



STUDENT EXPERIMENTS AND TEACHER TESTS USING EDAQ530

Katalin Kopasz, Péter Makra, Zoltán Gingl

Abstract: Experiments, as we all know, are especially important in science education. However, their impact on improving thinking could be even greater when applied together with the methods of inquiry-based learning (IBL). In this paper we present our observations of a high-school laboratory class where students used computers to carry out and analyse real experiments. During the class students used Edaq530, a low-cost, compact and easy-to-use digital measurement solution [<http://www.inf.u-szeged.hu/noise/edudev/EDAQ530/>]. It allowed them to see the results of the measurements real-time on the screen. This technique enables students to make a lot of measurements themselves, get to know the steps of data analysis, and discover relationships and laws in physics which were previously unknown to them.

Key words: computer-based learning, inquiry-based teaching, physics education

1. Introduction

One of the promising possibility for renewing science education is to use inquiry-based methods. As [1] points out, inquiry-based learning (IBL) is driven by questions or problems, and is based on a process of seeking knowledge and new understanding. So IBL offers exciting possibilities for reforming science education, focusing on knowledge constructed by the students themselves as opposed to teacher-transmitted information. [2].

Using simulations is a popular and successful way to combine IBL and the application of computers [3], see e.g. the widely used PhET, an online collection of interactive, research-based simulations, developed at the University of Colorado [4].

IBL can be implemented, for example, via computer-aided experiments, which can help students to discover concepts and their context. Our secondary school has a close cooperation with the Noise Research Group at the University of Szeged in developing and testing Edaq530, a low-cost, compact and easy-to-use digital measurement solution [5] in education. Our students and some of our colleagues had the possibility to use this open-source measurement solution and its free background software [6] as the first official users.

As the 9th-grade students were interested in physical experiments and measurements, we organised weekly labs for a year. At first, students got acquainted with the basic steps of computer-aided experiments: they learnt how to display results in real-time and how to save results to a file. After that, they could start to plan, execute, and evaluate the experiments listed hereafter. They learnt the use of Edaq, and also of some spreadsheet and charting software, which also improved their IT skills.

In the following sections, we first show how our students were introduced to computer-based measurements and how they studied two types of mechanical phenomena, collisions and pendulum motion. After that we show further measurements made by some of our colleagues in a teacher training.

2. Teacher experiments turned into student experiments

Some traditionally teacher-conducted experiment could be implemented as a student experiment applying our easily available and cheap experimental kit. We shall show two such experiments which helped 9th-grade students to discover some mechanical concepts. Text. Use as many sections as necessary.

Collisions

Students studied collisions of cars moving on aluminium rails using photogates of our own design. The 9th-grade students had not learnt about the concept of momentum before. Using Edaq, they were able to measure the velocities of known-mass cars before and after collisions. In that way, a typical teacher experiment became a student experiment.



Figure 1. *Students are measuring velocities of cars using Edaq*

The students studied first the elastic collision of cars. The masses of the two cars were m and $2m$. In the first case, one of the cars was stationary before the collision, while, in the second case, both of them were moving. Students recorded the measured velocities in a table, and monitored how these changed in different phases of collisions. They observed the constancy of the term $m\Delta v$. (Because it is a real measurement, the exact value of the sum of momentum changes was not zero, but the accuracy of the measurement is sufficient to prove the law.)

It was a surprise for the students that in the first case the originally moving car stopped after the collision. (Of course, they could see it without a measurement.) They were also amused at the fact that the speed of the car which had twice the mass of the other one would reduce to half of the original value. If the students work self-sufficiently, they get less leading questions from the teacher, so they come to know the concept of momentum from their own experience. It is important because this way the students build a more durable knowledge base and, at the same time, they also improve the cognitive and analytical skills essential in mastering natural sciences.

As one can see in Table 1, measurements are more accurate if the car which was standing before the collision has the larger mass. (In this case we are closer to an ideal elastic collision.)

Students were also curious what would happen during inelastic collisions. So we fixed a pin and a small lump of plasticine to both small cars to model this phenomenon. The measurement results are included in Table 2, which shows that the magnitude of terms follow what one would expect in the case of collisions. Students could discover the concept of momentum and the law of the conservation of momentum via their own measurements, in both elastic and inelastic collisions.

Table 1. Data measured and calculated by one of the participating students, Róbert Horváth (cars have the same weight). The first car was still standing before the collision. The last column shows the amount of momentum change. (*, **: The masses of small cars were taken as unity, while the dimension of momentum was arbitrary unit times m/s.)

