The Use of Method of Multidisciplinary Approach, Modeling and Simulation in Learning of Gear Ratios

Radek Nemec, Andrea Berkova, Stepan Hubalovsky

Abstract — This paper presents the development of Set for Measuring the Transfer Gears and its use in science classes in conjunction with teaching computer technology supported by interactive geometric software. The goal of developing measurement transfer kits for gears demonstration of speed gears is to show the real speed of the individual gears in relation to the number of gears to pupils of science. For better understanding, the animations of gears, drawings of various kinds of gears and gear teeth in interactive geometry software were used. Several school science subjects were involved in this project and their collaboration resulted in improved results of pupils in these subjects.

Keywords — DAQ, measurement system, computer aided experiment, GeoGebra, teaching science

I. INTRODUCTION

"THE preference of methods based upon observation, measurements, experimentation and the evaluation of real acts, objects and conditions, on visualization and modelling, on the active seeking and processing of information by the student is substantial for effective science education." [1]

Natural sciences examine and describe the regularities and natural laws of the real world. They are thus sciences based upon the learning of natural phenomenon through empirical and theoretical methods. The theoretical approach utilizes the intellectual activity of the pupils and the empirical one makes use of the sensorimotor activities.

Because of this, the simple transferring approach of passing complete and pre-made information is being partially replaced by alternative, constructive teaching methods that utilize

R. Nemec, University of Hradec Kralove, Faculty of Education, Department of Informatics, Rokitanskeho 62, 500 03 Hradec Kralove, Czech Republic (phone: +420 774220193; e-mail: radek.nemec@uhk.cz).

A. Berkova, University of Hradec Kralove, Faculty of Education, Department of Informatics, Rokitanskeho 62, 500 03 Hradec Kralove, Czech Republic (e-mail: andrea.berkova@uhk.cz).

S. Hubalovsky, University of Hradec Kralove, Faculty of Science, Department of Informatics, Rokitanskeho 62, 500 03 Hradec Kralove, Czech Republic (e-mail: stepan.hubalovsky@uhk.cz).

cognitive methods and also respect individual characteristics of pupils. The intellectual activity can be developed by introducing of the principles of modeling and simulation to the education.

This paper describes the development of Set for Measuring the Transfer Gears. Set mechanism of transfer gears clearly defines the ratio between gears. Set is constructed out of three motors, one of which is driving and the other two are driven. Driven engines therefore represent a speed sensor. As a display element, SMPSL measurement system is used [2], [3], **[4]**. The SMPSL system shows the process of the measurement on the graph during real measurement experiment. System SMPSL is a measurement system using a computer in the school laboratory. It is very cheap to assemble and the hardware and software are available for free. In this case, SMPSL system displays the speed of the driven gears.

The teaching with the support of the Set for Measuring the Transfer Gears is conducted through laboratory work in physics. Pupils are during the laboratory work verifying if their mathematical calculations agree with reality. Following aforementioned teaching, for better understanding, the dynamic interactive geometry software GeoGebra is used in computer technology classes for demonstration of work of gears. The mentioned technologies helped students to gain new knowledge or to apply the knowledge they already had more easily, clearly, quickly and above all more comprehensively.

II. MODELING AND SIMULATION AS EDUCATIONAL METHOD

A. Modeling

Many secondary schools as well as upper primary schools are realizing that modeling and simulation is becoming an important tool in solving and understanding numerous and diverse problems [5].

To engage modeling and simulation the mathematical model of the real system has to be first created. Models are approximations of the *real system*. The model is then followed by *simulation*, which allows for the repeated observation of the model. After the simulation's model is verified, a third step takes place - *visualization* of the model and the real system.

The ability to define a system, to build up a mathematical

model and to create a simulation model develops logical thinking skills and imagination and is an inseparable part of a pupil's study.

The main goal of modeling is describe the content, structure and behavior of the real system representing a part of the reality.

The first step in the process of computer simulation is creation of conceptual/mathematical model of the studied real system. The most used representations are of the models are mathematical equitation.

