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Mathematical Software in Croatian Mathematics Classrooms – A Review of Geogebra and Sketchpad

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Abstract

This paper explores the benefits and possible problems that may be encountered in mathematical classrooms using mathematical software. In addition to exploring different types of mathematical software, the paper also focuses on two mathematical tools which have been translated into Croatian and are in widespread use in Croatian mathematics classrooms. The advantages and disadvantages of both tools are reviewed, along with the software's capabilities, from the viewpoints of both foreign and Croatian scientists who researched the effect that such tools had on mathematics students. Lastly, a comparison between the two mathematical tools in use in the Republic of Croatia is presented, featuring both technical details as well as purely practical ones.

Key words: *geometry; ICT; mathematical tools; mathematics education*

Introduction

The use of computers as tools for both teaching and learning is becoming more widespread, and the value of CT has been long recognised by the educational system in Croatia. This paper reviews the most popular computer tools for both teaching and learning in the Republic of Croatia, as well as the advantages and disadvantages of the use of computers in a mathematics classroom.

The scope of benefit the students receive from the use of mathematical software while learning is broad. However, some researchers, like Hennessy et al. (2005) argue that their use is often limited to the use within classrooms and only for repetitive, delimiting activities (Hoyles, Noss, & Kent, 2004; Kirschner & Wopereis, 2003;

according to Reed, Drijvers & Kirschner, 2009). It has also been shown that the benefits of the use of mathematical software are not always exploited to their full potential (Artigue, 2002; Guin & Trouche, 1999; according to Reed, Drijvers & Kirschner, 2009). For instance, students may learn how to use the software and master it, but that does not imply that they have mastered the underlying concepts (Hennessy et al., 2005; according to Reed, Drijvers & Kirschner, 2009) and as Vom Hofe pointed out in his research (2001; according to Reed, Drijvers & Kirschner, 2009), those students who focused on mastering the software lost sight of the meaning of the mathematical concepts used and reached an "intellectual dead end" (p.117). On the psychological side, which also has an impact on the final results of the learning process, Pierce and Stacey (2004, according to Reed, Drijvers & Kirschner, 2009) found that those students who have a positive attitude toward mathematics and mathematical software used the software in order to overcome the initial struggles and difficulties, and it resulted in the use of the tool in order to explore and develop their understanding of the mathematical concepts and problems. Negative attitudes have led to the avoidance of the use of the mathematical tool.

Based on their experiences with mathematics, students develop attitudes toward its nature, and value their own abilities and interest in it (Boekaerts & Simons, 2003; according to Reed, Drijvers & Kirschner, 2009). Secondly, students may have a specific attitude toward the use of mathematical software based on their previous use. Even if they do not directly have experience with such tools, they may connect their experience with computers in general with their use in mathematics, particularly if these attitudes are extremely positive or extremely negative (Shook, Fazio, & Eiser, 2007; according to Reed, Drijvers & Kirschner, 2009).

It has been found that effective mathematics learning needs to involve active engagement, discourse and reflection of one's own work and the work of others (Gravemeijer, 1994; according to Reed, Drijvers & Kirschner, 2009), which is particularly important in contemporary mathematics education, where skills are attained through inquiry, investigation and perseverance in solving problems (National Council of Teachers of Mathematics (NCTM), 2000; according to Reed, Drijvers & Kirschner, 2009). Simultaneously, communication and reflection are considered as important tools for the attainment of skills such as generalisation, thus allowing the student to reach a higher level of learning (Gravemeijer, 1994; according to Reed, Drijvers & Kirschner, 2009).

There are different types of CT worldwide used for mathematics learning and teaching. Researchers (Means 1994; Lou et al. 2001; according to Li & Ma, 2010) have divided the CT used for learning mathematics into five main categories: a) tutorials; b) communication media; c) exploratory environment; d) tools; e) programming languages.