	1. car					2. car					$\Sigma \Delta p$ [**]
	m [*]	v_b [$\frac{m}{s}$]	v_a [$\frac{m}{s}$]	Δv [$\frac{m}{s}$]	Δp [**]	m [*]	v_b [$\frac{m}{s}$]	v_a [$\frac{m}{s}$]	Δv [$\frac{m}{s}$]	Δp [**]	
elastic collision	1	1.696	0.847	-0.849	-0.849	1	0	0.847	0.847	0.847	-0.002
	1	1.689	0.831	-0.858	-0.858	1	0	0.831	0.831	0.831	-0.027
	1	1.398	0.678	-0.72	-0.72	1	0	0.678	0.678	0.678	-0.042
	1	1.114	0.42	-0.694	-0.694	2	0	0.42	0.42	0.84	0.146
	1	0.829	0.276	-0.553	-0.553	2	0	0.276	0.276	0.552	-0.001
	2	0.985	0.554	-0.431	-0.862	1	0	0.554	0.554	0.554	-0.308
	2	0.847	0.666	-0.181	-0.362	1	0	0.666	0.666	0.666	0.304

Table 2. Data measured and calculated by Ágnes Nemes. In the first series the two cars had the same weight, while in the second series the weight the moving car was two times larger than that of the standing one. (*, **: The masses of small cars were taken as unity, while the dimension of momentum was arbitrary unit times m/s.)

	1. car					2. car					$\Sigma \Delta p$ [**]
	m [*]	v_b [$\frac{m}{s}$]	v_a [$\frac{m}{s}$]	Δv [$\frac{m}{s}$]	Δp [**]	m [*]	v_b [$\frac{m}{s}$]	v_a [$\frac{m}{s}$]	Δv [$\frac{m}{s}$]	Δp [**]	
inelastic collisions	m	0.896	0.374	-0.522	-0.522	m	0	0.374	0.374	0.374	-0.148
	m	1.216	0.472	-0.744	-0.744	m	0	0.472	0.472	0.472	-0.272
	m	0.827	0.508	-0.319	-0.319	m	0	0.508	0.508	0.508	0.189
	2m	0.9	0.497	-0.403	-0.806	m	0	0.497	0.497	0.497	-0.309
	2m	0.902	0.477	-0.425	-0.85	m	0	0.477	0.477	0.477	-0.373
	2m	0.901	0.549	-0.352	-0.704	m	0	0.549	0.549	0.549	-0.16

Our method proved a viable implementation of IBL in scientific education.

Our setup could also be useful in ‘traditional’ lessons, when there is less time for experiments and we cannot provide experimental kits for every student. We can measure time and velocities with Edaq

using a conventional photogate; and import the measured data to a prepared Excel spreadsheet. This way, a much shorter period of time (e.g., in a classroom lesson) can be enough to prove the law of the conservation of momentum via measurements and calculations.

Study of pendulum motion

The ninth-grade students already knew the concept of energy when they first met the pendulum in our study circle. Seeing the pendulum, the first idea of the children was to examine the influence of the starting height on the speed measured at the lowest point.

At the same time, they had still not learnt anything about potential energy. From their measurements they inferred that the speed increases with the launch height, and they could also see that this relationship is not linear. After some experimentation they figured out that the starting height is linearly proportional to the square of the velocity at the lowest point. This exercise also taught the students the method of linearisation and its importance in physics.

During this measurement the students had also got some experience about the importance of Shannon's sampling theorem. It was a common mistake that the students did not take into account the value of the sampling frequency. It happened several times that the speed measured at the lowest point did not show any relationship with the launch height. As it turned out, its main cause was the inaccuracy of the measurement that resulted from setting the sampling frequency too low. When they applied sampling frequencies that were high enough, they were able to measure the correct value of the velocity.

