The Teaching of Geography Using Dynamic Geometry Software

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ABSTRACT
The use of dynamic geometry software (DGS) in all kinds of mathematical games has become a widespread phenomenon. Rich features and availability of free DGS, such as GeoGebra, have caused a growing interest for developing teaching materials for subjects other than matematics. We present the teaching materials that we developed in GeoGebra for the subject of geography at elementary and middle school level. An interactive component that we developed, aimed specifically at applications in computer geography, is also discussed.

Categories and Subject Descriptors
D.2.2 [**Software Engineering**]: Design Tools and Techniques – *Object-oriented design methods, User interfaces*; I.3.2 [**Computer graphics**]: Graphics Systems – *Stand-alone systems*

General Terms
Design, Experimentation, Human Factors

Keywords
Dynamic geometry software, GeoGebra, geography games

1. INTRODUCTION
Mathematics can be found in almost any subject taught in school. In geography, there are many examples in which mathematics is used, either explicitly or in a less prominent way. For instance, we may need to measure the distance between two points by following a polygonal line, such as a river or a road. Another good example is using a compass to find the correct bearing in order to get from one place to another. Reading maps and determining locations of various points (e.g. cities) is yet another example. Geographic maps can be represented as collections of polygons, polygonal lines and points, therefore dynamic geometry software (DGS) can be used to create interactive maps.

Such maps can be used for testing or as teaching and self-study materials. Our aim was to develop a set of teaching and testing materials which would help the pupils learn more efficiently.

Thanks to its ability to import bitmap images, measure angles and draw polygonal lines, GeoGebra is a well-suited tool for development of interactive teaching materials for geography. However, in more complex scenarios, GeoGebra has some limitations which can not be easily overcome. The main problem we encountered is the need to convert between the geometric coordinate system in GeoGebra and the geographical coordinate system used in maps. Although conversion formulas can be implemented in GeoGebra, this may not always be practical. Another problem is importing geographic maps into GeoGebra in either vector or bitmap format. Those tasks can be performed, but usually at the cost of creating many auxiliary objects which burden the drawing. Furthermore, they can be tedious or simply too complicated for the users.

We developed a specialized interactive compoment, called GeoMap, for the SLGeometry DGS ([1], [2], [3], [4]) to address this problem. The GeoMap component is able to display a selected portion of the world map, place custom markers on the map and handle input from users. It comes pre-loaded with map data, and it is easy to use.

We conducted an experiment in the "Jovan Jovanović Zmaj" middle school in Novi Sad. The purpose of the experiment was to measure the efficiency of the teaching of geography supported by interactive materials that we developed.

In Section 2 coordinate system transformations are explained. Two interactive drawings, created in GeoGebra, which implement an exercise in measuring the length of a river and the "Point at cities" game, are presented in Section 3. Section 4 covers the implementation. Section 5 describes the GeoMap component, which we developed. In Section 6 we give an overview of related work. A short description of the experiment that is being conducted in the "Jovan Jovanović Zmaj" middle school is given in Section 7. Conclusions are given in Section 8.

2. COORDINATE TRANSFORMATIONS
Every DGS has to maintain at least two coordinate systems: the screen coordinate system (measured in pixels) and the geometric coordinate system, which is usually the common Cartesian coordinate system of the drawing. When a user is working with a DGS, transformations between the two coordinate systems are constantly performed.

The most commonly used transformation is a combination of linear planar transformations such as scaling and translation. That way a rectangular part of the Cartesian plane can be shown in a rectangular window on the screen. In order to convert mouse position in pixels back to coordinates in the Cartesian plane, inverse transformations must be employed.

If a geographic map is to be displayed as a geometric drawing, an additional set of transformations may be used in order to convert geographic coordinates to coordinates in the Cartesian plane (see Figure 1).