Tutorials refer to programs that teach students by setting up a stimulating environment where information, demonstration, and practice are combined (Lou et al. 2001; according to Li & Ma, 2010). This type of CT also includes computer-assisted instruction (CAI), mathematics games (e.g., Math Blaster) and drills and practice software (e.g., A+Math, Math Facts in a Flash, Maple 13, and Math Realm). *Communication media* refer to communication tools such as email, computer supported-collaborative learning systems, video-conferences and internet (Lou et al. 2001; according to Li & Ma, 2010), in short, those tools which enable effective communication and information sharing. *Exploratory environments* encourage active learning via exploration and discovery (Lou et al. 2001; according to Li & Ma, 2010). For instance, Logo and various simulations are examples of this type of CT. *Tools* refer to software such as Geometer's Sketchpad, Accelerated Math, Microsoft Office, Cabri etc. and aim at connecting visual images with abstract symbols, therewith helping students to build a foundation for understanding abstract mathematical concepts. They serve to make the teaching and learning process effective and efficient (Lou et al. 2001; according to Li & Ma, 2010).

There are four aspects that mathematical software (specifically, computer algebra systems, CAS in short) can offer to the process of mathematics teaching (Schneider, 2002; according to Glasnović-Gracin, 2009): 1) *multiple display options*, that is, the availability of different ways of displaying mathematical content, along with gradual transition from one display to the other, e.g. symbolic to graphic. Indeed, Dakić (1993) points out that different display possibilities are a storeroom of potential which the use of a computer brings into a classroom, since visualisation and clarity have always been very important for understanding mathematical ideas during the process of learning and problem solving; 2) *experimental work*, that is, the possibility of students using experimentation in order to gain new knowledge, ideas and problem solving approaches; 3) *elementarisation of mathematical methods,* that is, computers allow the use of elementary methods which have been abandoned due to the complex calculations; 4) *modularity,* that is, the ability to directly invoke commands and not have to bother with algorithms or calculation methods.

What is the place of the use of computers in classrooms in the Republic of Croatia? The goals of mathematical courses in the Republic of Croatia can be found in the Educational Plan and Programme issued by the Ministry of Science and Sports of the Republic of Croatia. With the use of computers in classrooms, the following goals appear in the foreground (Schneider, 1999.; according to Glasnović-Gracin, 2009): 1) *focus on application, modelling, authenticity and problem solving*; 2) *emphasis on the presentation aspects and interpretation in mathematics*; 3) *focus on the appropriate concept formulation*; 4) *discussion on the possibilities and limitations of mathematical methods*; 5) *focus on the fundamental mathematical ideas*; 6) *interdisciplinarity;* 7) *learning about historical and socio-psychological aspects*; 8) *different social goals of mathematics teaching* (Glasnović-Gracin, 2009).

Mathematical Software in Use in the Republic of Croatia

In this section the most popular mathematical software for education and teaching in use in the Republic of Croatia will be listed and reviewed, explore the advantages and disadvantages of use of the specific software, as well as review empirical data concerning the software in question. Two mathematical tools have been translated to Croatian and are in use in schools throughout the Republic of Croatia, namely GeoGebra and Geometer's Sketchpad (Varošanec, 2007). Therefore, the selected software will be reviewed both from the viewpoint of foreign and Croatian scientists.

Geogebra

GeoGebra is certainly one of the most popular programmes. Recently developed, its popularity has already blossomed worldwide (Hohenwarter, 2002; Hohenwarter & Preiner, 2007, according to Hohenwarter & Fuchs, 2004). GeoGebra is an interactive geometry software that simultaneously offers algebraic input. The use of GeoGebra has been aimed at students from the age group 10 to 18 and at secondary school teachers. It encourages experimentation, from the geometrical point of view, but also from the algebraic point of view. For instance, students may drag the drawn circle with the mouse and thus investigate the changes in the equation of the circle, but at the same time change the equation and follow the altered version of the circle in the geometry window. Here the emphasis is put on the exploratory aspect of learning, and GeoGebra allows redoing the constructions, inserting new elements and changing the order, which enhances the students' awareness of functional dependencies.

The basic objects in GeoGebra with which students can work are points, vectors, segments, polygons, straight lines, all conic sections and functions. The constructions can be altered dynamically and it is possible to enter coordinates of points or vectors, equations of lines, conic sections or functions directly.