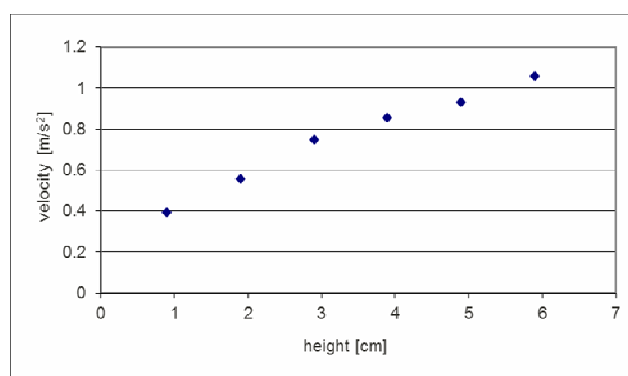


Figure 2. Students are measuring velocities of the speed of the pendulum at the lowest point vs starting height. While the square root profile was discernible to some, the students were still prompted to study the connection between the starting heights and the squares of velocities

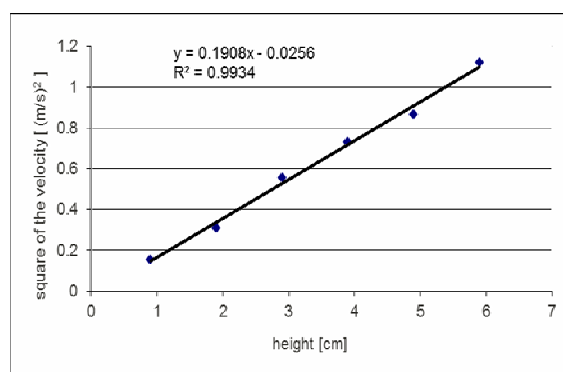


Figure 3. The square of velocity of the pendulum at the lowest point vs starting height. With the help of this figure, the students could reveal the linear connection between the parameters

The panel of the Edaq software shows not only the measured velocities but also the (half) period of the pendulum calculated from the actually measured velocity. The students observed that the period does not depend on starting height.

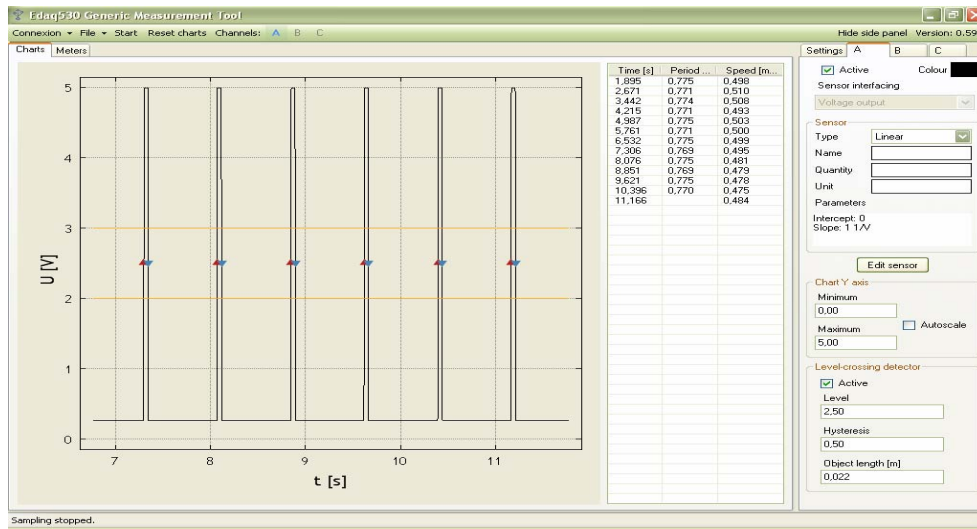


Figure 4. A snapshot of the panel of the Edaq software we used. The program shows not only the actual velocities but also the (half) period of the pendulum.

The students tested their own ideas about what the period of the pendulum depends on, so they carried on a self-sufficient research work. They studied the connection of the length and the mass with the period. They realised that the mass does not affect it.

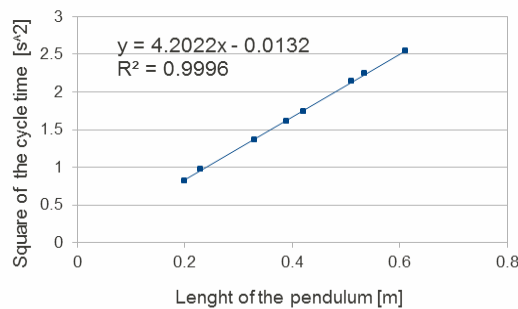


Figure 5. The linear relationship between the square of period and the length of the pendulum (measured by Blanka Bindics).

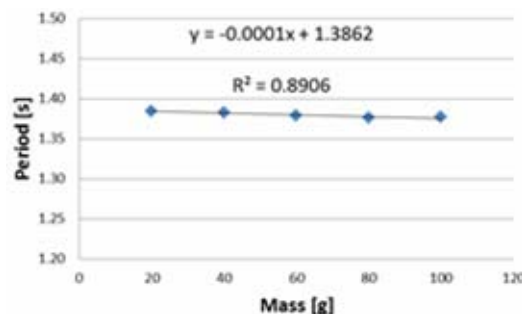


Figure 6. The period does not depend on the mass (measured by Frigyes Vass).