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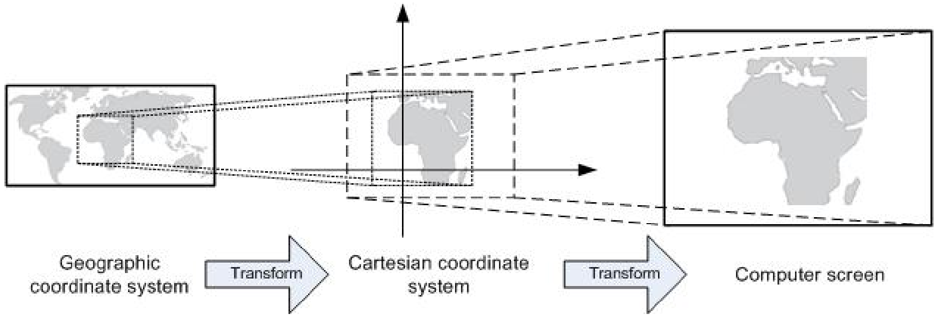

Figure 1: Mapping the geographic coordinate system to the computer screen.

Although the linear transformations which are used here are a relatively simple concept, they can nevertheless be difficult to program in a DGS environment. Every point, line and polygon coordinate needs to be wrapped in a conversion function, that leads to cluttered definitions which are difficult to read and manipulate.

3. EXERCISES IN GEOGEBRA

We present two exercises, created with GeoGebra, which are based on geographic maps. The first example teaches how to determine the scale of a map and to measure non-linear distances, e.g. along roads and rivers. A bitmap image of a map was used in this example.

The second example is a game in which students are required to guess locations of cities on a map. It is designed to be played by two players and it has a simple scoring system. The map used in this example is a polygon in which the coordinates of the vertices are expressed as longitude/latitude pairs.

From the implementation point of view, the second example is more complex, as it requires the author to first obtain a suitable definition of a map in vector format, extract the needed data from it, create a list of points in a DGS and apply transformations to each point in order to have the map displayed as a polygon on the screen.

3.1 Measuring Lengths of Roads and Rivers

Measuring distances along roads and rivers on geographical maps is one of the exercises which can be too complicated for pupils to perform by conventional means. In GeoGebra, however, this is easily accomplished by tracing a road or a river with a polygonal line on a bitmap picture. Figure 2 shows such a polygonal line along the Tisa river on a map of Serbia.

The length of the polygonal line is 4.78 units in the drawing. In order to determine the length of the river in kilometers, the scale of the map needs to be determined. By measuring in Google Earth, we determine that the linear distance between towns of Subotica and Sombor is approximately 55km. From there we calculate the scale of the map by dividing the distance in kilometers with the length of the line segment between Sombor and Subotica in the drawing. The scale is determined to be 55 / 1.67 = 32.86 kilometers per unit. Using these values we can calculate the length of Tisa in Serbia as 4.78 * 32.86 ≈ 157 kilometers.

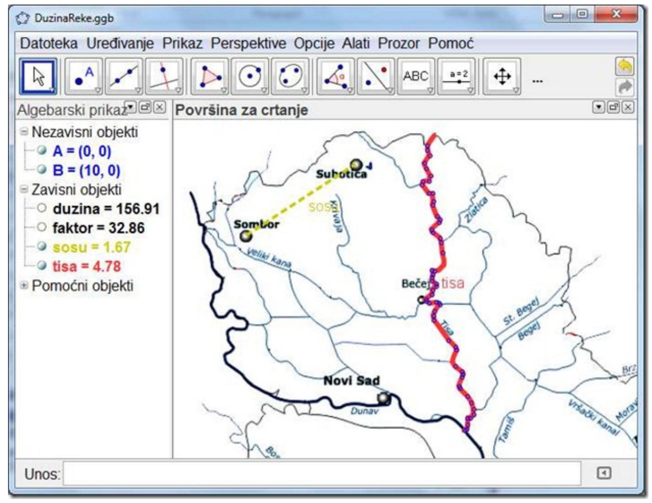

Figure 2: Measuring the length of the Tisa river on a map.