B. Simulation

The process of modeling is closely related to the simulation. Simulation can be understood as process of executing the mathematical model. Simulation enables representation of the modeled real system and its behavior in real time by means of computer. The simulation enables also visualization and editing of the model.

A typical simulation model can be written both through specialized programming languages [6] that were designed specifically for the requirements of simulations, or the simulation model can be created in standard programming languages [7]. In our paper the real system is simulated in the dynamic interactive geometry system *GeoGebra*.

The simulation is very useful from educational point of view. Using the simulation model and animation of simulation results on the screen, students can better understand the basic features of the real systems and develop their intuition. It is also essential that the teaching by means of simulation is much cheaper and faster than the teaching carried by real system. In some cases providing the real system cannot be feasible.

In our paper the real system - a*nimation of gears* will be presented.

The simulation model should be confirmed by real system. The real system of the gears can be designed and created by means of system SMPSL.

C. Model verification and validation

Verification and validation are important aspects of the process modeling and simulation [5].

In modeling and simulation, verification is typically defined as the process of determining if executable computer simulation model is consistent with its specification – e.g. mathematical model. Verification is also concerned with whether the model as designed will satisfy the requirements of the intended application.

Validation is the process of determining the degree to which the model is an accurate representation of the real system.

Validation and verification are both ultimately activities that compare one thing to another. Validation compares real system and mathematical model. Verification compares conceptual model and executable simulation model. Sometimes validation and verification are done simultaneously in one process.

Validation of the mathematical model as well as verification of the simulation model of our real system – **geers** – will be tested by SMPSL system.

D. Multidisciplinary approach

Another important benefit associated with the modeling and simulation of reality is a multidisciplinary approach, without which the identification mathematical model and simulation model cannot be realized.

Multidisciplinary approach generally means that specialized disciplines are applied in a study of real processes. These disciplines provide partial analysis of the processes. These mono-disciplinary analyses are integrated to overall solution by integrating the solver who has basic multi-disciplines knowledge.

In our case study four disciplines are integrated, namely, technical science, programming and mathematics [6].

III. SYSTEM SMPSL

System SMPSL was created by eProDas platform, developed in the University of Ljubljana, Slovenia [8]. An important feature of the system is the ability to produce it, not only due to the very low price, but also thanks to readily available libraries and documentation [9].

The hardware part of the system is connected via USB. The hardware part contains 4 analogue inputs, 4 digital outputs and 1 analogue output. See Figure 1.
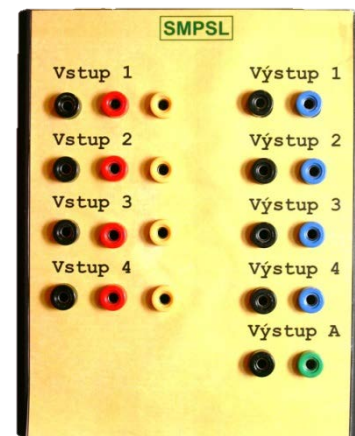

