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DYNAMIC GEOMETRY SYSTEMS IN MATHEMATICS EDUCATION: ATTITUDES OF TEACHERS

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Abstract

At present, the innovative trends in education are also often associated with the integration of ICT into the teaching process. The relationship between mathematics, teaching and computers are long-standing and complex. The actual practice of mathematics has changed its nature considerably because of the availability of powerful computers, both in the workplace and on researches' desks. Several software systems are available for mathematics teachers, among which have dynamic geometry systems a significant presence. Although various forms of education for teachers are currently organized and teachers have at their disposal a variety of learning materials and ideas for teaching, it is questionable to what extent these factors are reflected in school practice. The article describes a survey which was aimed to assess the state of the use of dynamic geometry systems in mathematics teaching at elementary and secondary schools and to find out teachers' views about suitability and possibilities of using it to improve mathematics education. The survey was conducted by questionnaire and subsequently also by interviews with teachers.

Keywords

questionnaire, interview, dynamic geometry system, GeoGebra, mathematics teaching, modelling

Introduction

Present time is characterized by rapid development of ICT that permeate all areas of social life. In today's information age, the information can be relatively easy to obtain, share and exchange. Some visionaries began to think about the use of ICT in education shortly after completion of the construction of the first computers. This idea is not to appear unrealistic given the possibilities and versatility of ICT. Seymour Papert is one of the main representatives of those policies. He is the founder of constructionism theory that characterizes the use of ICT for the formation of the internal system of knowledge the students (Papert, 1980).

ICT make its way into schools for more than 40 years. The first efforts to use ICT in education were associated mainly with testing students and with solving routine exercises focused on the training of the calculation operations. Over time have been improved a graphic and computational potential of ICT and the programmers developed a variety of software applications. A revolutionary leap in the exchange of the information meant connecting computers into the networks that allow easy acquiring and sharing information. Currently, the Internet provides a range of educational portals and interactive applications to support active learning.

Experiments in the applications of computer technology to mathematics teaching have been widespread over the last 30 years or so. The advent of fast and widespread communications such as e-mail, the internet and video-conferencing are radically changing our access to data and information. Many of the techniques associated with school mathematics were developed to solve important problems at times when tools such as electronic calculators and computers were not available. The very existence of these computational tools is now having a profound effect on the way mathematics is begin developed and applied in the world outside education. New skills of modelling, estimating, validating, hypothesizing and finding information are becoming more important than many traditional ones, such as accuracy of recall. An important issue for mathematics teachers is to ensure that their students are well prepared for their future lives and careers by gaining necessary skills, whether or not the curriculum and examination system explicitly encourage them (Oldknow et al., 2010).

So ICT can enable students to concentrate on more interesting and important aspects of content. Of course, most teachers do not have a great deal of control over the curriculum they teach. So they need to be able to apply ICT in ways that enhance the teaching and learning of the current established curriculum while also seeking to bring out some of the important relationship between mathematics and computer technology. The role of ICT in the teaching and learning process is not just confined to uses such as an "electronic blackboard" to assist in a teacher's exposition, or for "hands-on" use by students working at a task, important as both those applications are. The technology may aid the teacher in the preparation for a lesson, e.g. in gathering data, or preparing materials. It may also have a role to play in the assessment of students' learning (Oldknow et al., 2010).

In this paper, we focus on dynamic geometric systems (DGS) which provide various tools for mathematics education. The first DGS were developed early 80s of last century. One of the first applications of this type has been Geometric Supposer. On the present, GeoGebra is the most widespread DGS in the mathematics education. GeoGebra is created in the Java programming language and it is independent of the software platform. The created dynamic constructions can be easily published on the Internet in the form of applets. The name GeoGebra indicates that this program is a complex system integrating tools of geometry and algebra. This dualism can be seen mainly in the equivalence of two basic ways of defining geometric objects: geometric construction in a graphical window and insertion of an analytical representation of the object in the input line.

Markus Hohenwarter began in 2001 to develop software GeoGebra, but the team gradually extended to other programmers. The creators of GeoGebra continue its development and constantly replenished with new features and modules. In an attempt to create a complex mathematical program was implemented in the system GeoGebra module for computer algebra systems (CAS). The current version (version 5.0) enables users to present a window on the 3D geometry that allows to work with objects in three-dimensional coordinate system. Markus Hohenwarter (Hohenwarter, Lavicza, 2007) called on mathematics teachers at least to try GeoGebra system although they do not yet have experience of using ICT in mathematics teaching. Our experience of education of mathematics teachers shows that if they acquire the basics of working with GeoGebra, then they try to present their skills to students. They used GeoGebra mainly to demonstrate mathematical relationships or to solve mathematical problems. However GeoGebra provides possibilities to develop inquire skills of students. In the next section we present three ideas for modelling activities for independent students' work.

