COMPUTER BASED REAL LAB WORK AS A COGNITIVE TOOL IN PHYSICS EDUCATION

Violeta Šlekienė, Loreta Ragulienė
Šiauliai University, Lithuania
E-mail: fk@fm.su.lt

Abstract

This paper deals with application of Computer based real lab work (CBRLW) as a platform for helping students to acquire a functional understanding of physics. CBRLW can be described as an "active engagement" learning environment in a practical works, where computer-assisted data acquisition and analysis tools are used together with experiment equipment and carefully developed worksheets. CBRLW are interpreted as cognitive educational tools and not only as technological ones. The specific technical equipment and software of PASCO scientific and FHYWE were applied in laboratory works of general and special physics of Šiauliai University. Laboratory works of Mechanics, Thermodynamics, Electricity, Optics and Solid State Physics were created and improved by using this universal interface-measurement-system. The varieties of sensors use the same interface box and the same software format. Students are able to focus on the investigation of many different physical phenomena without spending a large amount of time learning to use complicated tools. It provided to integrate modern science tools into physics teaching labs and made it possible to prepare and carry out experiments with a minimum of preparation time and a maximum of technical comfort. An attachment of interface (Figure 1) with a suitable sensor to the computer created very powerful system for collection, analysis and display of experimental data. Two CBRLW are discussed in this paper (Investigation of linear motion using an Atwood's Machine and Investigation of Frictional Force).
Keywords: *physics education, computer based lab work, interface-measurement-system, linear motion, frictional force.*

Introduction

Sufficient to convert scientific journal or pass through a physics lab and we accept all computers. Computers have become a very important tool for experimental physics. Often, it concerns all phases of the laboratory experiment: from hardware design, the control apparatus during the experiment and to data collection and processing. It is possible to perform experiments that would otherwise be impossible.

Physics is one of the first areas where the possibilities that computers may offer for the employment of new teaching methods have been and are still explored. A variety of computer applications have been developed and used in teaching Physics, such as spreadsheets, multimedia, simulations, computer-based laboratories and etc (Bernhard, Lindwall, Engkvist, Zhu, Degerman, 2007; Finkelstein, Adams, Keller,

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Kohl, Perkins, Podolefsky, Reid, LeMaster, 2005; Pol, Harskamp, 2005; Wieman, Perkins, 2005).

Computer-based teaching can help us deliver a deep and meaningful physics education, increasing the interaction between the student and the concepts under investigation. Interactive, multimedia experience cannot replace the real laboratory work but can enhance the learning process of many students, help them find the relation between the theoretical principles and the observed behavior in an easy and intuitive way (Avouris, Tselios, Tatakis, 2001). Since Physics is an experimental science, the role of lab-work in physics education has been often paid attention by research studies (Bernhard, Norrköping, 2001; Harms, 2000; Sassi, 2001).

Computer – based laboratories are applications of special interest in physics teaching because they can support powerful modeling environments involving physics concepts and processes. Appropriate use of this educational software allows students to build knowledge by giving them opportunities to explore the equipment to be used beforehand in a safe for them and the machinery way, interact with it, experiment, problem-solve, and collaborate.

Over the past twenty years, considerable experience has been gained in the technical development of sensors and software environments, so now several friendly *Computer-based* systems are commercially available, together with some home-made ones. PASCO scientific (http://www.pasco.com/) is a leading developer of innovative, technology-based solutions for hands-on science. PASCO has focused exclusively on science education-designing, developing and supporting better ways of teaching and learning science. PHYWE (http://www.phywe-systeme.com/) is a leading supplier of experimental equipment, teaching materials, e-learning solutions and associated services from schools up to universities in the fields of physics, biology, chemistry, applied sciences.

The aim of this study has been to develop and implement *COMPUTER-BASED REAL LAB-WORK* (CBRLW) as a platform for helping students to acquire a functional understanding of physics. CBRLW can be described as an "active engagement" learning environment in a practical works, where computer-assisted data acquisition and analysis tools are used together with experiment equipment and carefully developed worksheets.

So we assume that students using (CBRLW) in the learning/teaching process will be able easier to promote cognitive and conceptual activeness and improve their professional competence.

In this paper the acronym CBRLW will be used to indicate those teaching/learning strategies and activities which make significant use of real objects or materials, electronic experimental data, collected by sensors, and transferred by interface. CBRLW are interpreted as cognitive educational tools and not only as technological ones. It involves deep integration of software system and the laboratory equipment.