Maps must be carefully chosen, especially at higher latitudes, as to avoid distortions due to the cylindrical projection, which could affect the accuracy of this method.

3.2 The "Point at Cities" Game

The "Point at cities" game helps pupils learn where the cities in their home country, and other countries, are. Our GeoGebra construction implements one variation of the "Point at cities" game, designed for two players (see Figure 3).

The first player needs to place blue dots, representing cities and towns, on appropriate places on the map. The second player needs to do the same with red dots. Players earn points by placing dots closer to the correct locations than their opponent. When all the dots are placed, GeoGebra calculates the score and displays the correct locations.

Scoring was implemented by comparing the distances between the correct locations and the dots placed by players.

4. IMPLEMENTATION DETAILS

At each step of the implementation, we encountered several problems, which, in our view, would pose significant difficulty to geography teachers who wish to develop their own teaching materials in GeoGebra. Each step of the implementation requires programming skills, mathematical skills and time, that geography teachers may not have.

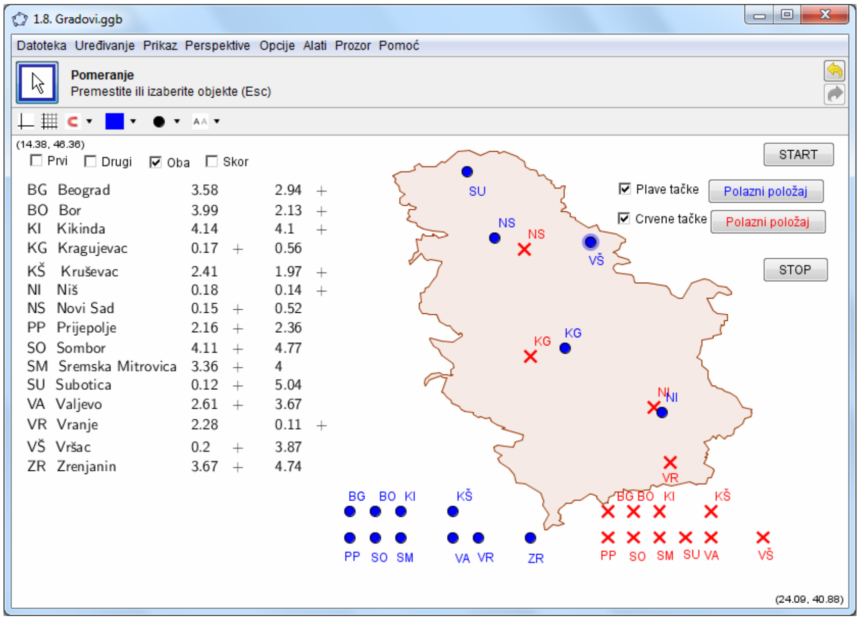

Figure 3: The "Point at cities" game for two players.

4.1 Obtaining Map Data

In order to draw a country map, geographic coordinates of the country's borders must be obtained. These data can be downloaded from the Internet, for example, in the ESRI Shapefile format ([14], [15], [16]), or as a list of polygon definitions, using the **CountryData** function in *Mathematica* [17]. In the case of shapefiles, an external program ([18]) must be used to extract polygon definitions. Extracting data from *Mathematica* is simpler, thanks to the built-in **Export** function, but still requires technical knowledge.

4.2 Drawing Maps in GeoGebra

GeoGebra has the Polygon keyword, which draws a closed polygon defined by a list of vertices. For countries which consist of one continuous territory, maps are easily drawn by executing the **Polygon((x_1, y_1), (x_2, y_2), ..., (x_n, y_n))** command. A single named polygon is then generated in GeoGebra's list of objects. If a country consists of several disjointed territories, a separate polygon must be drawn for each territory, producing several unrelated named objects. Geographic coordinates belong to the interval [-180, 180] × [-90, 90]. As GeoGebra can easily draw polygons defined by vertices from this interval, coordinate conversion may not be necessary in this step. However, the resulting maps will be shown in cylindrical projection only. If a different projection is needed, coordinate conversion must be performed for each polygon. This conversion may be simple, but also very complex, depending on the projection type.