Modelling activities using the DGS

The application of innovative trends in mathematics teaching may also include modelling activities to stimulate active learning based on the investigation and discovery of mathematical relationships. We present some proposals of modelling activities from different areas of mathematics that could be used in mathematics teaching already at primary school. The main focus is on visualizing mathematical objects and relationships which could contribute significantly to the development of students' mathematical knowledge and improve understanding of mathematical concepts.

The first activity can be used to investigate symmetry of geometric shapes. It enables students to explore the images of the right triangle in axial and central symmetry for different position of an axis of symmetry or a centre of symmetry. Students should focus not only on observing relative positions of the right triangle and its image, but also on the possibility of creating a variety of specific types of quadrilaterals. The kite and parallelogram are formed in Figure 1.

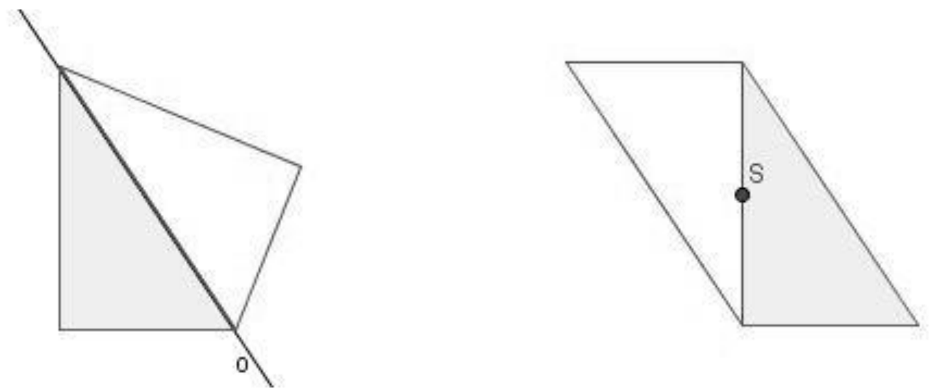

Fig. 1: Reflection of the right triangle in the axial and central symmetry

The left side of Fig. 1 shows the position of the axis of symmetry determined by the hypotenuse of the right triangle in which the right triangle and its image form the kite. The right side of Fig. 1 shows the location of centre of symmetry in the middle of the leg. The right triangle and its image form a parallelogram. Changing the position of the line of symmetry and the centre of symmetry enables students also get isosceles triangles and a rectangle. Students could write results of the investigation into a table with the position of the axis or centre of symmetry and the type of the quadrilateral. This activity could be the introduction into the investigation of specific types of symmetrical quadrilaterals.

Creation of multiple center-symmetrical geometric figures is the purpose of the activity which requires the composition of five identical squares to symmetrical figures.

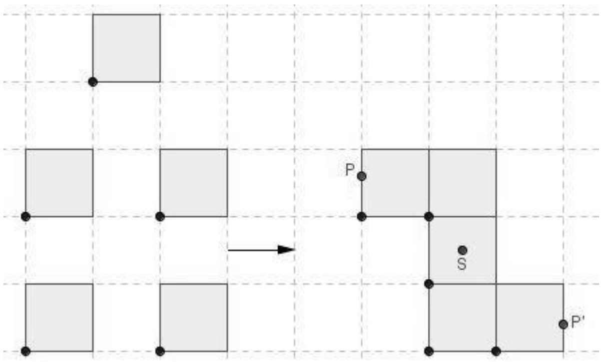

Fig. 2: Creating a centrally symmetrical image

On the left side of Fig. 2 are five squares constructed with, which is easy to move using the highlighted vertices. The students' task is using all the squares to set together centrally symmetrical shape. On the right side of Fig. 2, one possibility to create a centrally symmetrical shape of those squares is displayed. Students can construct the expected center of symmetry in a figure. Using a selected point on the square and its image they can test the symmetry of the composed shape. In the activity, students have the opportunity to create several types of a centrally symmetric figures.

The third activity can be used for modelling of the linear dependence. We have chosen an example to exploring the relation between the height of water column and volume of water for the uniform filling of the cylinder with water (see Fig. 3). Students can use the first slider (water) to simulate the flow of water into the cylinder. The height of water column in relation of the water volume in the cylinder is displayed in the coordinate system at the same time. Students should predict the type of dependence before the simulation.