The specific technical equipment and software of PASCO scientific and FHYWE are applying in laboratory works of general and special physics of Šiauliai University. Laboratory works of *Mechanics, Thermodynamics, Electricity*, *Optics* and *Solid State Physics* were created and improved by using this universal interface-measurement-system. It provided to integrate modern science tools into physics teaching labs and made it possible to prepare and carry out experiments with a minimum of preparation time and a maximum of technical comfort. An attachment of interface (Figure 1) with a suitable sensor to the computer created very powerful system for collection, analysis and display of experimental data. The associated software is easy to use and allows the experimental data to be displayed as: digital meters, analog meters, oscilloscope, and spectrum analyzer using a FFT-routine, graphs and tables.

The software provides the possibility for further data analysis such as curve fitting, derivation, integration, histograms and user defined functions. Raw data, displays and analyzed data can be printed or exported to a word processor for report writing or to a spread sheet for further analysis (Figure 2).

It was prepared the worksheets which helps students incorporate electronic data collection into science experiments when using interface-measurement-system. Each worksheet has the following parts: equipment list; purpose; background; safety reminders; procedure, analyzing the data, lab report.

It is not possible in this paper to discuss all CBRLW. The examples described should give some flavor of the technique of CBRLW. CBRLW, in the implementation discussed in this paper, consist of two lab works (*Investigation of linear motion using an Atwood's Machine* and *Investigation of Frictional Force).*

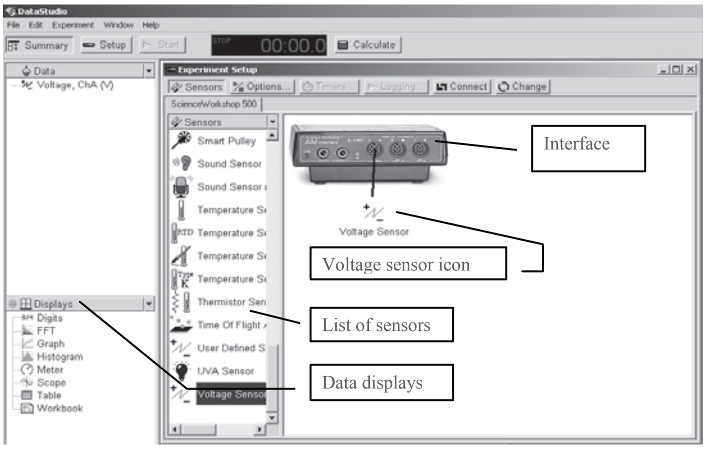

Figure 1. **Data Studio software window as seen on the computer screen.**

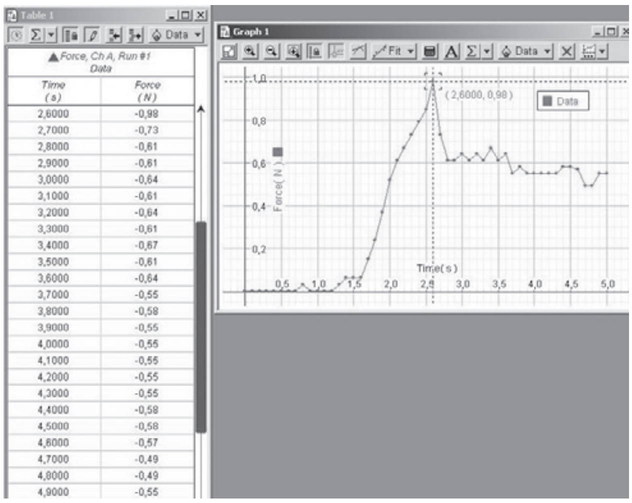

Figure 2. **Experimental data table and graph analysis.**

One of the first topics in a physics course is motion, including the concepts of position, velocity and acceleration. Another one is – force. Graphs of objects in motion and force are the best summary of a functional relationship. Use of graphs in a laboratory setting are of critical importance for reinforcing graphing skills and developing an understanding of many topics in physics, especially motion and force (Svec, 1995).

Investigation of Linear Motion Using an Atwood's Machine

The **purpose** of this lab work is to study the relationship among position, velocity, and acceleration and among force, mass, and acceleration using an Atwood's Machine apparatus.