The students also tried to measure the effect of the gravitational field. They placed magnets below the iron bob of the pendulum to modify the resultant force. They found that the period of the pendulum decreased because of the pull of the magnetic force (see Table 3.).

Table 3. *The period of the pendulum with and without magnet (measured by Gergő Kosztándi).*

												average [s]	deviation [s]
T [s]	without magnet	1.0917	1.0880	1.0930	1.0901	1.0872	1.0929	1.0860	1.0910	1.0908	1.0899	1.0901	0.0023
	with magnet	1.3726	1.3719	1.3730	1.3712	1.3732	1.3709	1.3735	1.3695	1.3743	1.3682	1.3718	0.0019

Although the results of the measurements do not lead directly to the formula $T = 2\pi \cdot \sqrt{\frac{l}{g}}$, our students deduced that the period of the pendulum does not depend on the mass and the starting height (in the cases of not too large heights), but it does depend on the square root of the length.

The students also examined further circumstances (e.g. the starting height or the initial speed there) and found that they did not affect the period. Although the students required more time to learn a topic in this way, they were able to understand easier how nature works and what kind of empirical evidence stands behind the formulae. Instead of teaching bare formal relationships, this method helps to reveal the exact meaning of all the influencing factors and considerably reduces the probability of later mistakes.

There are some new possibilities of connecting special sensors to Edaq. Therefore we can also do experiments in other science classes with these tools. We have also tested these sensors together with some of our teacher colleagues to see what they think about the application possibilities of these devices.

Relative pressure sensor

One method of operation of relative pressure sensors is based on the piezoresistive effect, when resistivity changes due to the applied mechanical stress. Due to the deformation of the semiconductor crystal there is more or less room for charge carriers, which results in their drift becoming faster or slower, respectively (in other words, the specific resistivity changes). The pressure difference one could measure on the sensor's output is proportional to the input pressure difference [7].

We can also use our device to measure water level. For that, we have to fix a fuel tube to one of the connecting stubs, closing the free end of the tube with plastic foil and an insulating tape. In this way, we get a sensitive membrane that is easy to handle and can be used to measure the pressure changes without the influence of the curvature pressure of the water flowing into the tube. Since the tube bends easily, it is worth fixing it to a rod (e.g. a glass rod) to get the exact value of water level. It was a typical mistake that the participating teachers, using the scale of the measuring cylinder, did not take into account the effect of the water displacement on the scale. We can avoid inaccuracies resulting from water displacement by marking the scale on the rod (e. g. with insulation stripes as seen in Figure 7.); using this technique, we will always measure the exact value of the water level.

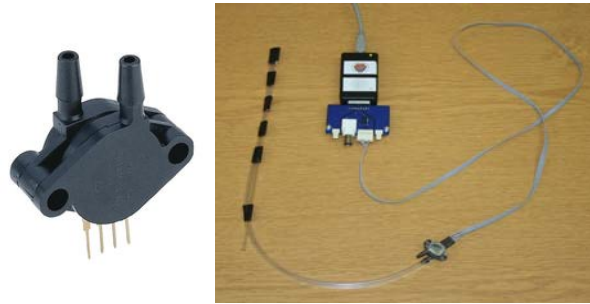


Figure 7. Relative pressure sensor connected to Edaq530. We fixed a fuel tube to the positive port. The scale is made with insulating tape, which improves the accuracy of the measurements.



Figure 8. One of the participating teachers, Imre Csiszár, is calibrating the pressure sensor

A possible way of calibration is to measure pressures in centimetres of water (it is a common unit in medical practice). It also allows the measurement of the density of liquids. If we measure the pressure of a liquid (salted water, in our case) at different levels, we can obtain the density of the liquid and also some information about density distribution. The pressure in our salt water solution changed proportionally to the water depth, which means that the solution was homogeneous. We found its average density 1.13 times larger than that of tap water.