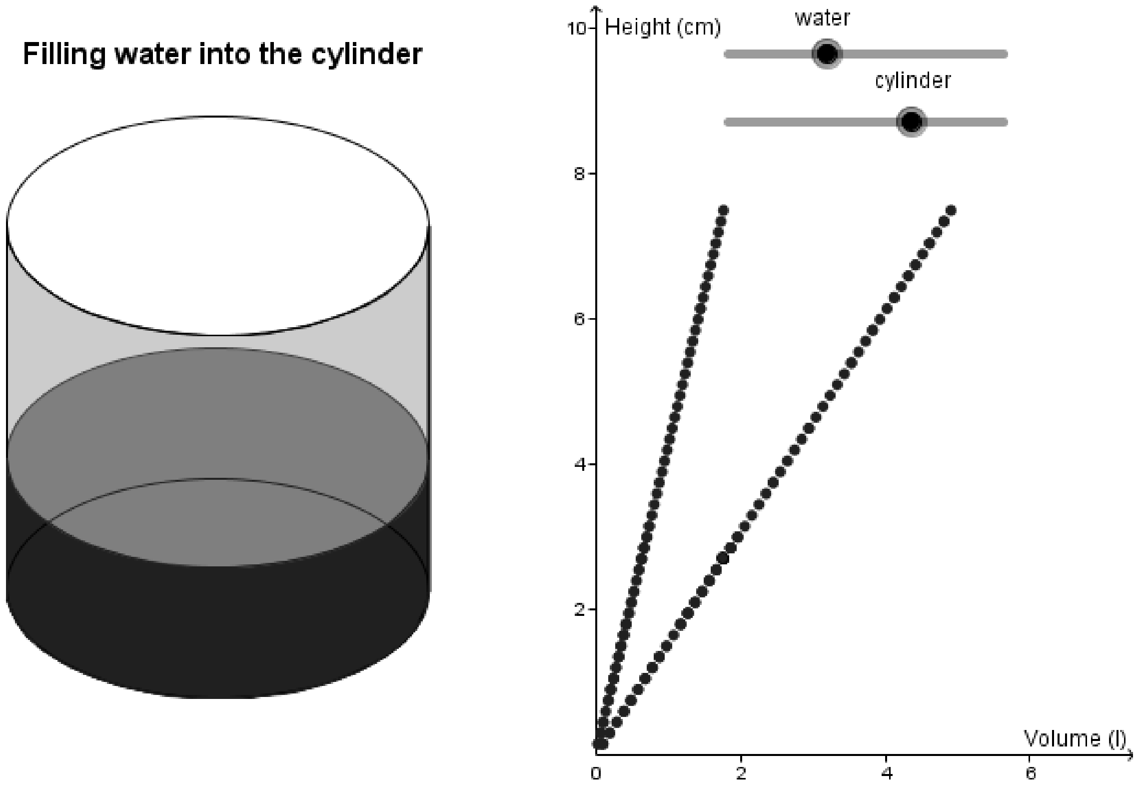

Fig. 3: Simulation of filling the cylinder with water

Then students may change the diameter of the base of the cylinder using the second slider (cylinder). Students can thus observe how change of the diameter of the base will affect the graphic representation of this dependence. Similar interactive demonstrations are available at http://demonstrations.wolfram.com/FillingAContainerDefinedByACurve/. Demonstrations also offer more complicated shapes of containers.

Studies to determine the status of the use of ICT in mathematics education

Application of innovative trends in mathematics education is often associated with the integration of ICT in the learning process. National Council of Teachers of Mathematics (NCTM) in the United States published the basic principles and standards for modern teaching mathematics in 2000 (NCTM, 2000). This document identifies six basic pillars of modern mathematics education. The integration of ICT in teaching mathematics to encourage active work with information and facilitate the learning was included among the basic pillars. Efforts to integrate ICT in education are clearly show also in the United Kingdom. The UK Government's Department for Education and Skills (DFES) was established in this country. The important aim of DFES is to characterize the potential for integration of ICT into the school curriculum subjects. The set of documents named ICT across the curriculum was created for the goal to present ICT in mathematics education.

Many studies and reports focused on the characterization of the potential of ICT in mathematics education were developed for DFES. Report for the project ImpaCT2 (Cox et al., 2004) states that 67 % of primary school students never or rarely used ICT in mathematics. It was more than 80 % of students in secondary school. The description of the situation in the USA in 2000 was one of the conclusions of the survey (Cox et al., 2004). One conclusion is that students used the computer in mathematics teaching occasionally, and only a small proportion of work with ICT was used productively. Goos mentioned in the document (Cox et al., 2003) about the results of a three year project in Australia. Research team came to the conclusion that ICT is most frequently used to enhance traditional approaches to teaching.

The situation did not change significantly over the next few years. The report of agency OfSTED (The Office for Standards in Education) (NCETM, 2010) states that the majority of students have only a little opportunities to use ICT for active work with the information in mathematics. The same document shows a graph (see Fig. 4), which characterizes the rate of the use of ICT in mathematics teaching at primary and secondary schools in the UK. The survey covered 1,990 primary schools and 2,061 secondary schools. The sum of percent in the chart does not 100 due to missing answers in some questionnaires and rounding numbers.