4.3 Scaling and Translating Maps

If only a single map needs to be shown in a drawing, then the view can be adjusted so that the map, defined by geographic coordinates, is shown accross the entire screen. However, if two or more country maps need to be placed next to each other, then their geographic coordinates are not suitable. For example, if France and Japan need to be shown side-by-side, then there would be a large empty space between them if the original coordinates were used. In such cases, at least one country's coordinates must be translated, and possibly also scaled by using linear transforms. In practice, this means that a suitable linear transform must be found, and the definitions of each point, line and polygon must be wrapped in the conversion function. This leads to cumbersome expressions in GeoGebra, increases the complexity of drawings and makes subsequent changes difficult (see Figure 4).

4.4 Placing Additional Shapes on Maps

Cities, rivers and text labels are drawn on maps as circles, polylines and text objects respectively. Their coordinates must be transformed by the same transforms which were applied to the map itself. These additional shapes also appear as independent objects in drawings.

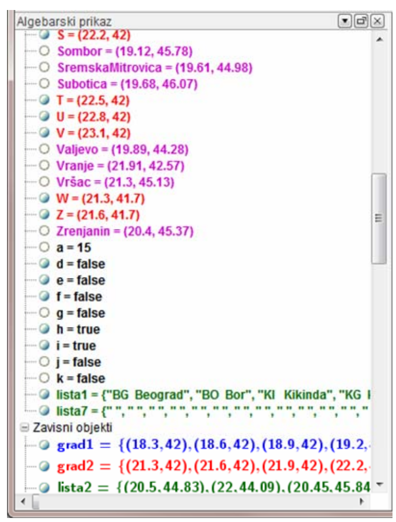

Figure 4: Partial list of the many objects contained in the "Point at cities" drawing.

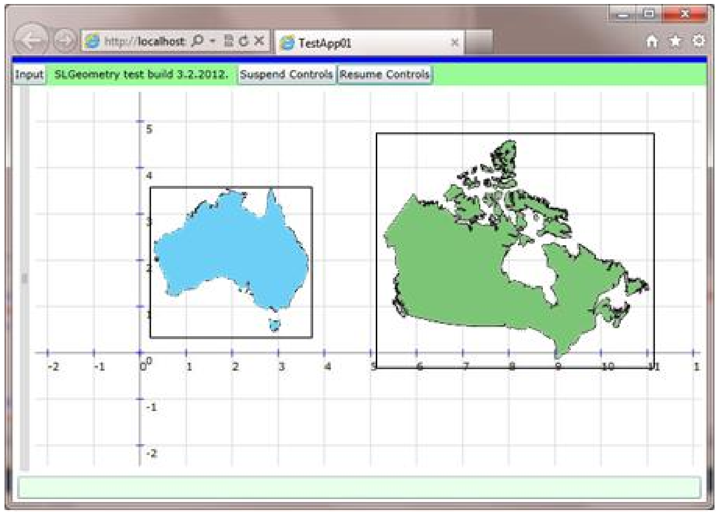

Figure 5: Two instances of the GeoMap component in SLGeometry.

5. THE GEOMAP INTERACTIVE COMPONENT

We decided to take the concept of geographic maps in DGS one step further. Our goal was to have several interactive maps displayed on screen at the same time, with each map able to display a different part of the world and handle user input. Also we wanted to hide the complexities of implementing geographic maps, covered in Section 4, from the final user. We developed an interactive component, called GeoMap, for the SLGeometry DGS. The component is displayed as a rectangular area, inside of which a part of the world map is shown.