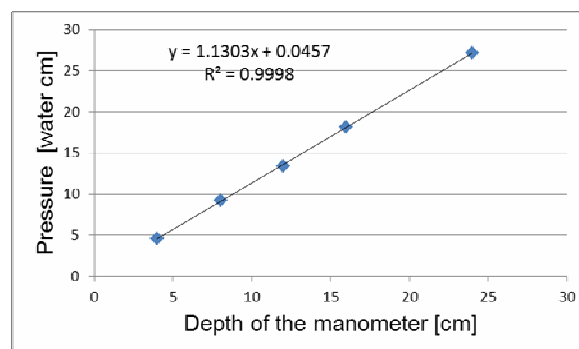


Figure 9. The pressure of the salted water as a function of manometer position

Hall sensor

The Hall sensor detects the presence of a magnetic field. If current is passing through a thin piece of semiconductor material placed into a magnetic field (where the plane of the piece is normal to the field), some voltage (the so-called Hall voltage) will induce in the semiconductor perpendicular to the direction of the current. Changes of the Hall voltage are directly proportional to the changes of magnetic induction [8].

Hall sensors can be used to measure rotational frequency, for example, in the case of a simple DC motor. To test our device, we used an old PC fan with a small iron disc. Fixing a neodymium magnet to the disc, we could measure the distance between the fan and the Hall sensor (see Figure 10). (We used some bluetech to fix the fan to the table.)

Using the so-called level-crossing function of the software (which detects when the voltage reaches a certain value), we can determine the period of cyclic processes, e. g. the rotation of a fan. (To avoid false detection there is a possibility to use hysteresis.) Figure 11 shows the measured signal with its level crossings. The software continuously calculates the time differences of the consecutive, codirectional level crossings, and records the calculated periods in a table. We measured the rotational frequency of the motor at different voltages as shown in Figure 12. These kind of data processing develop also the spreadsheet-using skills of the students.

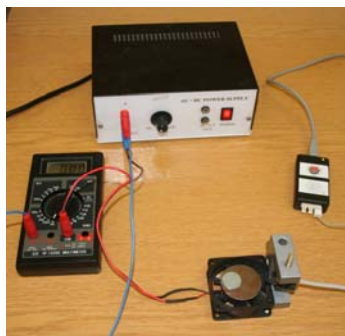


Figure 10. Experimental set-up to measure rotational frequency with a Hall sensor.

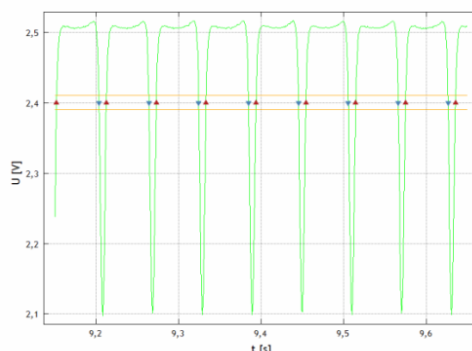


Figure 11. Changes of the Hall voltage vs time, while the voltage of the motor is constant. We can measure the period with the level-crossing detector function of our software.

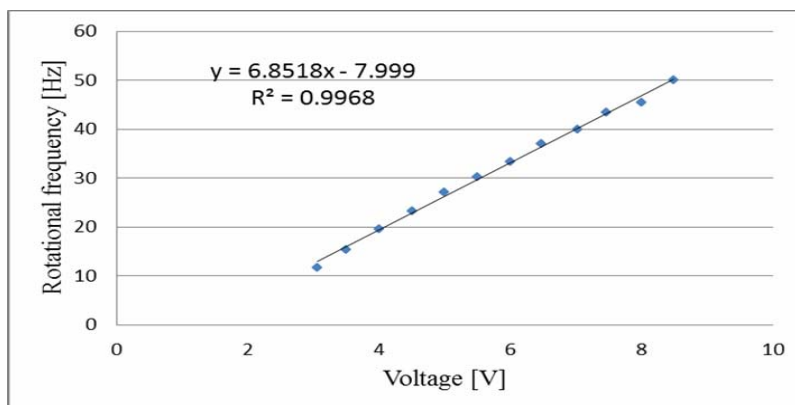


Figure 12. Rotational frequency vs voltage of the DC motor (measured by Károly Tóth)

The sensitivity of the Hall sensor allows the measurement of the strength of the magnetic field of school demonstration coils at different current levels. We fixed the sensor to the end of the coil, and recorded the Hall voltage as a function of the current in the coil. As it can be seen in Figure 13, in our experiment variable direct current flowed through a coil with 1200 turns and a serial ammeter. The Hall sensor was fixed to one of the ends of the coil—though the amount of magnetic induction here is half of that in the centre of the coil, the appropriate direction of the sensor is easier to set.