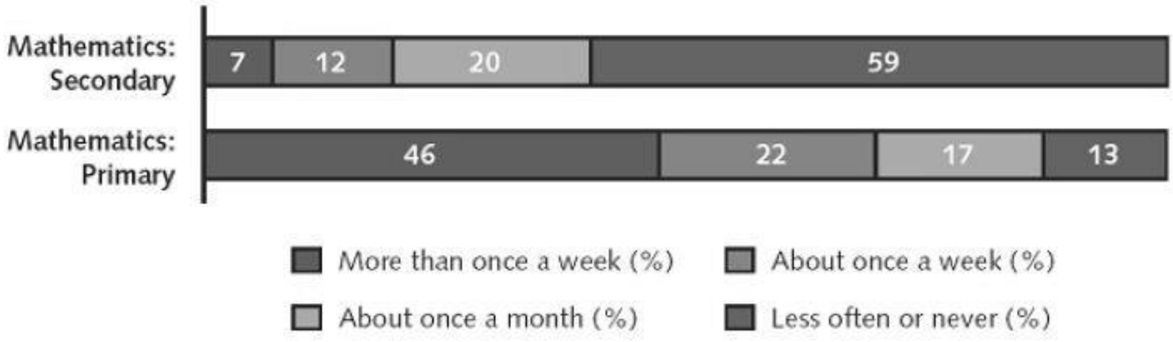

Fig. 4: The use of ICT in mathematics education (Keating, 2009)

Let us look at utilization rate of ICT in the teaching to our neighbours. In 2008 and 2010 Stehlíková and Špačková conducted surveys in the Czech Republic, which were focused on the utilization rate of e-learning at Czech secondary schools. The authors present that 48 % of secondary schools not used e-learning in 2008, when as the percentage decreased to 37 % of secondary schools in 2010. In 2008, e-learning was not use at secondary schools mainly because of lack of money to buy the software technologies. In 2010, inadequate technology equipment of schools was the main reason for non-use e-learning. We present a graph (see Fig. 5) from the paper (Stehlíková, Špačková, 2011) to compare other factors affecting the non-use of e-learning at Czech secondary schools.

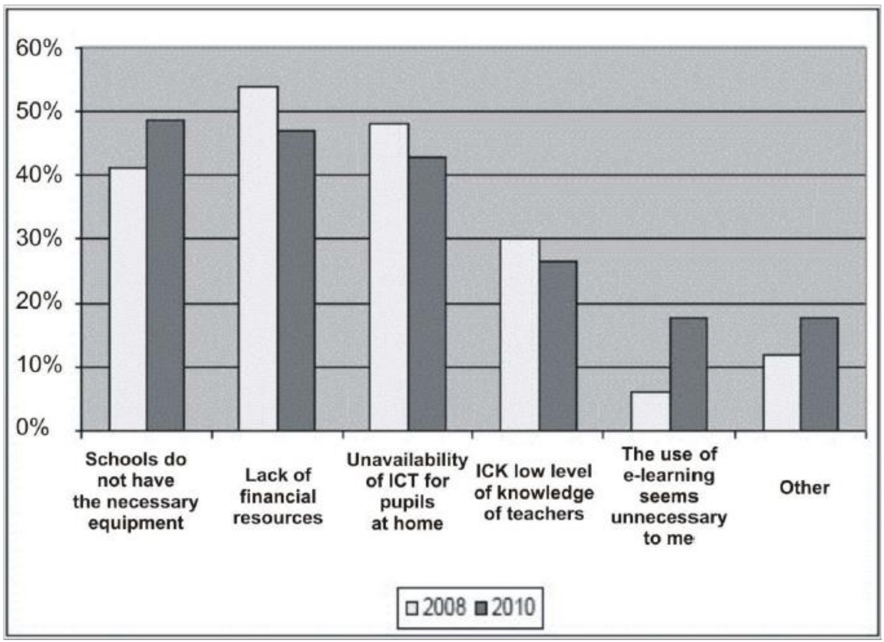

Fig. 5: The reasons for non-use of e-learning in secondary schools in ČR (Stehlíková, Špačková, 2011)

The efforts for innovation of the mathematics education with the support of ICT have been reflected in a variety of national and international projects. ICT can be used in the educational process in different ways. Teachers can include a presentation into teaching to supplement their explanation. However ICT provides a great potential to create the stimulating learning environment in which students can experiment, model, and discover new relationships.

International Project SITES (Second International Technology in Education Study) (Ainley et al., 2010) tried to bring more information for analyzing impact of ICT on teaching and learning and to create the more detailed view of the use of ICT in mathematics. The comparative research program SITES was launched in 2006 in 22 countries, among which was included also Slovakia. Great attention was paid to teaching mathematics and science in the 8th grade of primary schools. Norway was ranked in the first place of the participating countries who have declared the use of ICT in mathematics teaching in the 8th grade of primary school (80,29 % of teachers). Slovakia took the 11th place (51,17 % of teachers) in the list of participating countries.

