Digital competence in physics in the frame of the national project Development of Natural Science Competences

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Abstract. *The national project Development of Natural Science Competences which started in October 2008 is now in full swing. Learning materials are being prepared periodically, and then they are tested in schools and revised afterwards. The main goal of these materials is to indicate better didactics strategies for systematic development of students' natural science competences. One of these competences, taken from the wide frame of eight key competences – Key Competences for Lifelong Learning from the EU Legislation (Education, Training, Youth) – is the digital competence. Several of our materials in the project written so far include this competence in different ways: e-learning materials, use of the computer in experiments and measurements, numerical modelling, graphic tools, etc. Here we focus on particular cases from our physics materials. The tests have shown indubitably that students are prone to acquiring digital competence.*

Keywords. key competences, natural science competences, digital competence, education

1 Introduction

There are different definitions of competences and their classifications. For instance, Coolahan proposed the following definition on symposium of the European Council in 1996: Competences are general operational abilities which are based on knowledge, experience, ethic principles and dispositions developed by a person during his/her education

[3]. On the other hand, on the same symposium Weinert interpreted competences as rather specialized system of abilities, experience and skills which are necessary to achieve specific goals [3]. In the EU Legislation – Education, Training, Youth (Key competences for Lifelong Learning) eight key competences are defined [4]:

1. Communication in the mother tongue
2. Communication in foreign languages
3. Mathematical competence and basic competences in science and technology
4. Digital competence
5. Learning to learn
6. Social and civic competences
7. Sense of initiative and entrepreneurship
8. Cultural awareness and expression

The third competence refers to science and more specifically to natural sciences, but also other key competences are interconnected with science. For instance, in regard to science the first competence in the upper list could be translated into Communication in the mother tongue in the area of natural sciences, and so on. Here we focus on the significance of digital competence for natural sciences and on its implementation in the education of science. This competence includes the use of computer and other Information Communication Technology (ICT) tools in natural sciences. More generally (not only in science) its definition in EU Legislation is: "Digital competence involves the confident and critical use of information society technology (IST) and thus basic skills in information and communication technology (ICT)."

In October 2008 the National project Development of Natural Science Competences began and it will finish at the end of 2011 [6]. Its main purpose is to indicate better didactics strategies for systematic development of students' natural science competences. Learning & testing materials are being prepared periodically, and then they are tested in schools and revised afterwards. Typical materials include instructions for teachers and for students, materials with the topic contents, exercises, pretests and post-tests, etc. Authors of these materials in the project closely cooperate with teachers who test them in school. All educational levels from the first year of 9-year primary school to the end of various secondary schools are considered; some materials are prepared even for preschool children (in kindergartens). Besides the three basic natural science subjects in school – biology, chemistry and physics (or their topics in wider subjects at the lower educational level), also some supporting subjects are included in the project: mathematics, technics and computer science.

In addition to key competences listed above, we focused in the project also on a specific set of generic competences defined by the Mayer committee, Australia, which are also related to natural sciences [2]. Each of these generic competences has a narrower meaning as compared the key competences above; a few examples of these competences are: 1) ability of collecting information, 2) ability to synthesize conclusions, 3) implementation of theory in practice, 4) care for quality, 5) ability of individual work, 6) verbal communication, etc.

Since we are aware of the ever growing importance of digital competence in life and science, this competence has been considered in many prepared materials in all natural science subjects and supporting subjects. In this paper we focus on materials in physics which include digital competence in different ways: e-learning materials, use of the computer in experiments and measurements, numerical modelling, graphic tools, etc. Digital competence is interconnected with some generic competences mentioned above, e.g., with the ability of collecting information (from the web), etc.

2 Examples of physics materials with digital competence

We give the examples of the physics materials with training digital competence written so far. In the next materials we plan even larger extent of using ICT.