Fig. 1 - System SMPSL – hardware part

The software part allows the connection of hardware to your computer. The software is a user interface for measurement using a computer with which users control their own measurements, setup, operation and management of the system itself. See Figure 2a, 2b.
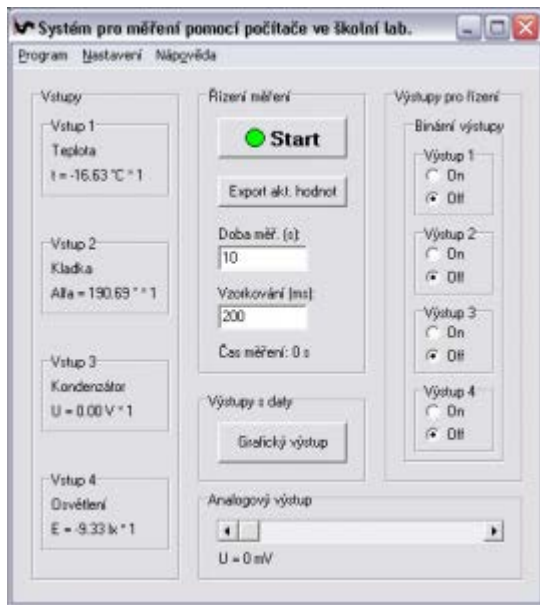
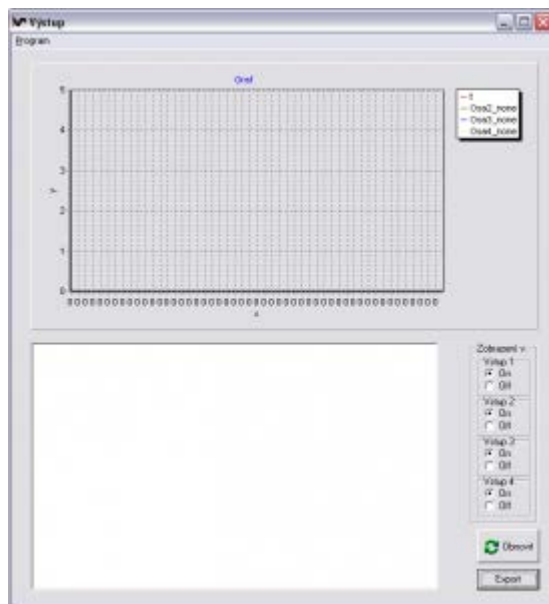Fig. 2a - System SMPSL – software part

Wherein n_1 is the frequency of rotation of the driving wheel, n_2 is the frequency of rotation of the driven wheel, d_1 is the radius of the driving wheel, d_2 is radius of the driven gear, z_1 is the number of gear teeth of the driving wheel and z_2 is the number of gear teeth of the driven wheel.

The set uses tooth wheels with a given number of teeth. The driving wheel is fitted with 34 teeth. Driven wheels are fitted with cogwheels, which have 34 and 83 teeth. The ratio can be calculated on the basis of relation. SMPSL system displays the resulting stress on the driven wheels. Number of teeth of the driving wheel z_1 is 34, the number of teeth of the driven gear is in the first example $z_2=34$. The ratio is therefore 1:1. In the second example, the number of teeth of driven gear is $z_2=83$. Output ratio of 1:1 (34:34) is 4.14 V. The output ratio of 34:83 is 1.67 V. If the number of teeth is introduced into the relation, then at a ratio 34:83 of teeth it is 1.7. As can be seen from the results, the ratio corresponds mathematically as well as using measurement. The real measurement shows theoretically calculated values which is the main purpose of measurement using a computer [11]. The set for measuring transfer gears is shown in Figures 3a, b and c.
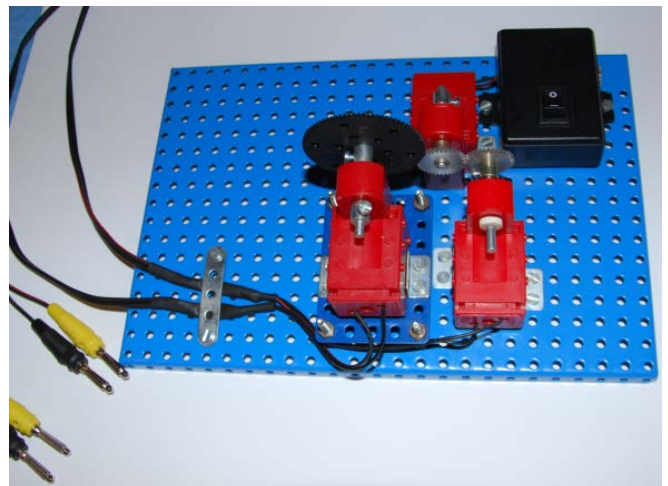

Fig. 2b - System SMPSL – software part

Fig. 3a - Set for measuring the transfer gears

IV. SET FOR MEASURING THE TRANSFER GEARS

Set for Measuring the Transfer Gears consists of three electric motors and of "Merkur" base [10]. One is used as the source. Source motor is intended as a driving motor. It is powered by an external power supply. Another two electric motors are used as driven. These are therefore outputs.