Teachers should comment in the questionnaires also to the purpose and ways of the use of ICT. If we focus only on the use of ICT in teaching and learning, then teachers most used ICT to find information, to use of the educational resources available on the Internet (57,1 %) and to present information (51 %). The most mathematics teachers in Slovakia have claimed the use of additional devices such as projector and different types of calculators (48 %). Only 2 % of math teachers declared the use of modelling software.

Stols G. and J. Kriek in their survey (Kriek, Stols, 2011) devoted on analysis of the reasons why mathematics teachers do not use DGS. The survey was realized through questionnaires for mathematics teachers in South Africa in 2011. The positive, statistically significant correlation (0,754) was found between perceived confidence in their abilities and the digital literacy of teachers. The highly significant correlation (0,902) was observed between the teacher's perceived usefulness of DGS and the rate of the use of DGS in mathematics teaching. The important conclusion of the survey pointed to the finding that teacher will use DGS in the teaching process regularly only if he is satisfied that it will be useful for him and for students.

The survey to the use of DGS in mathematics teaching

The aim of the survey was to determine the status of the use of DGS in mathematics teaching at secondary and elementary schools. We are also interested in the evaluation of the teachers' opinions about the possibilities of the use of DGS to support the learning and in teachers' views on the benefits and effects of DGS for improving the teaching and learning. When we planned a survey, we focused on the following research questions:

- What is the rate of the use of DGS in mathematics teaching at elementary and secondary schools?
- Where teachers have acquired the skills of using DGS?
- How do teachers perceive and assess the benefits of DGS for teaching purposes and enhancing the quality of teaching?
- At what stage of the learning process do teachers use most frequently DGS and how do they organize learning?

The survey was conducted through distribution of the electronic questionnaire in December 2014. After the closure of the questionnaire, 48 completed questionnaires were recorded. One questionnaire was filled by the university teacher and therefore we did not include it in the final evaluation. The summary of responses to the questionnaire items is available at: https://docs.google.com/forms/d/1RkQTGeTCmpWweiPkjDFTQ5i1Hc-c9Xb4znJ2sxNuR3c/viewanalytics.

In January 2015, we distributed to teachers in the course of innovative education the same questionnaire in printed form. We have included in the final assessment 60 from the 61 questionnaires. The questionnaire was completed by 24 elementary school mathematics teachers (second stage) and by 36 secondary school mathematics teachers (grammar school, vocational schools). The questionnaires showed that 12 primary school teachers (50%) and 23 secondary school teachers (63,9%) use DGS in mathematics teaching of 60 participating teachers.

The information about other approbation subject that teachers have studied may be interesting for the evaluation of utilization rate of the DGS by teachers. Graph in Fig. 6 shows this information about teachers using DGS in the classroom that are divided by length of their teaching praxis.

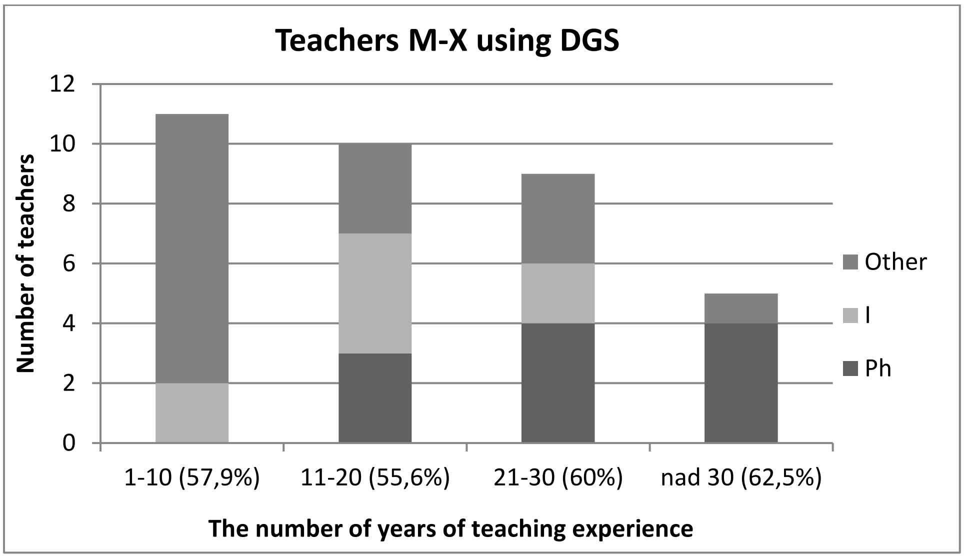

Fig. 6: The rate of the use of DGS by mathematics teachers

Between teachers with teaching experience more than 10 years the significant group consists of teachers that have studied physics or informatics with mathematics. Teachers with teaching experience over 30 years could not study informatics as a second subject of approbation. Teachers with teaching experience less than 10 years had a richer offer to select another subject. The graph in Fig. 6 shows that the most teachers using DGS has teaching experience less than 10 years. However, the situation is different considering the number of teachers in each category. The percentage of teachers using DGS is shown in the graph in Fig. 6 in brackets after the number of years of teaching experience. The survey sample of teachers shows that the length of teaching experience has not significant impact on the use of DGS in mathematics teaching.