2.1 Success of traditional learning techniques in incorporation of modern scientific achievements in primary school physics

Two authors prepared a series of materials where they tested three different didactic methods for introducing some actual physics topics in school: 1) frontal work, 2) individual work with hardcopy learning materials, and 3) frontal work with the help of ICT. The topics prepared (and most of them already tested) so far are quite interesting [7]: 1) Nuclear Power Plant Krško in Slovenia, 2) Photovoltaic cells, 3) Optical fibres, 4) Nuclear waste, 5) Colour Perception, 6) Weather Forecast. The materials are intended for the 8th and 9th grade of 9-year primary school. The three methods were tested in parallel classes of the same level (and usually by the same teacher who teaches at least in three parallel classes). Using ICT was usually meant as searching for specific information on web pages by individual students. The pre-tests and post-test were short – they contained 7 questions of increasing cognitive degree, where the correct answer from the four had to be selected. The first question is asking for the pupil's relation to physics (pre-test) and the treated subject (post-test). To avoid memorizing the solutions from the pre-test, the questions in the post-test were different but were actually asking for the same level of knowledge (or competence). Preliminary results of the school tests showed that the combination of the frontal work and ICT is preferable when the unfamiliar topics are learned.

2.2 Web textbook about Galileo

One of the materials was dedicated to Galileo's life and work. The year 2009 was declared as the International year of astronomy (briefly IYA 2009) by Unesco and the International Astronomical Union since this year was the 400th anniversary of the first Galileo's important and revolutionary contributions to the further development of astronomy. In 1609 Galileo made key observations of Moon surface through his improved telescope, and in the next year some of his further discoveries followed (e.g., the moons of Jupiter). In addition, his book Starry Messenger was published in 1610. Galileo's work finally discarded the geocentric view of the Universe and accelerated the development of the science and scientific concepts as we accept today. IYA 2009 stimulated us to write a short web textbook (e-book) with the title Galileo and International Year of Astronomy 2009 in Slovene [1]. The aim of this e-book was also encouraging students to use ICT and develop digital competence. In addition, the learning material appropriate for testing in the 9th year of primary school (topic Astronomy within physics for this level) or in secondary schools (for instance, for optics topics in physics) was written. The structure and philosophy of our e-book as well as preliminary testing results have already been described elsewhere [1, 8], thus we only briefly mention key points about training digital competence in education. Depending on teacher's planning the physics lesson about Galileo and astronomy (or other topics in the e-book) and his corresponding instructions, either one student in the class or a few of them or all the students get the task of reading the part of the e-book. Reading the e-book is a good exercise of the student's navigation through this material and other e-materials with similar design; our e-book contains also a searching key by using the keywords. There are also many external links in this e-book.

It should be mentioned that a large fraction of students are relatively inert (or to be said more sincerely – lazy) and dislike reading of any kind. Teachers' experiences in using our material in connection with Galileo e-book in school tests only confirmed this general finding. But perhaps at least some of students may be encouraged to read a little more with the help of user-friendly e-books if they are not willing to read printed books. Using e-materials helps the student to develop a generic competence ability of collecting information and their organization. In addition, a part of the e-book, for instance, the section Development of astronomy, should be presented as a seminar lecture by one or more students to their schoolmates. This means training of the use of the program Powerpoint. This material is appropriate for training teacher's digital competence, too. The teacher should read the Galileo e-book before his/her students do. Some other addresses of e-materials about Galileo are suggested for further reading.

2.3 An introduction to percolation theory at elementary level

Percolation is involved in a broad range of physical phenomena including forest fires, propagation of epidemics, oil fields, transport through porous media, ferromagnetism, communication in an unreliable network etc [9]. One of the easiest and most interesting percolation-related phenomena to study is the electrical behaviour of a system of conducting particles dispersed in an insulating matrix. When the fraction of the conducting material, p, is lower than a critical fraction pc, no macroscopic conducting pathway exists, and the composite remains in the insulating phase. Only if the fraction of conducting material is greater than the critical fraction, the system becomes electrically conducting. The value of pc is the critical threshold, in which the properties of a percolation system suddenly change; the percolation phase transition is a second-order phase transition point. Due to its straightforwardness, these disordered conductor-insulator composites represent an efficient way to introduce the theory of percolation and the general ideas of critical phenomena to high school or perhaps even to elementary school students.