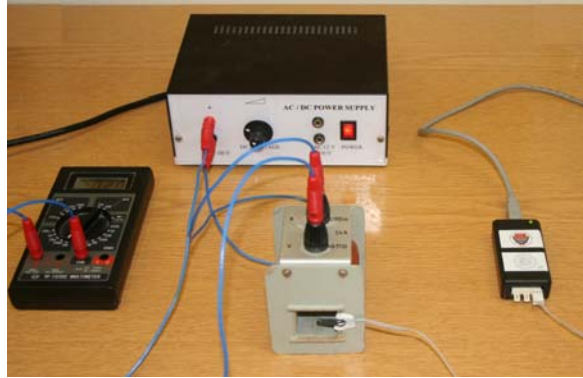


Figure 13. Experimental set-up to measure the strength of the magnetic field of a demonstration coil.

Table 4. The first column: the current through the solenoid, second column: voltage of the Hall sensor (measured by Károly Tóth).

I [A]	U [V]
0.5	2.453
0.45	2.458
0.4	2.463
0.35	2.468
0.3	2.474
0.25	2.48
0.2	2.485
0.15	2.49
0.1	2.495
0.05	2.5
0	2.504

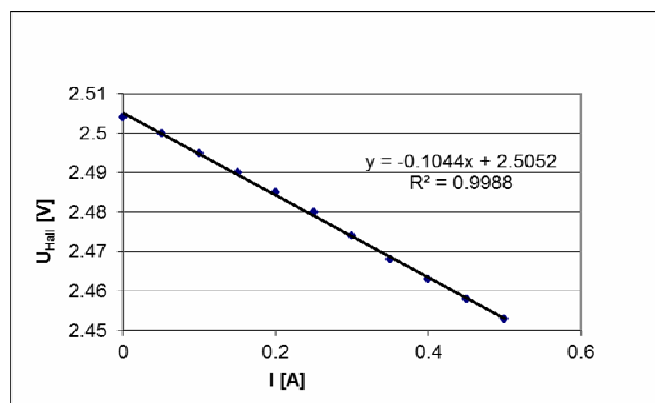


Figure 14. The Hall voltage as a function of the current in the solenoid (measured by Károly Tóth).

pH electrode:

There is a possibility to connect a pH electrode to Edaq530. We found a cheap model, Pico pH sensor [9], whose robust epoxy body makes it safe to be also used by students. The pH sensor consists of a standard electrode capable of measuring the full 0 to 14 pH range with an accuracy of 0.1 pH. The electrode comes complete with a small bottle of storage solution to prevent it from drying out. Output is via a BNC connector. Using the sensor with Edaq makes this configuration very cheap, because there is no need to buy any other processing units.

Our primary goal with the use of this sensor was to call the attention of chemistry teachers to the possibilities of computer-based experiments. To measure pH values digitally is a significant development as compared to licmus papers usually used in high schools.

For calibration, we used puffer solutions with pH values of 2.20 and 7.06. To test the abilities of our new experimental set-up we measured the pH values of some daily used liquids. The results are shown in Figure 16.

Teachers not involved in chemistry were surprised to find the milk was not alkaline; some of them believed it to have turned sour. Most people do not realise that almost every natural food is acidic or occasionally neutral. If we would like to find alkaline substances in our environment, we have to look for cleaning products. To demonstrate this fact, one of the studied liquids was a kind of detergent.

Figure 18 shows a comparison between two independent measurement sequences carried out by two of our colleagues. Based on these results we can state that this experimental set-up is applicable in student labs. Combining pH measurements with continuous temperature measurements (which is easily to realise with Edaq, see 3.), we can analyse chemical processes, which could be very useful in chemistry student labs and could help the preparation for the chemistry final exam.

The easily accessible, accurate pH measurements could also help teachers to reveal the truth about trendy ‘alkaline diets’. Measuring the pH values of different foods will convince the students of the fact that almost all we eat (including fruits and milk) is not alkaline.