The vast majority of teachers using DGS (77%) indicated that they use the system GeoGebra. Since the item of acquiring the basics of working with DGS had the open form, not all teachers using DGS wrote down the answer. The most teachers reported various forms of further education (16) and self-study (8).

The views of teachers on the benefits of DGS for facilitating learning and increase the quality of teaching were divided into five-point scales. The most positive views were assigned to the value 1. The graph in Fig. 7 shows the positive views of teachers divided into two groups by the use of the DGS in mathematics education. Opinions of teachers that do not use DGS are not based on their own experience, but they are derived from their knowledge about the tools and functionality of DGS.

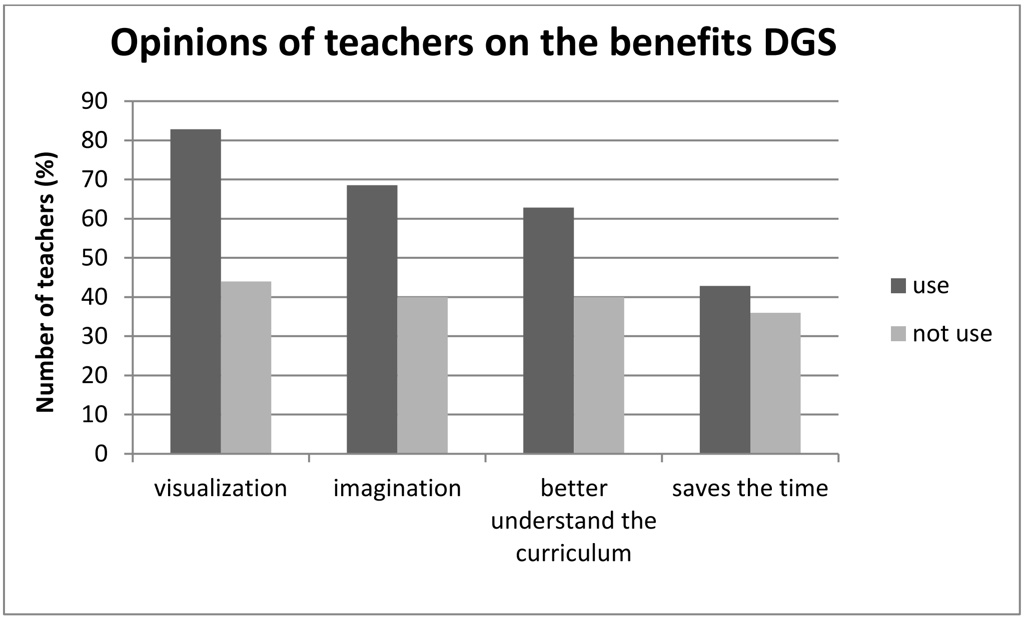

Fig. 7: The teachers' opinions on the effects of DGSin mathematics teaching

The evaluation of respondents sample showed that teachers using DGS in education have greater conviction about the appropriateness and benefits of the use of DGS for teaching purposes. The most teachers (34) reported that they use DGS in the teaching of geometry. Then follow: function (24), equations, inequalities and their systems (8).

The graph in Fig. 8 shows stages of the learning process in which teachers most frequently use DGS and how they organize learning. We evaluated 34 responses because one of the teachers using DGS did not answer. Teachers use the most frequently DGS in the explaining the new curriculum. In terms of organizing learning is represented demonstration, individual and group work nearly as well.