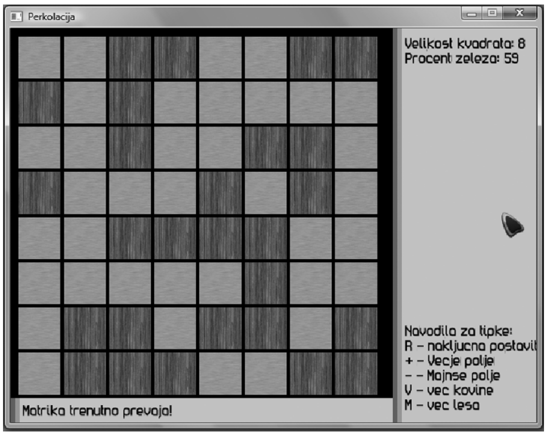

Figure 1: A snap-shot of the user-friendly program for an introductory overview of the percolation theory at the elementary level.

In view of that we prepared an experiment, where the students randomly arrange conducting and insulating cubes between capacitor plates. Then, the conductivity of the setup is being tested in dependence on the ration between conducting and insulating elements, thus providing an introductory overview of the field at elementary level. Along with that we also developed two computer programs, which can nicely supplement or even substitute the experiment. The first program is very user-friendly and is meant to acquaint the students with the basic idea of the functioning of the conductor-insulator composites. The students are allowed to change the fraction of conducing elements and the size of the lattice, whereby for each setup the program indicates if the lattice is conducting. Because of the graphical interface on can easily observe the particular arrangements at different parameter values. A characteristic snap-shot of the program is shown in Fig. 1. The second program enables a more quantitative insight into the percolation phenomenon. It gives the students the opportunity to perform calculations on larger lattices and it calculates the statistics of the probability of conduction in dependence on fraction of the conducting material p. Consequently, the students are able to quite precisely estimate the critical fraction pc and for instance observe the behaviour near the transition point for different lattice sizes.

Nevertheless, the percolation theory surely represents a topic where the concept of interdisciplinarity is emphasized. First, in this manner students improve not only their knowledge in physics, but also in mathematics and computer science. Second, students realize that approaches and discoveries ascertained during a physics lesson can be of great importance in various disciplines, thus giving rise to the development in specialized competencies, which are characteristic for physics and other natural sciences. Furthermore, with this kind of work generic competencies are being evolved as well. In particular, students certainly improve their skills considering the usage of mathematical ideas and techniques.

2.4 Refraction of light

We prepared materials for the realization of a physical experiment in which refraction of light is being studied. Our main objective was the elaboration of a material in which students develop several generic and specialized competencies with special emphasis on digital competencies. The main idea is that the students perform an experiment, in which the refraction index of water is being measured. For the analysis and the subsequent calculations they make use of a digital photo camera, a computer program enabling the representation and manipulation of image data, a spreadsheet application and at last they prepare the final report using a word processor.

The refraction index is a measure of the bending of a ray of light when passing from one medium into another. The relationship between the angles of incidence and refraction and the refraction indexes of both mediums is given by the Snell's law $\frac{sin\ \alpha_1}{sin\ \alpha_2} = \frac{n_2}{n_1}$, where α_1 and α_2 are the refraction angle and the angle of incidence, respectively, whereas the quotient $\frac{n_2}{n_1}$ gives the ratio between the refraction indexes of both media.

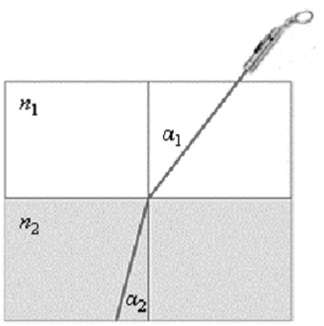

Figure 2: Scheme of the experiment indicating the bending of a ray of light as it enters the water.