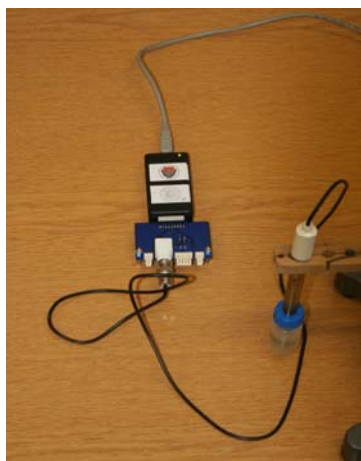


Figure 15. *pH electrode with a preamplifier.*

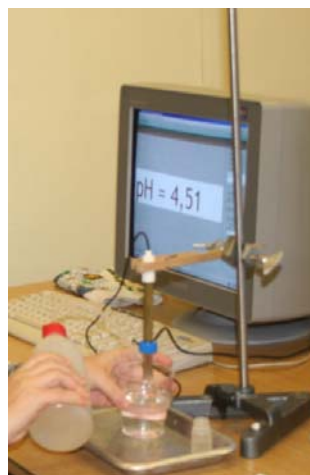


Figure 16. *pH electrode in use.*

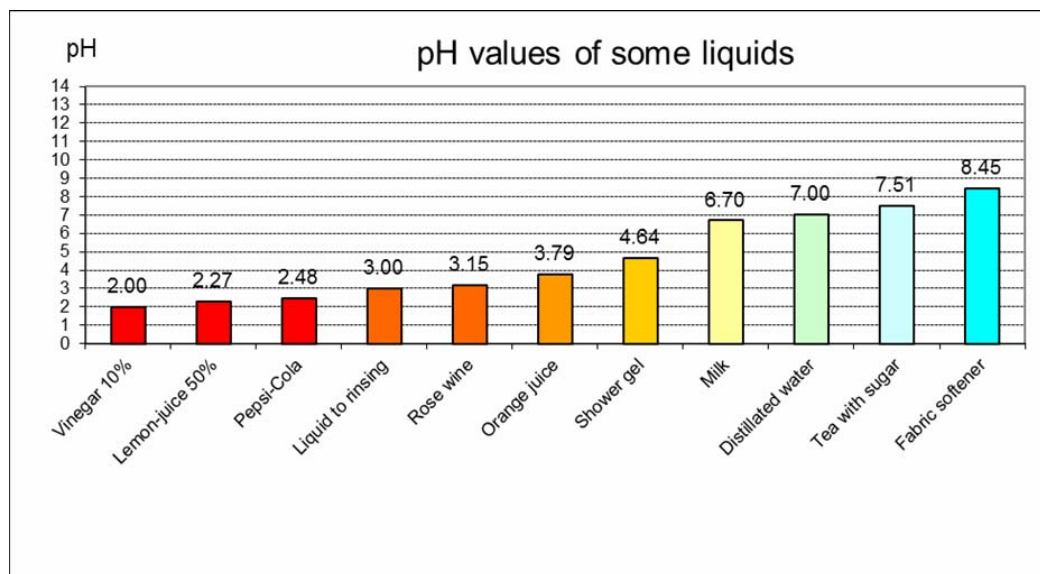


Figure 17. pH values of some liquids; measured by Ferenc Lakatos.

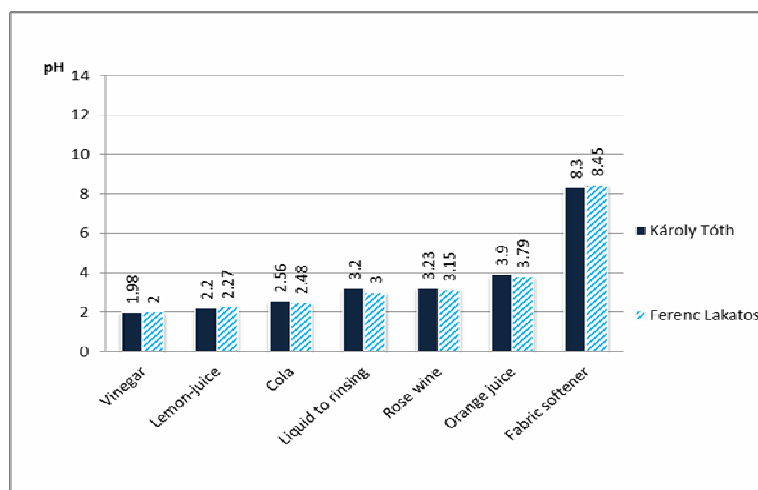


Figure 18. Comparison between two independent measurement series of pH values of the same liquids.

Optical finger plethysmograph

Edaq530 could also prove useful for biology teachers. Here we present an example of its potential in biological measurements: how to apply it to study the changes of heart rate.