***Equipment needed*:** Atwood's Machine, Photogate/Pulley System, Mass and Hanger Set, Interface, Computer.

Background

Equations for motion, given a constant acceleration (a), are:

Position: $x = x_0 + v_0 t + \frac{1}{2}at^2$,

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where x_0 and v_0 are the initial position and initial velocity. Note that if x_0 and v_0 are zero, the equation is a parabola.

Velocity (1st derivative of position): $\frac{dx}{dt} = v_0 + at = v$.

Note that the 1st derivative of position is the slope of the position vs. time graph. This equation is linear. The slope of the velocity vs. time graph is the constant acceleration. The acceleration can also be written:

Acceleration (2nd derivative of Position): $\frac{d^2x}{dt^2} = a$.

The acceleration of an object depends on the net applied force and the object's mass. In an Atwood's Machine, the difference in weight between two hanging masses determines the net force acting on the system of both masses. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward, and the lighter mass is accelerated upward.

Based on the above free body diagram (Figure 3), T is the tension in the string, $M_2 > M_1$, and g is the acceleration due to gravity. Taking the convention that up is positive and down is negative, the net force equations for M_1 and M_2 are:

$$\begin{aligned} T_1 - M_1 g &= F_{net} = M_1 a \\ T_2 - M_2 g &= F_{net} = M_2(-a) \end{aligned}.$$

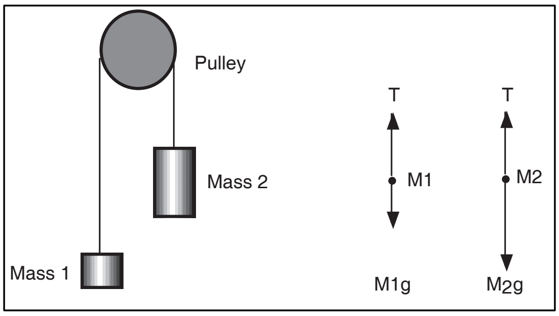

Figure 3. System of two bodies and the forces affecting.

Assuming that the pulley is massless and frictionless, and the string has no mass and doesn't stretch, let $T_1 = T_2$. Solving for a, the acceleration of the system of both masses, the theoretical acceleration is g times the difference in mass divided by the total mass:

$$a = g\left(\frac{M_2 - M_1}{M_1 + M_2}\right).$$

What to do

Use the Photogate/Pulley System to measure the motion of both masses as one moves up and the other moves down. The Photogate/Pulley System includes the Photogate Head (Figure 4), a cable for connecting to an interface or a timer, a Pulley Mounting Rod, an attachment screw, and a Super Pulley. The Photogate Head emits an infrared beam from one side of it's 'U' shape to the other. Timing begins when an object interrupts the infrared beam. A light-emitting diode (LED) on the top of the Photogate Head shows when an object blocks the beam. We can use the software to record the time that the beam is blocked or the time from when the beam is first blocked until it is blocked again or a variety of other combinations. Use the Photogate Head is very easy and convenient. There is no need for intermediate calculations for drawing graphics. The apparatus is precisely measure the time changes. The computer immediately draws all the desired drawings. In addition, the error is very small: if the body 1 cm segment is moving with velocity 10 m/s, track error is less than 1mm.

Use *DataStudio* to record the changing speed of the masses as they move. The slope of the graph of velocity vs. time is the acceleration of the system.

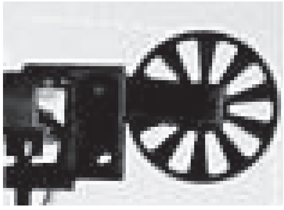

Figure 4. The Photogate / Pulley system.

Connecting the equipment used in the laboratory work is shown in Figure 5

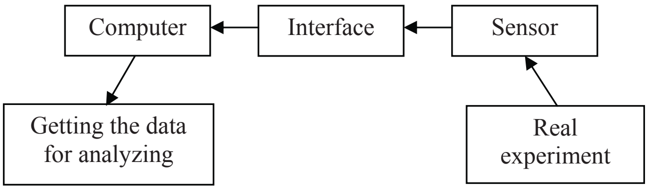

Figure 5. Connecting the equipment.

Analyzing the data

Results are obtained by the analysis of these graphs: velocity vs. time (Figure 6), acceleration vs. time (Figure 7), and force vs. acceleration (Figure 8).