In teaching mathematics, GeoGebra can be used in multiple ways (Hohenwarter & Fuchs, 2004):

1. *for demonstration and visualisation* – GeoGebra as a tool for demonstration and visualisation has a broad coverage.
2. *as a construction tool* – GeoGebra has all the abilities demanded from a suitable drawing/designing software, which are, as Karl Fuchs pointed out in 1990, very important for teaching constructive geometry.
3. *a tool for discovering mathematics* – the experimental form has been added to the traditional form of a teacher concentrated education and GeoGebra can be used as a tool for creating a suitable atmosphere for learning. Research has proved that a positive influence of computer algebra systems on teaching mathematics exists (Artigue & Lagrange, 1997; according to Hohenwarter & Fuchs, 2004).
4. *a tool for preparing teaching materials* – GeoGebra can be used by teachers as a cooperation, communication and representation tool.

With GeoGebra it is possible to create interactive HTML pages (worksheets), which can be used by any browser that supports Java. GeoGebra does not have to be installed on a specific machine in order to use the worksheet. GeoGebra itself can be used on any platform (Hohenwarter & Fuchs, 2004).

GeoGebra is free to download under an open source license and can also run directly from a web browser. It is easy to learn how to use it, so there are no limitations in that aspect. Files can be saved in the ".ggb" format or as dynamic web pages. It can also produce a step-by-step geometric construction for the purpose of presentation, which does not have to be done live. The program can output files as pictures or as encapsulated postscript for the purpose of publication of illustrations. The open source nature of this program encourages the users to publish their work online. One drawback of the current version of GeoGebra is that its features can be exhausted relatively quickly, however its ease of use still make GeoGebra a very popular tool for both students and teachers, and has also found application in higher education mathematics learning (Sangwin, 2007).

With the translation of GeoGebra into Croatian, a virtual laboratory has been created, that is, a research tool for the exploration of geometrical facts, properties of geometrical objects and mathematical claims connected to geometry (Šuljić, 2005). Šuljić (2005) found that GeoGebra has grown in popularity in the Republic of Croatia because, among other reasons, it is a freeware software. He gives other reasons for this popularity: 1) it is a professionally made programme, which has won many European software rewards (including those for educational software); 2) it has been translated to Croatian; 3) it covers mathematical programmes for primary and secondary schools in the Republic of Croatia well; 4) is able to bring geometry and algebra closer than any other program; 5) entails an intuitive algebraic equation input (e.g. $(x-3)^2 + (y+2)^2 = 25$); 6) it is easy to use for both teachers and students; 7) a pupil can use it starting in the fifth grade of primary school until he graduates from secondary school; 8) it has high-quality graphics, suitable especially for classroom projections; 9) can easily produce a dynamic drawing on a web page (applet); 10) the constructions can be transferred to other presentations or program, including LaTEX (Šuljić, 2005).

Geometer's Sketchpad

Sketchpad aims to move the students away from the classic pen-and-pencil work to the use of technology, with the help of which they can experiment on their own; the lessons become student-centred rather than teacher-driven, and this alone can be a great advantage as the teacher can then focus on small groups or individuals, adding quality and depth to the teaching process. It is necessary to devote some time to teaching the students on how to use this software tool, which pays off, because a knowledgeable user can quickly alter his constructions, which would take a whole lot more time if done using a pencil. The software makes geometric transformations such as translations, rotations, reflections, and dilations, once reserved for college-level courses, also accessible to the secondary-level math students (Hollebrands, 2002; according to Capstone, 2008). The dragging features of Sketchpad allow students to see multiple examples of the same figure without having to draw each using paper and pencil. Using the measurement tool the students can test their conjectures regarding the properties of certain figures and at this point mathematics becomes a whole new world to discover.

The dynamic and experimental nature of Sketchpad enhances a positive attitude of students toward the software as a learning tool (McClintock, Jiang, and July, 2002; according to Capstone, 2008). However, Arzarello et al. (1998, according to Capstone, 2008) showed that precisely this dynamic feature of Sketchpad may prove to be a distraction tool in the sense that some students may find playing with their constructions interesting without paying attention to the underlying mathematical concepts and not actually using it as a learning tool. Another aspect of Sketchpad that can be a source of distraction is the animate feature, which allows the many dynamic aspects of the software to come to life. McClintock, Jiang, and July (2002, according to Capstone, 2008) find that the students really enjoy this feature, which can be regarded as a powerful tool when used for the purpose of learning. In both cases it is the task of the teacher to monitor the students' work and to guide them toward the goal of the lesson instead of allowing them to use Sketchpad as a toy.