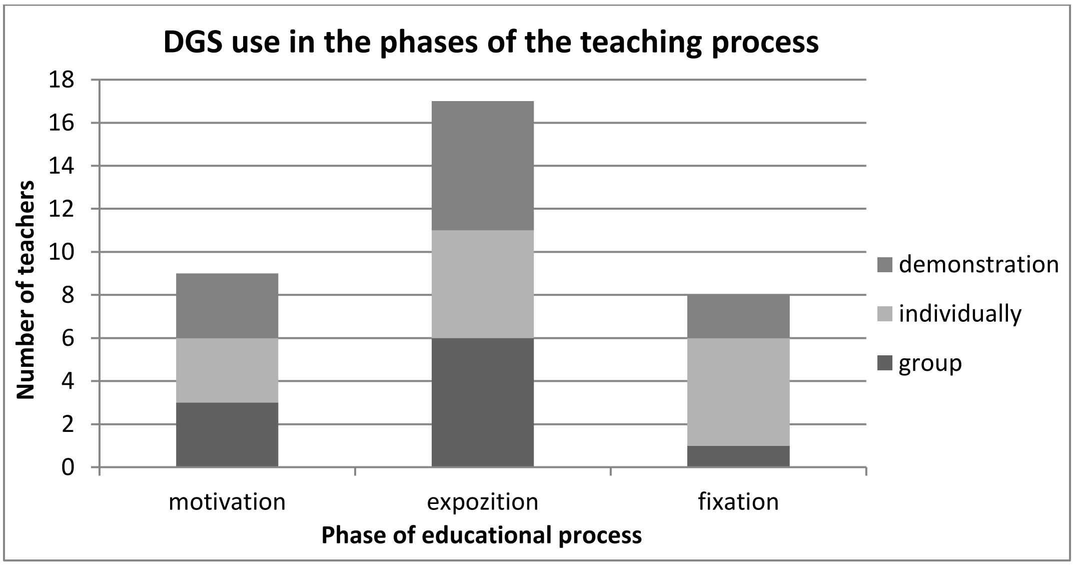

Fig. 8: The teachers' opinions on the use of DGS in the teaching process

The most teachers (12) mentioned as a reason for non-use DGS a lot of the time needed to learn the program by the students. Seven teachers reported about their insufficient working skills of the use of DGS. Teachers reported the following additional weaknesses of the use of DGS in the mathematics teaching:

- the time required for preparation of teaching plan and teaching materials,
- a large number of students in the classroom,
- concern about the weakening of traditional skills of students,
- the benefit from the use of DGS is not adequate to time spent in teaching process.

Interviews with the teachers

We have made interviews with teachers as a complement to a survey we conducted means of a questionnaire. The interviews were conducted in September 2015. We talked with three secondary school teachers from three grammar schools. Two teachers were from Kosice and one was from Presov. The first teacher (marked with A) uses DGS in the mathematics teaching for more than 10 years. The second teacher (marked with B) uses DGS in the mathematics teaching approximately six years. Finally, the third teacher (marked with C) using DGS in the mathematics teaching only the first year.

Two teachers are involved in the project APVV in which are drawn lessons plans and interactive activities where they use GeoGebra in the teaching a plane geometry and the functions.

The interview had uniform structure and it is consisted of four parts. The first part was devoted to DGS and to the conditions for its use in schools. The second part was focused on a preparing of teachers to teaching with using DGS. The third section was about the teaching process. Finally, in the fourth part, we asked the teachers to evaluate the impact of DGS on teaching outcomes and understanding of mathematical educational content.

In the first part of the interview, all three teachers consistently say, that they use the software GeoGebra. Teacher **A** said: *"In the beginning I used the Cabri and later I switched to GeoGebra, because it seems to me that GeoGebra is better because provides a connection between geometry and algebra. GeoGebra is accessible and yet free."* Regarding the technical equipment of schools, there are also teachers responded similarly. They noted that the schools have a computer rooms, but do not have enough computers to ensure that every student works alone. They also do not have access to computer labs still when they need it. Although GeoGebra is also available on the mobile platform, schools do not have a sufficient number of tablets for classroom teaching.
On the question how they have acquired a working with DGS, we got different answers:

A: *"I learned a majority in a course for teachers."*

B: *"I am a completely self-taught in a control of GeoGebra."*

C: *"For the most part I'm a self-taught, but a colleague at the university also helped me."*

The second part of the interview was focused on the preparation of teachers on teaching. We asked, where teachers obtain teaching materials from, respectively, ideas for teaching.

Experience of the teacher **A** will be demonstrated in this section. The teacher A said: *"I mostly used my own materials which I have used before in the some interpretation or discovery. I just created them by GeoGebra."* Teachers **B** a **C** answered similarly that they look for ideas on various internet portals (*http://mathworld.wolfram.com/*, http://www.realisticky.cz/) and then they edit them using GeoGebra. The teacher **B** explained the reasons for this procedure: *"GeoGebra is more convenient for processing and more comfortable for students."*

Then teachers evaluated the time devoted to preparing lessons with using DGS and appropriate teaching materials. Teachers **B** and **C** have said consistently that their preparation takes approximately as much time as a preparation on traditional lessons. Teacher **A** has a different experience: *"The preparation takes me a lot of time. Producing some applets can take me up to 6 hours, as they are quite complex and useful at different stages of the learning process. One applet can be used to discover and also even at practicing. From my perspective, definitely worth the sacrifice a time to prepare teaching materials. Students appreciate it."* This teacher try to create a more complex applets containing a more complex interactive elements and questions for students and therefore the preparation on the teaching takes more time.