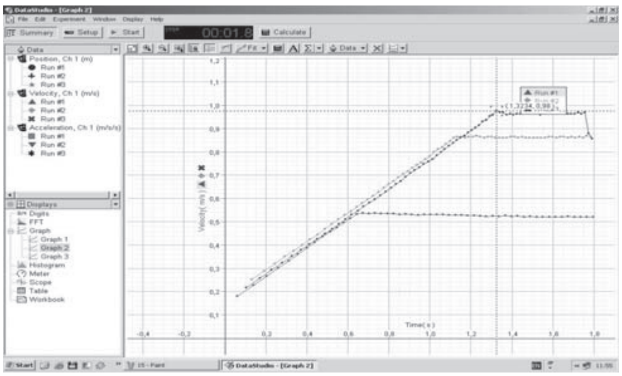

Figure 6. Graph of velocity vs. time.

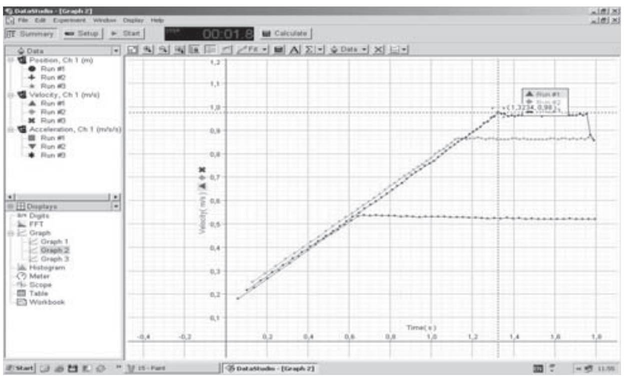

Figure 7. Graph of acceleration vs. time.

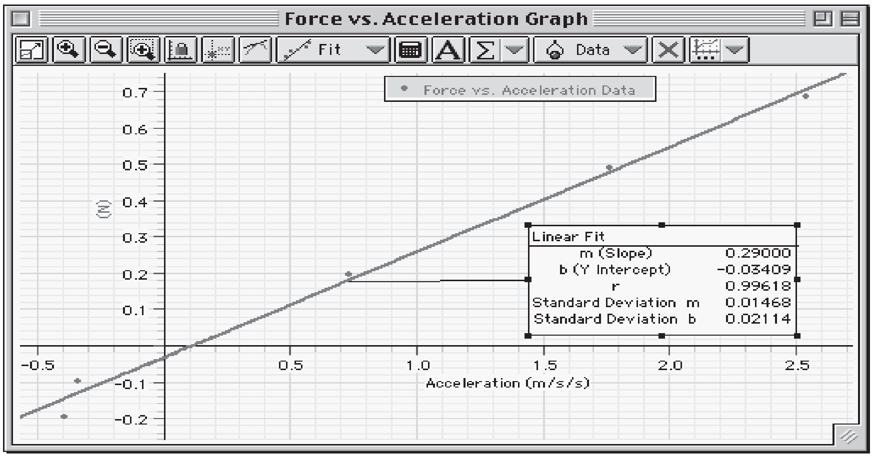

Figure 8. **Graph of force vs. acceleration.**

By examining these graphs, students have to answer the questions such as:

- What is the appropriate unit for the slope of the velocity vs. time plots?
- How close does the plot of velocity vs. time fit a linear regression? (Hint: In *DataStudio*, the closer r is to one, the better the fit of data to the curve.)
- Is the acceleration in the acceleration vs. time Graph constant? (Remember, a nearly horizontal line of fit (near zero slope) indicates a constant value.)
- Why is the acceleration vs. time plot so much "noisier" than the other plots?
- Compare the experimental acceleration with the theoretical acceleration by determining the percentage difference. What are some reasons that would account for this percent difference?
- Draw the best-fit line on your graph of Fnet vs. aexp. What does the slope of the best-fit line represent?
- How does the Force vs. Acceleration plot relate to Newton's Second Law?

Investigation of Frictional Force

The **purpose** of this lab work is to determine the difference between the dead and the kinetic frictional force and to study the parameters of what the coefficient of kinetic friction for an object depends on.

Equipment needed**:** Photogate/Pulley System, Force sensor, Mass and Hanger Set, Friction Block, Table Clamp, Interface, Computer.

