	0.39	0.84	0.79	0.71	0.61	0.84	0.82	0.45	0.55	0.79
GIS2	Pre-Test	0.15	0.85	0.60	0.75	0.45	0.45	0.55	0.30	0.35	0.65
	Post-Test	0.20	0.90	0.65	0.80	0.50	0.60	0.60	0.45	0.40	0.60

Q8 & Q9 assessing component "choosing the best location based on several spatial factors" proved to be rather difficult for students to answer given the low scores the two groups had both pre- and post-the educational intervention. Q10, shaped around "spatial concepts", was well taken by all students with GIS1 also overperforming the rest.

Figure 2: Pre-Test score differences between groups

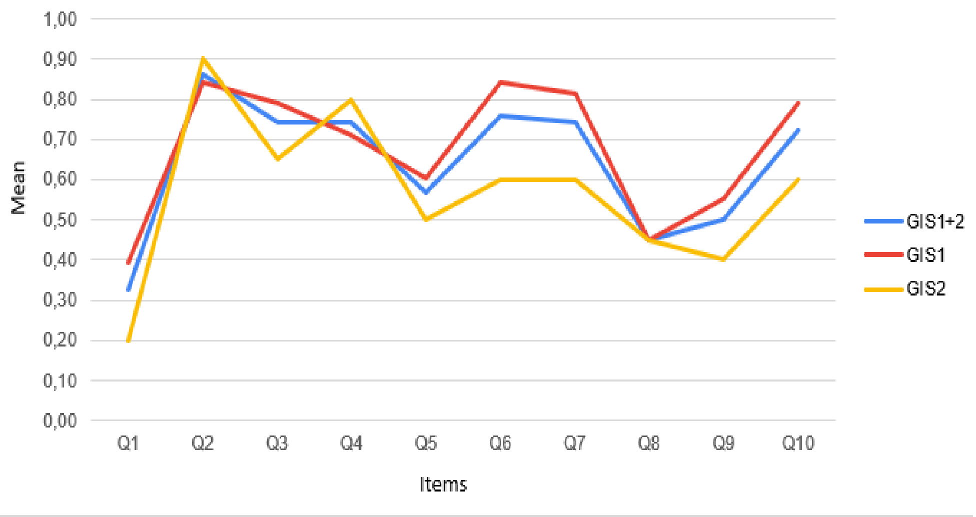

Figure 3: Post-Test score differences between groups

Studying figures 1 and 2, a similarity in shape can be seen. This is a rather important finding, as it shows that regardless of the group, students were faced with the same level of difficulty in the test questions. Kim [21] reports similar findings in his thesis as well as those of Lee [20] who not only studied high school students but also university ones.

3.2. Results by students' gender

This section of the study will examine whether gender affects Spatial Thinking Skills performance.

Initially, an assessment of gender performance within the same group will be made using the Independent Samples t-test both pre- and post- the educational intervention. Table 9 contains the full results of the genders taking part in the test (male, female) both for GIS All and GIS1 groups. Test results showed that there was not a statistical significance between male and female students of the same group neither pre- nor post- the WebGIS-Based Project intervention, as confirmed by the p-value>0.05 in all scenarios. It can, therefore, be concluded that the Spatial Thinking skills of both genders were equal both pre- and post- the teaching input. Next, a Paired Samples test is taken into consideration in order to examine whether the improvement pre- and post- the educational intervention was comparable between the two genders in the experiment.

Table 9

A comparison of male and female scores by test (Independent Samples Test)

			Male		Female			
		N	Mean	SD	Mean	SD	Score difference	p-value
GIS All	Pre-Test	58	5.61	2.06	5.69	1.39	0.08	0.865
	Post-Test	58	6.61	1.67	6.29	1.36	0.32	0.423
GIS1	Pre-Test	38	6.13	1.10	5.83	1.44	0.30	0.584
	Post-Test	38	7.13	1.46	6.57	1.24	0.56	0.205

According to the above-mentioned Paired Samples test (Table 10), the difference between the total mean value pre- and post- the educational intervention both for male and female students was statistically significant ($p<0.05$) for both groups (GIS All, GIS1). The Effect Size of the independent variable on the dependent one, was medium to large for female students (Cohen's $d>0.50$) and small to medium for male students ($d>0.30$). As a result, it can be concluded that both genders substantially improved their Spatial Thinking Skills post the educational intervention and by taking Table 10 into consideration, female students trailed the male ones.

Table 10

A comparison of pre- and post-Test scores by gender (Paired samples T-test)

			Pre-Test		Post-Test				
		N	Mean	SD	Mean	SD	Score difference	P value	Cohen's d
GIS All	Female	23	5.61	2.06	6.61	1.67	1.00	0.007	0.62
	Male	35	5.69	1.39	6.29	1.36	0.60	0.045	0.35
GIS1	Female	15	6.13	1.10	7.13	1.46	1.00	0.030	0.63
	Male	23	5.83	1.44	6.57	1.24	0.74	0.044	0.45

4. Discussion – Conclusions

NRC [1], maintains that basic and essential special literacy skills can be learned and acquired and can, thus, be formally taught to students with the use of appropriate technology, appropriately designed tools, and respective curricula. For the purposes of the current research, a learning environment was created which incorporated the PBL learning model, based on WebGIS technology (ArcGIS Online). In this framework, 3 projects were designed and implemented. Project 1 and 2 combine and incorporate fieldwork with GIS and it pertains to local community problems and Project 3 was conducted indoors, in the computer lab only with web-based data. The main Research Question of the current study was whether the realization of the aforementioned projects had a positive impact on students' Spatial Thinking skills.

Statistical analysis showed that Spatial Thinking Skills improved significantly for all students in total (GIS All). Taking a closer look at separate groups, however, proves significant improvement for GIS1 students, as opposed to GIS2. As for both genders' Spatial Thinking Skills, these improved statistically significantly for both boys and girls after educational intervention.

The above-mentioned results are consistent with several studies which highlight the relationship between GIS and the cultivation of Spatial Literacy. Lee and Bednarz [2] argue that the use of GIS technology in education enhances Spatial Abilities, while the NRC [1] recognizes that GIS has clearly proven valuable as a support system for spatial thinking. According to Kotsopoulos [24], GIS-supported teaching has a positive effect on the creation of spatial thinking and reasoning. Additionally, Jo et al. [26] used the STAT tool to investigate the educational effects of Web-GIS on the spatial Thinking Skills of undergraduate students. The findings showed that the GIS online activities implemented in the aforementioned study significantly increased the spatial thinking skills of the students and according to Baker et al. [7], "the use of GIS in the classroom helps students to think critically, use data and connect it back to the local community".

All in all, it is evident that the learning environment developed in the present study has had a positive effect on Spatial Thinking Skills. The above conclusions do not differ in terms of gender and are particularly reinforced when research projects include the capturing of real-world field data in order to solve practical problems in the local community. In addition, the present study further highlights that students should first be shown how to use GIS and then use it as a learning tool. In practice, it means that before conducting a GIS-based learning activity, a relevant workshop should precede the activity, showing students how to use the tools. Additionally, the duration of the projects plays a significant role, as there is more time for GIS-related activities to be completed. Finally, the ArcGIS Online mapping platform, despite being a professional GIS software, has all the necessary features in order to be used in a pedagogic setting, too.

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