The next part of the interview was focused on the course of mathematical lessons using the DGS. Teacher C, which has a less experience, said that it she used GeoGebra only for motivation and exposition of the new educational content. Teacher **A** and **B**, that have more experience answered the same way that they work with GeoGebra throughout the lesson and at all stages of the learning process, except for diagnostic. All three teachers work with GeoGebra on lessons just frontally. Thus, teacher or the selected student works on a computer and a projector displays images for the students. The teachers try to use a problem explanation and questioning. Teachers ask from students to formulate hypotheses and conclusions. Teacher **B** has an interesting experience that she tried to use GeoGebra also for independent work of students: *"When the students work with GeoGebra, so it is very slow and it takes a lot of time out of lessons."* Teacher **B** stated as a reason that students have a different skills of exploitation of GeoGebra and some students are not interested in exploration and problem solving.

Experience of the teacher **A** focused on topics in which she use DGS is as follows: *"I use GeoGebra for teaching functions and also for the solving construction problems. Very good is the use of DGS in the geometric constructions on the same view. I think it's very useful. Also, it's great in the differential calculus."*

Teacher **B** said that she uses GeoGebra in teaching geometry and also by the constructing graphs of functions. And the teacher **C** uses DGS only in the geometry.

During the interview we will not avoid the topic of geometric constructions. It also shows the difference in the experience of the teachers. Teacher **A** expressed the opinion that, DGS is unnecessary in solving simple geometric constructions. On the other hand, teacher **C** is convinced that the GeoGebra is also very helpful for solving the construction tasks. Teacher **B** sees the benefit of GeoGebra for solving the construction tasks especially in the discussion about number of solutions.

The last part of the interview was focused on overall assessment of the benefits and limitations of the use of DGS in mathematics teaching. We were interested in the opinion of teachers about the use of DGS from students' views. The final evaluation of the teachers looked like this:

A: *"This generation of students is so fast that they have no problem in coping with the program GeoGebra. Many students obtain the necessary imagination when handling with applets. Then students will better understand the educational content. The use of DGS can certainly facilitate the work of the teacher."*

B: *"DGS are suitable for students who have problems with an imagination. Because they can have good analytical thinking, can be perfectly in algebra, but they have difficulties with the solution of geometric problems and DGS can help them. I believe that the possibility to change the parameters in the constructions is a great benefit for the students.*

C: *"I see the greatest benefit of the use of DGS in mathematics teaching in improving imagination and conceptual understanding. Of course lessons by using DGS are more diverse and therefore the atmosphere is more creative."*

Finally, the teachers were asked to comment whether the use of DGS in mathematics teaching increases the motivation, respectively, improves the attitude of students towards mathematics.

A: *"The students appreciate teaching with GeoGebra. When not used for some time GeoGebra in the teaching, so students are already asking when we will work with GeoGebra."*

B: *"The motivation is elevated, some students work with GeoGebra at home and they are interested in mathematics."*

C: *"I think so yes, but students can lose interest, if the teaching with the use of GeoGebra is getting too stereotyped. Although, it may be motivating mainly at the start of selected mathematical topics."*

Our interviews with teachers indicate that teachers use GeoGebra especially for the frontal teaching. As the main reasons for this form of using GeoGebra they had given insufficient technical equipment of schools, students' different skills and to save the time. GeoGebra functionality on mobile platform could help to remove the first hurdle. Our knowledge from the survey shows that teachers do not yet have experience of using GeoGebra on tablets. If students should use GeoGebra also to solve some homework, they would gain skills that could be used also in mathematics classes. At present on Slovak secondary schools, teachers can divide one lesson of mathematics a week. Divided lessons give a more space for independent work of students and for the use of ICT.

Conclusion

In respect of small sample of mathematics teachers at the elementary and secondary schools we cannot make general conclusions about the use of DGS in the mathematics teaching. We were unable to obtain information from the teachers, whether they use DGS also for create a stimulating learning environment which could enable students to experiment, explore and discover the properties of objects and mathematical patterns. Similarly to other studies (Kriek, Stols, 2011) our survey showed that enthusiasm and internal conviction of teachers are crucial to integrate DGS into the mathematics teaching. We have found during interviews with teachers, how teaching materials they are used and how much time teachers spend on preparing teaching with using GeoGebra. We managed to get the detailed information about the course of lessons of mathematics teaching with the help of DGS. Teachers believe that students appreciate their work. Based on the interviews, we realized we can say that the experience and years of work experience with the use of DGS in mathematics teaching, affect the quality and processing of teaching materials and methods used in teaching with support from DGS.

Acknowledgement

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