Background

The block of mass **M** is placed on a level table connected by a string to a mass (**m**) hanging over a pulley (Figure 9). As the mass is released and starts to fall the block will slide across the table.

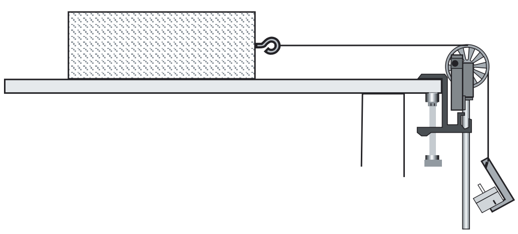

Figure 9. **Lab work equipment.**

Treating both masses together as one system, the free-body diagram includes two forces: the force of gravity pulling on mass **m** and the kinetic friction acting on mass **M**. According to Newton's Second Law, the vector sum of the forces equals the total mass of the system times the acceleration of the system.

$$\sum F = mg - F_k = (M + m)a \,,$$

where F_k is the force of kinetic friction which is given by:

$$F_k = \mu_k N \,.$$

where $\boldsymbol{\mu_k}$ is the coefficient of kinetic friction and $\boldsymbol{N}$ is the normal force acting on the block:

$$N = Mg.$$

Solving for the coefficient of kinetic friction gives:

$$\mu_k = \frac{mg - (M + m)a}{Mg} \,.$$

In general, the coefficient of kinetic friction for the block depends only on the type of materials that are rubbing together.

What to do

Use the Photogate/Pulley System to determine the difference between the dead and the kinetic frictional force and to study how the coefficient of kinetic friction for an object depends on the normal force between the surfaces, the area of contact between the surfaces, the types of materials making contact, and the relative speed of the surfaces.

Analyzing the data

The difference between the dead and the kinetic friction is determined by analyzing the graph of friction force vs. time (Figure 10).

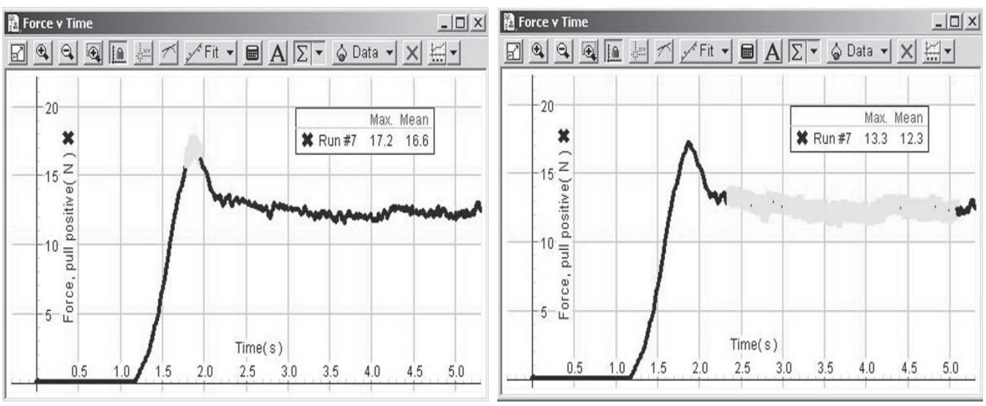

Figure 10. Graph of friction force vs. time.

After recoding their results into Data Table (Figure 11) students have to answer the questions.

Data Table

Part and Description	M total block mass (kg)	m total hanging mass (kg)	a_{exp} acceleration (m/s^2)	μ_k coefficient of friction
Largest smooth side of block				
Largest smooth side of block				
Larger mass of block				
Smallest smooth side of block				
Largest rough side of block				
Smallest rough side of block				
Larger hanging mass 1				
Larger hanging mass 2				
Larger hanging mass 3				

Figure 11. Data Table.

Questions

- What is the difference between the dead and the kinetic friction?
- How does the coefficient of kinetic friction vary with the mass of the block?
- How does the coefficient of kinetic friction vary with the area of contact between the block and the horizontal surface?
- How does the coefficient of kinetic friction vary with the type of material between the block and the horizontal surface?
- What is the relationship between the coefficient of kinetic friction and the mass, surface area, or speed of the object?
- When the mass of the block is increased, does the force of kinetic friction increase? Why?