Set for mechanism of transfer gears serves to demonstrate the ratio between the individual wheels. This can be expressed using the variable named gear ratio i:

$$i = \frac{n_2}{n_1} = \frac{d_1}{d_2} = \frac{z_1}{z_2}$$

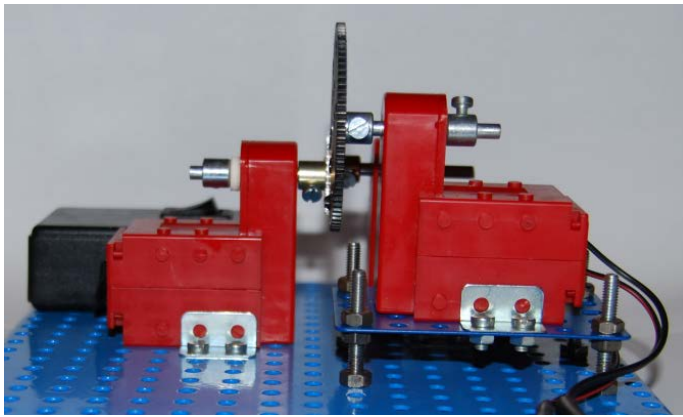Fig. 3b - Set for measuring the transfer gears

Fig. 3c - Set for measuring the transfer gears

V. Laboratory work

This laboratory work can be processed into prepared laboratory protocols. Based on the theory and led by a teacher, pupils create predictions (hypotheses), write them down and invent a procedure for their verification. The example can be seen in the following Figures 4a, 4b and in [12].
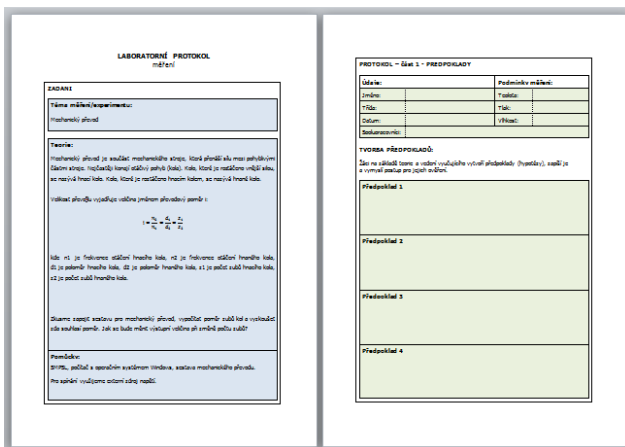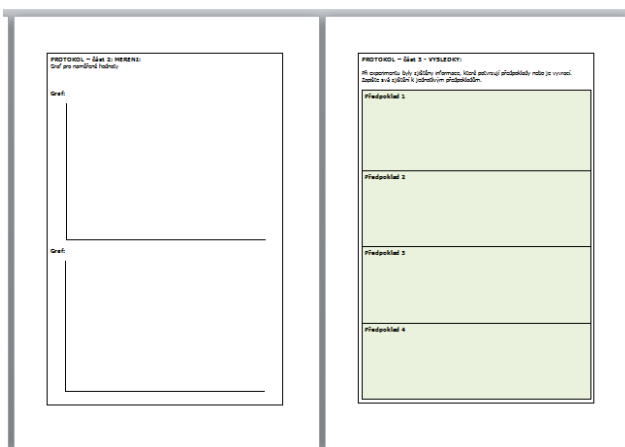

Fig. 4a - Laboratory protocol

Fig. 4b - Laboratory protocol

VI. Demonstrations using GeoGebra

In lessons of computer technology, pupils learn how to work with a dynamic interactive geometry system GeoGebra [13]. Following the laboratory work, drawings of gears and animations of gears are shown (Fig. 6) to students in computer technology lesson. GeoGebra offers us both manual and automatic animation. For the purposes of animation of the free numbers/angles, we need Slider in the Graphic view (Figure 5).
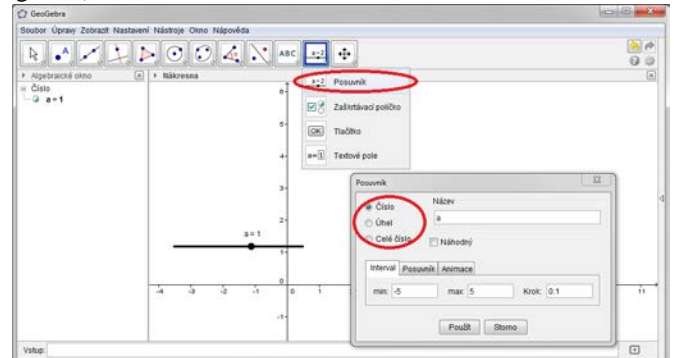