Scher (2000, according to Capstone, 2008) notes that Sketchpad brings a new freshness in the process of learning in the meaning that the students feel a sense of control over their learning, as they determine facts on their own instead of having a teacher giving the information to them.

The use of Sketchpad creates a learning environment where being incorrect is accepted and not ridiculed. The students are encouraged to make their own conjectures and then test them using Sketchpad, and should they be eventually proven wrong, there is still a lot to learn from the incorrect assumptions, which also leads toward enhancement of the understanding (Capstone, 2008).

Dixon (1997, according to Capstone, 2008) found that students using Sketchpad outperformed the group which did not on measures of rotation, reflection and two-dimensional visualisation. However, he did not find any significant differences concerning three-dimensional visualisation; a possible reason may lay in the fact that Sketchpad shows itself in two dimensions on the computer screen. McClintock, Jiang, and July (2002, according to Capstone, 2008) found that using Sketchpad did have a positive effect on the students' three-dimensional geometry learning abilities. It must be noted, however, that a traditional learning environment was combined with the use of Sketchpad, the combination of which may have had a positive influence on the students' grasp of the three-dimensional geometry.

Most researchers investigating the impact of the use of Sketchpad focused on only one mathematical unit and some researches tracked the students' work which involved only the use of Sketchpad. It may be more fruitful to combine the traditional way of learning along with the use of Sketchpad over a longer period of time, thus covering more mathematical units and gaining more insight into the students' work (Capstone, 2008).

Although the Geometer's Sketchpad has been translated to Croatian and the Croatian Mathematical Society has endeavoured to promote its use in Croatian mathematical classrooms, clearly GeoGebra is more popular among Croatian mathematics students. One reason for this can be that the Geometer's Sketchpad does not have the ability of bringing together algebraic input and geometrical display, which is one feature of GeoGebra that has been proved to be popular and educational (Hohenwarter & Fuchs, 2004). Another reason may certainly lie in the fact that GeoGebra is a freeware program, thus available to students at home and also to schools which have limited financial means at their disposal.

Comparison between Geogebra and the Geometer's Sketchpad

Sketchpad conforms to the Euclidean norms, whereas GeoGebra differs from those norms in several respects. The objects in Sketchpad do not require a coordinate system and their size is independent of the coordinate axes, whereas GeoGebra's objects are automatically defined in terms of GeoGebra's coordinate system, and the size and shape of the object rescales if the axes are rescaled. While Sketchpad creates labels at user's request, GeoGebra creates them as the objects are being constructed, which may lead to exhaustion of simple labels. It has been noted that while Sketchpad's notation is easy for students to understand, GeoGebra's notation has certain faults that may result in students having difficulties.

An important feature of geometry software is certainly dragging. Sketchpad allows "drag tests", meaning testing the integrity of an object by dragging different parts of it. During this process they can test various conjectures and assess their work. On the other hand, GeoGebra allows some objects to be dragged, but not all of them (for instance, the user can drag an entire polygon and its vertices, but not its sides). This may discourage students from dragging at all, thus limiting their investigating abilities.

Animation is also an important and educative feature. Sketchpad treats animation as dragging, whereas in GeoGebra, animation is limited to sliders. A significant difference between transformations has been found. Sketchpad supports an unlimited set of transformations (isometries, similarities, affinities and custom transformations), and allows the user to apply them to various objects, including pictures. GeoGebra is limited to the similarity of transformations, point reflections and circle inversions.

Sketchpad can show two graphs simultaneously and in different coordinate systems, which is useful when graphs require different scales. While Sketchpad supports polar coordinates and polar functions, GeoGebra does not, nor does it support multiple coordinate systems. While Sketchpad allows graphing y as a function of x and x function of y, GeoGebra supports only graphing y as a function of x. In Sketchpad even multiple intersections can be found regardless of the function type, whereas GeoGebra can find one intersection at the time.