The GeoMap component has the following features:

- Displays a rectangular region of the map, specified by geographic coordinates, inside an rectangular area on the screen;
- Has a library of predefined geographic maps in vector format;
- User can select which countries are to be shown;
- Can import and display custom maps;
- Can render points, lines, polygonal lines, polygons, arrays of points, strings;
- Supports a movable marker that can be placed on the map, either by mouse or programatically;
- Has a number of properties which affect visual appearance and behavior, that can be accessed programatically.

The GeoMap component hides the complexities of its inner workings (coordinate conversion etc.) from the user, and enables easy creation of teaching materials based on interactive geographic maps. Maps are placed on the screen (see Figure 5) by executing the following commands in SLGeometry:

a = GeoMap("Australia")

b = GeoMap("Canada")

The position of the marker is exposed through the GeoMap.Marker property. The property is of the Point data type and it is updated dynamically as the user moves the marker on the map. It can be used in various expressions in order to, for example, measure distances between the marker and some predefined locations, such as cities.

6. THE EXPERIMENT

We conducted an experiment with the pupils of the "Jovan Jovanović Zmaj" middle school in Novi Sad, Serbia. The purpose of the experiment was to measure the efficiency of the teaching of geography supported by interactive materials that we developed.

During the first phase of the experiment, the pupils were taught about map scales. The first lecture was presented in the "classical" way. In the second lecture, an example in GeoGebra was presented. The pupils were taught how to import a bitmap image of a map into GeoGebra and how to determine the scale of the map relative to the coordinate system of GeoGebra. Afterwards, they were shown how to trace a river with a polygonal line, and, finally, how to calculate the real length of the river by using the previously obtained scale of the map. The whole process was demonstrated in class, and lecture notes were published on a web site [6]. Similar exercises were assigned as optional homework and a deadline of one week was given.

The pupils' response to the lecture was overly positive. Also, almost all pupils handed in their homework. However, preliminary results show that only about 16% of the pupils were able to complete the assignment successfully, while another 40% completed it partially.

In the second phase of the experiment, we organized a competition between the pupils in class, based on the "point at cities" game. As a result, the pupils were highly motivated to learn the locations of the cities.

After the classes, the pupils were polled for opinions (Table 1).

Table 1: Poll Results

Question	Yes	No
Did you like these classes?	53	4
Were the classes like you imagined?	35	22
Was your task difficult?	9	46
Was your task too complicated?	12	43
Was the teacher helpful?	54	2
Should the teacher help less?	3	51

7. RELATED WORK

There exist a multitude of frameworks for rendering geographic maps and spatial data, such as SharpMap [7]. They support coordinate system transformations and loading of geographic data in various formats, such as ESRI Shapefiles [8]. The list of features provided by SharpMap includes:

- Easy-to-use mapping library for use in web and desktop applications;
- Access to many types of GIS data;
- Spatial querying;
- Map rendering;
- Built-in coordinate transformation functions;
- Creating clickable maps;
- Support for layers: WMS layer, ShapeFile layer, PostGIS layer, Label layer;
- Rendering X and Y columns from a database as points.

Also, there are many web sites which incorporate Flash or Java applets with interactive geographic maps. Most of these web sites are designed as learning games ([10], [11], [12], [13]).

8. CONCLUSIONS

Contemporary methods of the teaching geography rely on interactive electronic teaching materials, that can be developed in dynamic geometry software (DGS). Although the majority of DGS present today were not developed primarily for geography, they can be and are used by teachers in schools.

This paper demonstrates one use of GeoGebra for developing exercises based on interactive maps. There are some problems which stem from the fact that GeoGebra was not designed for such applications. An interactive visual component, developed for the SLGeometry DGS, which enables easy handling of multiple geographic maps and simplifies the task of coordinate conversion is also presented. An experiment to assess the efficiency of computer aided teaching using our exercises and software was conducted. Poll results show that the pupils show more interest in learning geography when interactive learning materials are used.

Further information on SLGeometry can be found at [5].

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