Fig. 5- Slider in GeoGebra

For automatic animation, we first have to right-click on the desired object and then select the option "Animation on" in the appropriate context menu. Animation can be stopped by deactivating this option (we uncheck the option) in the same context menu. After activating automatic animation, a button labelled animation control appears in the left bottom corner of the screen. This button enables us to start and stop the animation. In the dialog Properties of the animated object, the behaviour of the animation can be changed - the speed of the animation and the methods of repeating the animation cycle (oscillating, increasing and decreasing). The free number or angle can be animated, as well as the dependent point. The following figure shows a sample of animation of gears in GeoGebra.
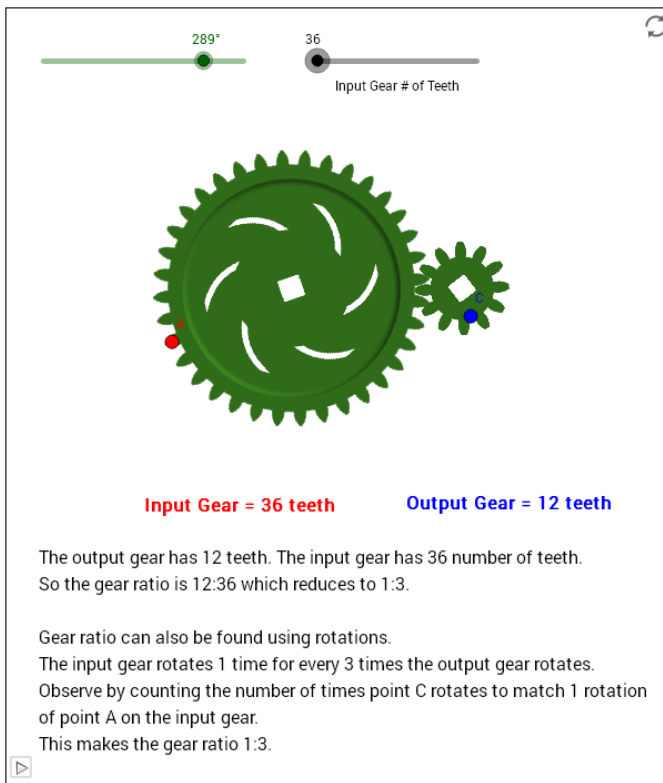
Fig. 6a – Animation of gears in GeoGebra – Input 36 teeth (taken from the materials available in [14], author Matt Arnold)

Fig. 6b – Animation of gears in GeoGebra – Input 60 teeth (taken from the materials available in [14], author Matt Arnold)

Green slider in the upper left-hand corner represents the angle. With the change of the angle, the rotation of the gears occurs. To start, it is necessary to turn on the automatic animation (in this case on the Figure 5a just select the Play button in the lower left-hand corner). The black slider in the upper right-hand corner represents the number of teeth of the input gear. To see how the input gear size impacts the gear ratio, it is necessary adjust the input gear number of teeth (manual animation).