The course of the experiment is as follows: Students draw two right-angled lines on a white sheet of paper, whereby the horizontal line indicates the water level and the vertical line specifies the right angle on the water surface. The scheme is shown in Fig. 2. After that, they glue up the paper behind a glass container, which is half full of water, so that the horizontal line is even with the water surface. By using a laser pointer they light along the paper, whereat the beam must enter into the water at the point of intersection (see Fig. 2). Using a proper photography technique, the students take a picture of the arrangement. This procedure is then repeated for different angles of incidence. All the photos must then be copied to a hard drive and imported in an image editing software. The subsequent graphical manipulation allows then the students to measure the angles of interest from the photographs (see Fig. 3). Afterwards, students enter the measured angles into a spreadsheet application, which enables them to graphically present the results and to calculate the refraction index of water for different realizations of the experiment. Finally, the students have to write a report about the experiment and their findings using a word processor.

The proposed material represents a good example of how students can develop various competencies during a physics lesson. In particular, a lecture based on our materials encourages the students to improve their abilities in collecting of information as well as in organizing and planning of work. Furthermore, the students develop several other competencies, such as handling of mathematical ideas and techniques, the ability of individual and team work and they improve their skills for oral and writing communication. Nevertheless, the most important aspect of our proposed material is the development of the digital competence, which is without doubt expressed at every step of the lesson.

2.5 Measurement and presentation of the results with tables and diagrams

This material is intended for the 9th year of primary school, the physics topic Accelerated movement, more exactly, the rolling of balls down the slope. The realization strategy is interesting. In the first lesson students perform experiments in small groups where the inclined desk represents the slope (Fig. 4). They measure the time dependence of the small steel ball's distance from the starting point, $s(t)$, and write the results in the form of tables. They are encouraged to use the timer on their mobile phones. Finally, they draw manually the $s(t)$ diagram on paper with millimetre grid and notice that the functional dependence $s(t)$ is not linear. In the next school lesson the teacher performs the computer-aided demonstration experiment of rolling the ball down the slope (the playing ball is used, Fig. 5). The ultrasonic distance detector is used and it is connected with the USB computer input. The software package Logger Pro (Vernier) [11] is used to manipulate the information from the detector and to draw the corresponding $s(t)$ and $v(t)$ diagrams. Students compare the correspond-

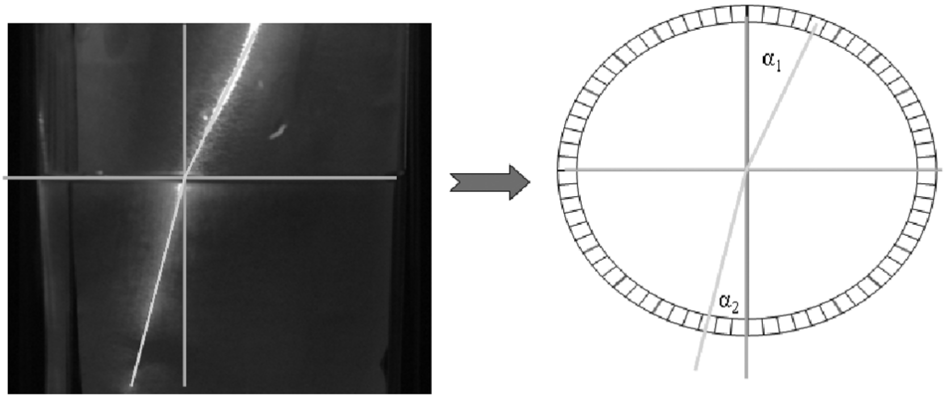

Figure 3: Photography of the experiment and the corresponding procedure of measuring of the angles.

Figure 4: Setup of the experiment with rolling steel balls.

Figure 5: Setup of the computer-aided experiment with rolling playing balls.

ing $s(t)$ diagram on computer with their former diagrams. Among generic competences, the care for quality should be emphasised.