Sketchpad provides features supporting aspects of the way in which users express themselves: through the construction itself, in their writing about mathematical thinking and presentation of their investigations. While Sketchpad provides a number of options to enhance the way in which constructions are expressed, such as 1) the marker tool (allowing freehand drawing, creating angle markers etc.), 2) the information tool (when clicking on any object the user can see its description and links to related objects, thus making it possible for the user to learn about the structure of the construction and which objects depend on which), 3) measurements, calculations and functions are properly mathematically formatted, 4) angles in radians are displayed using multiples and fractions of π when it is appropriate. GeoGebra does not have any of these features (Steketee/keycurriculum.com, 2012).

Conclusion

Effective mathematics learning needs to involve active engagement, discourse and reflection on one's own work and the work of others. At the same time, communication and reflection are considered as important tools for the attainment of skills such as generalisation, thus allowing the student to reach a higher level of learning (Gravemeijer, 1994; according to Reed, Drijvers & Kirschner, 2009). There are four aspects that mathematical software (specifically, CAS) can offer to the process of mathematics teaching (Schneider, 2002; according to Glasnović-Gracin, 2009): 1) *multiple display options;* 2) *experimental work*; 3) *elementarisation of mathematical methods,* and 4) *modularity.*

There are two mathematical tools that have been translated into Croatian and are currently in use in Croatian mathematics classrooms – GeoGebra and Geometer's Sketchpad.

GeoGebra is an interactive geometry software that simultaneously offers algebraic input. The exploratory aspect of learning is emphasized and GeoGebra allows redoing constructions, inserting new elements and changing the order, which enhances students' awareness of functional dependencies (Hohenwarter, 2002; Hohenwarter & Preiner, 2007, according to Hohenwarter & Fuchs, 2004). With the translation of GeoGebra to Croatian, a virtual laboratory has been created, that is, a research tool for the exploration of geometrical facts, properties of geometrical objects and mathematical claims connected to geometry (Šuljić, 2005). In teaching mathematics, GeoGebra can be used in multiple ways (Hohenwarter & Fuchs, 2004): 1) *for demonstration and visualisation; 2) as a construction tool; 3) as a tool for discovering mathematics; 4) as a tool for preparing teaching materials*.

The dragging features of Sketchpad allow students to see multiple examples of the same figure without having to draw each using paper and pencil. Using the measurement tool the students can test their conjectures regarding the properties of certain figures and at this point mathematics becomes a whole new world to discover. Sketchpad's features like its dynamic and experimental nature and animate feature make it very popular among mathematics students (Capstone, 2008). While using Sketchpad the students enjoy the sense of control over their learning (Scher, 2000; according to Capstone, 2008). Its use creates a learning environment where being incorrect can lead to improved understanding (Capstone, 2008).

The reason for the popularity of GeoGebra among Croatian mathematics students can be that the Geometer's Sketchpad does not have the ability of bringing together algebraic input and geometrical display, which is one feature of GeoGebra that has been proved to be popular and educational (Hohenwarter & Fuchs, 2004). Another reason may certainly lie in the fact that GeoGebra is a freeware program, thus available to students at home and also to schools which have limited financial means at their disposal.

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Matematički softver u nastavi matematike u hrvatskim školama – pregled GeoGebre i *Geometer's Sketchpada*

Sažetak

Ovaj rad istražuje korisnost i moguće probleme s kojima bi se nastavnici mogli susresti u matematičkim učionicama koje upotrebljavaju matematički softver. Nakon kratkoga pregleda raznih tipova matematičkoga softvera rad se koncentrira na dva matematička alata koji su prevedeni na hrvatski jezik i koji su u upotrebi u hrvatskim matematičkim učionicama. Navedene su prednosti i nedostaci ovih programa kao i njihove mogućnosti sa stajališta hrvatskih, ali i stranih znanstvenika koji su istraživali utjecaj tih programa na učenike i studente. Također je dana usporedba između dva matematička programa koji se koriste u Republici Hrvatskoj, a koja se odnosi na tehničke, ali i na praktične detalje.

Ključne riječi: *GeoGebra; matematički softver; nastava matematike; Sketchpad*