Similar animations are freely available from the GeoGebra homepage [13] and presented to pupils. Then the pupils have to create their own similar (but simplified schematic only) animations to represent work of gears. Sketching of various types of gears and gear teeth using geometric objects or performing calculations of gear ratios belong also to their work. Pupils then present their works to the classmates. In this project, therefore, there is a curricular collaboration of school subjects – mathematics, physics and computer technology.
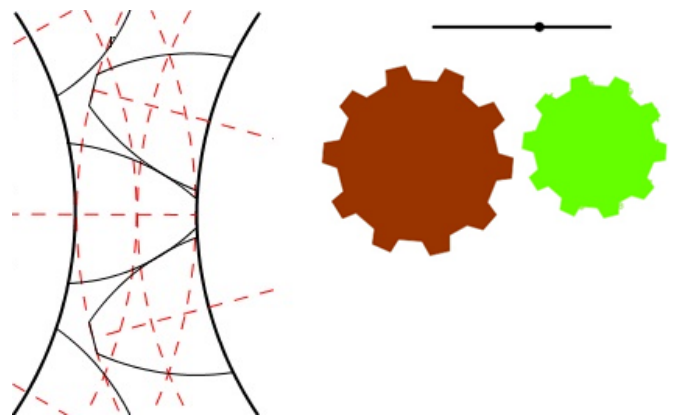

Fig. 7 –Pupils works in GeoGebra

Pupils also demonstrate the practical use of gears in everyday life. For example, they present pictures or photos of

things that they normally use – such as a printer or a bicycle (Figure 8, 9). Pupils then explain to classmates how these things work.

Fig. 8a – Practical use of gears in everyday life (from pupils' presentations)

Fig. 8b – Practical use of gears in everyday life (from pupils' presentations)

VII. Final test

After practising aforementioned way of teaching, the pupils filled in a test to verify their knowledge (Figure 9).

*První kolo soukolí ozubených kol má 60 zubů. Druhé kolo zapadající do prvního kola má 42 zubů. Třetí kolo zapadající do druhého kola má 15 zubů. První kolo se otočí sedmkrát. **Kolikrát se otočí třetí kolo?***

*Sestav do soukolí několik různě velkých ozubených kol a otáčej jimi. Když pootočíš největším kolem o 10 zubů, **o kolik zubů se otočí nejmenší kolo?** Které kolo v soukolí se otáčí nejrychleji?*

*Když chceme na jedno sešlápnutí pedálů ujet na jízdním kole větší dráhu, musíme na pedálech přeřadit řetěz na **menší/větší** ozubené kolečko a na poháněném kole na **menší/větší** ozubené kolečko.*

Fig. 9 – Sample questions of the final test

The test contains mathematical/physical open-ended questions with calculations such as:

*The first gear has 60 teeth. The second gear (falling into the first gear) has 42 teeth. The third gear (falling into the second gear) has 15 teeth. The first gear will rotate seven times. **How many times will the third gear rotate?***

Open-ended questions with short answers also appear in the test:

The gearing comprises of several gears. When the largest gear

*will rotate around the 10 teeth, **of how many teeth the smallest gear will rotate around?***
Which gear is rotating the fastest?

Furthermore, the test includes close-ended questions, an example of the simplest tasks are true-false ones such as:

*When we want to cover greater distances by a bike on one pedal, we need to shift pedals chain into **smaller / larger** sprocket gear and the driven gear to a **smaller / larger** sprocket gear.*

The final test results of pupils improved significantly after they had been introduced to these new teaching methods. The interviews with pupils show that students especially appreciated the possibility of creating their own projects and connection with reality.

VIII. Conclusion

Set for Measuring the Transfer Gears for demonstration of speed gears using the system SMPSL was used to help to demonstrate the gear speed, work of gear and gear ratio. The theoretically calculated values and reality were thus confirmed. The actual measurements and animations are more demonstrative for pupils than only a calculated value in natural science subjects.

It turned out that the results of pupils in the science tests are much better when teaching is conducted with the support of technologies such as measuring system SMPSL and mathematical software GeoGebra and with the curricular collaboration of school subjects. In comparison with pupils´ results from the previous years, not only the welfare of students improved, but also increase of students' interest in natural science was detected.