2.6 Heat conduction

This material has been written for secondary school physics. The experimental work in groups is suggested where the non-stationary heat-conduction problem is tackled. Hot water is poured into the pot from the material of known heat conductivity. The water is cooling down and the time dependence of its temperature, $T(t)$, is measured. Resistivity thermometers connected to the computer can be used. The graphs $T(t)$ can be drawn manually or with some computer programme, such as excel. The main challenge of the task is an effort to make a suitable interpretation and quantitative analysis of experimental results, so that the mathematical competence is crucial here. The students are offered three mathematical models (functions) for the $T(t)$ dependence: 1) C/t, 2) C/t^2, and 3) $C_1 e^{-C_2 t}$, where C (or C_i) is an appropriate constant. They are asked to decide which of the three functions correctly describes the time dependence of the temperature of water. They are expected to guess the right answer – exponential decrease of the temperature since the algebraic solutions give a senseless infinite temperature at time zero.

Nevertheless, they can make a semi-quantitative checking that exponential function is the right one. First, the first two functions can be discarded in the following way. If the $T(t)$ dependence is $T(t) = Ct^{-m}$, where $m = 1$ or 2, the corresponding log-log dependence is linear: $ln\ T = -m\ ln\ t + ln\ C$. The student can use excel to insert the pairs of the measured values (t, T) in two columns, calculate the natural logarithms of these values and draw the corresponding diagram. He/she can see that

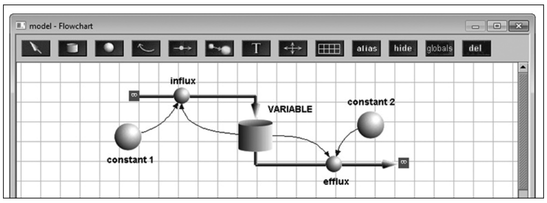

Figure 6: Graphic base of computer program Berkely Madonna. Illustration of the variable by the reservoir is shown. The fluid flux is regulated by valves which can be influenced by constants or variables.

the graph $ln\ T(ln\ t)$ is not a straight line and concludes that the dependence $T(t) = Ct^{-m}$ does not fit the experiment. Second, to check that the exponential dependence is true the logarithm of only the temperature (and not of time) is to be taken, so that $ln\ T = -C_2 t + ln\ C_1$. The diagram $ln\ T(t)$ thus yields the straight line.

2.7 Dynamical models

Understanding natural phenomena generally requires the description with appropriate mathematical models [5, 10]. Such modelling proved to be a successful scientific method in combination with experimental work. Mathematical models are significant in dynamical systems where they can be used to predict the time evolution of the system. There arises a question of the transfer of mathematical modelling into educational area. Study of the relations between quantities (variables) determining the system state usually demands solving the system of differential equations and this represents one of the key difficulties of the system modelling in education. Therefore, simplified systems are generally considered which often fail to agree with real experiments what results in poor understanding of physical systems.

In this paper, we present the possibility of treating dynamical systems in primary school with the help of graphic oriented programmes, such as Berkeley Madonna, Dynasys and Stella. These programmes enable an easy and evident connection of graphical symbols for parameters, variables and their fluxes into composed mathematical model the simulation of which is handled by computer. In prepared learning materials we considered some study cases of fluid flow where pupils discover the relations between variables and their fluxes (Fig. 6). Next, we illustrated the movement of objects under the influence of forces: we took an example of free-falling objects in the air where air resistance had to be taken into account. After the input of mathematical relations and the initial values of corresponding variables the computer programme simulates and illustrates the time evolution of relevant variables.

Using such programmes offers the pupil the opportunity to use the minimal model for a given physical problem and start acquiring basic scientific principles together with digital competence.

3 Conclusions

In the materials described above the following computer programmes and tools were trained by teachers and students: Excel, Powerpoint, word processors (such as MS Word), web pages, programmes for reading documents (such as Adobe Reader), image editing software (such as Paint Shop Pro), some executable numerical programs (commercial programmes and our own programmes), etc.

ICT competences at school can be classified into three levels:

1. ICT fundamentals
2. ICT theory and practice
3. ICT application

Of course the third level of knowledge is desirable. We think that the application of prepared materials in schools within the National project “Development of Natural Science Competences” enhances the second and partially the third level of ICT competences.

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