The questions described above and in figure 6-8 are designed to meet common learning difficulties in kinematics. In physics laboratory it is common to use equipment with very low friction to show the "truth" of Newton's laws. However our life world is not free from friction, rather students' should learn to consider friction within a Newtonian framework. If friction is excluded, it would typically lead to students not believing in Newton's laws because absurd and counter-intuitive results. In the equipment used in the CBRLW it is possible vary friction and a frictionless world can be shown as a limiting case.

Conclusions

- By performing of CBRLW theoretical knowledge are strongly related with practical results. Laboratory works are more visual, the data are easy processing.
- Using CBRLW students are motivated to be not passive observers, but active participants of education process
- CBRLW allow student-directed exploration but free students from most of the time-consuming drudgery associated with data collection and display.
- The data are displayed in graphical form in real time, so that students get immediate feedback and see the data in an understandable form that can discussed.
- Because the data are quickly taken and displayed, students can easily examine the consequences of a large number of changes in experimental conditions during a short period of time.
- CBRLW and its use of graphs improve content knowledge specific to graphing problems and graphing skills.

- The hardware and software tools are, in general, independent of the experiments. The varieties of sensors use the same interface box and the same software format. Students are able to focus on the investigation of many different physical phenomena without spending a large amount of time learning to use complicated tools.

References

Avouris, N. M., Tselios, N., Tatakis, E. C. (2001). Development and Evaluation of a Computer-Based Laboratory Teaching Tool. *Journal Computer Applications in Engineering Education,* Vol. 9 (1), pp. 8-19.

Bernhard, J., Norrköping, C. (2001). Physics Learning and Microcomputer Based Laboratory (MBL) - Learning effects of using MBL as a technological and as a cognitive tool. *Science Education Research in the Knowledge Based Society.* [2009-09-15]. On line http://staffwww.itn.liu.se/~jonbe/fou/didaktik/papers/ESERA2001.pdf.

Bernhard, J., Lindwall, O., Engkvist, J., Zhu, X., Degerman, M. S. (2007). Making Physics Visible and Learnable Through Interactive Lecture Demonstrations. In.: *European Conference on Physics Teachings in Engineering Education PTEE 2007*. [2009-09-08]. On line http://ptee2007.tnw.tudelft.nl/Papers/Bernhard_paper.pdf.

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B, Perkins, K. K., Podolefsky, N. S., Reid, S., LeMaster, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics – Physics Education Research 1, 010103.* [2009-09-20]. On line http://prst-per.aps.org.

Harms, U. (2000). Virtual and Remote Labs in Physics ED. [2009-09-05]. On line http://citeseer.ist.psu.edu/old/404004.html.

Pol, H., Harskamp, E. (2005). Solving physics problems with the help of computer assisted instruction. *International Journal of Science Education,* Vol. 27, No. 4, 451–469.

Sassi, E. (2001). Computer supported lab-work in physics education: advantages and problems. In.: *International Conference on Physics Teacher Education Beyond 2000*. [2009-09-07]. On line http://143.225.163.184/_docenti/sassi-elena/doc/sassi-1-computer_supported_labwork.pdf.

Svec, M. T. (1995). Effect of micro-computer based laboratory on graphing interpretation skills and understanding of motion. *Annual meeting of the National Association of research in Science Teaching.* San Francisco CA [2009-09-05]. On line http://www.eric.ed.gov/ERICDocs/data/ericdocs2sql/content_storage_01/0000019b/80/13/fa/e1.pdf.

Wieman, C., Perkins, K. (2005). Transforming Physics Education. In: *Physics Today,* November, 2005. [2009-09-13]. On line http://www.physicstoday.org.

PASCO. [2009-09-15]. On line http://www.pasco.com.

PHYWE excellence in science. [2009-09-15]. On line http://www.phywe-systeme.com.

Adviced by Naglis Švickus,
SMC "Scientia Educologica", Lithuania

Violeta Šlekienė	Associate Professor, PhD, Faculty of Natural Sciences, Šiauliai University, 19 Višinskio Street, Šiauliai LT-76351, Lithuania. Phone: +370 41 595721. E-mail: fk@fm.su.lt Website: http://www.su.lt
Loreta Ragulienė	Associate Professor, PhD, Faculty of Natural Sciences, Šiauliai University, 19 Višinskio Street, Šiauliai LT-76351, Lithuania. Phone: +370 41 595721. E-mail: loretar@gmail.com Website: http://www.su.lt