References

[1] BÍLEK, M. Konstruktivismus ve výuce přírodovědných předmětů. Olomouc: Univerzita Palackého v Olomouci. [Constructivism in science teaching]. [Internet]. 2008 [cited 2012 Apr 5]. Available: http://esfmoduly.upol.cz/publikace/bilek1.pdf.
[2] NĚMEC R., TŘÍSKA J., ŠEDIVÝ J. System SMPSL. In: The 4th NAUN International Conference on CIRCUITS, SYSTEMS, CONTROL, SIGNALS (CSCS '13). Valencia, 2013, ISBN: 978-960-474-318-6. P. 43-47.
[3] NĚMEC Radek., TŘÍSKA Jan., ŠEDIVÝ Josef. System for measurement using a computer in the school laboratory. In: International Journal of Education and Information Technologies, Volume 8, 2014, s 37-47, ISSN: 2074-1316
[4] NĚMEC, R., TŘÍSKA, J.. Natural experiments using ICT. In: Circuits, systems, control, signals (CSCS 2013) : proceedings of the 4th

international conference. Athens: World scientific and engineering academy and society, 2013, s. 48-52. ISBN 978-960-474-318-6.

[5] HUBALOVSKY, S., Modeling, Simulation and Visualization of static Mechanical Properties of Frame of Elevator Cab. International Journal of Mathematical Models and Methods in Applied Sciences. 2013, Vol. 7, No. 6, p. 666-675. ISSN 1998-0140.

[6] HUBALOVSKY, S., MUSILEK, M., Modeling, Simulation and Visualization of Real Processes in LOGO Programming Language as a Method of Development of Algorithm Thinking and Programming Skills. International Journal of Mathematics and Computers in Simulation. 2013, Vol. 7, No. 2, p. 144-152. ISSN 1998-0159.

[7] HUBALOVSKY, Š., MILKOVA, E.: Modeling of a real situation as a method of the algorithmic thinking development. In: Advanced Educational Technologies, Proceedings of 6th WSEAS/IASME International Conference on Educational Technologies (EDUTE'10), WSEAS Press, Kantoui, Sousse, Tunisia, May 3-6, 2010, pp. 68–72. ISBN 978-960-474-186-1, ISSN 1790-5109

[8] COMLAB - Computerised Laboratory in Science and Technology Teaching: Home [online]. 2008 [cit. 2013-10-10]. Available: <http://e-prolab.com/en/>.

[9] Data Acquisition system, Users' guide and programming manual [online]. 2007 [cit. 2013-10-20. Available: http://lie.fe.uni-lj.si/eProDas/eProDas_Version_1_0.pdf.

[10] Merkur [online]. 2014 [cit. 2014-12-30]. Available: http://www.merkurtoys.cz/

[11] HUBALOVSKA, M., HUBALOVSKY, Š. Implementation of the Systems Approach in Mathematical Modeling, Dynamic Simulation and Visualization Using MS Excel Spreadsheet. International Journal of Mathematics and Computers in Simulation. 2013, vol. 7, no. 2, pp. 267-276. ISSN 1998-0159.

[12] NĚMEC, Radek. Systém pro měření pomocí počítače ve školní laboratoři [online]. 2014 [cit. 2014-12-30]. Available: http://smpsl.radeknemec.cz/wp-content/uploads/21-Mechanick%C3%BD-p%C5%99evod.docx

[13] GEOGEBRA. [online]. [cit. 2015-07-02]. Available: http://geogebra.org/

[14] Gears – GeoGebra [online]. [cit. 2015-07-02]. Available: http://tube.geogebra.org/material/show/id/1016545.

Radek Nemec was born in 1984 in the Czech Republic. He is a student of doctoral degree in Information and communication technologies in education on the University of Hradec Kralove, Faculty of Education, Czech Republic. His scientific activities are focused on measurement using a computer in the school laboratory, education and informatics.

Andrea Berkova was born in 1987 in the Czech Republic. She is a Ph.D. student in the field of Information and Communication Technologies in Education. She is also a lecturer in the Department of Mathematics at the University of Hradec Kralove. Her research interests include Mathematical Analysis, Mathematical Education, Technological Innovations in Education, etc.

Stepan Hubalovsky was born in 1970 in the Czech Republic. He obtained master degree in education of mathematics, physics and computer science in 1995 and doctor degree in theory of education in physics in 1998 both in Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic. He works as associated professor on University of Hradec Kralove His scientific activities are system approach, modeling and simulation.