Pulse is the rhythmic expansion of an artery that may also be felt with fingers. To carry out more accurate measurements, we can register this periodic movement as a pulse wave. We can record the data, for example, with the help of the photovoltaic effect. If we light a tissue filled with capillaries, the intensity of the transmitted and reflected light depends on the capillary saturation of blood, i. e. the volume of blood within the capillary lit. This method is called photo-plethysmography (PPG). Measuring PPG signals we can determine when the pulse wave arrives at a certain place [10].

The heart rate and its changes are also measurable with Edaq. After putting one of our fingers on an infra LED and a photoresistor placed side by side, we can observe that the voltage varies according to the phase of the pulse wave. We can observe two series of maxima with different amplitudes, which shows that the atrium and the ventricle of the heart contract at different times (see Figure 20).

Using the level-crossing method mentioned before we can measure the time between two heartbeats, which allows an easy determination of the heart rate. We can also study the changes of heart rate at rest and during/after some physical exercise (e. g. doing squats), see Figure 21.

Another interesting phenomenon which could be studied with our plethysmograph is the Valsalva manoeuvre, which is performed by attempting to exhale forcibly while keeping the mouth and nose closed. It is used as a diagnostic tool to evaluate the condition of the heart and is sometimes done as a treatment to correct abnormal heart rhythms or relieve chest pain [11]. During the exercise we can observe a marked increase of heart rate (see Figure 22).



Figure 19. Optical finger plethysmograph.

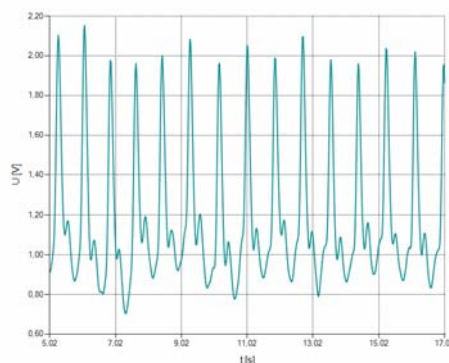


Figure 20. The plethysmographic signal shows two series of maxima (see details in text).

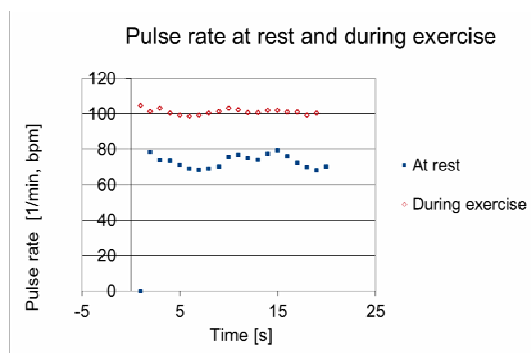


Figure 21. Heart rate at rest and during an exercise (measured by Imre Csiszár).

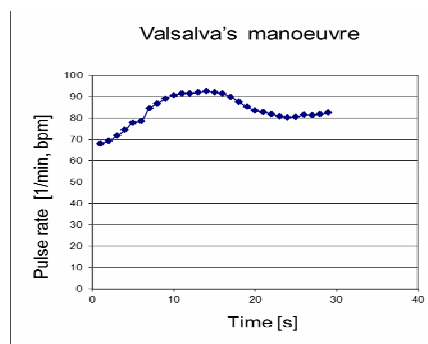


Figure 22. Heart rate during a normal response to the Valsalva manoeuvre (measured by Imre Csiszár.)

3. Conclusion

On the basis of the experience gained from the student lab presented herein we can conclude that our measurement solution is appropriate not only for teacher experiments but also for student measurements. Our students could learn to use the Edaq530 device and the software belongs to it quickly and easily. After that, they carried out measurements independently, studied different physical problems, and discovered physical laws and relationships. They were very enthusiastic during the lab, which is not so usual in the case of ‘classical’ measurement exercises. To sum up, this kind of computer aided experiment is a very well applicable form of IBL in high-school education, not only in physics classes but also to teach biology, chemistry or science.

References

- [1] Spronken-Smith, R., et al. (2007), How Effective is Inquiry-Based Learning in Linking Teaching and Research? (Paper prepared for An International Colloquium on International Policies and Practices for Academic Enquiry, Marwell, Wicheter, UK, April 19–21. 2007)

- [2] Franklin W. A. (2004), Inquiry Based Approaches to Science Education: Theory and Practice (<http://www.brynmawr.edu/biology/franklin/InquiryBasedScience.html>)
- [3] Bell, T., et al (2010), Collaborative Inquiry Learning: Models, tools, and challenges, *International Journal of Science Education*, Vol. 32, No. 3, pp. 349–377.
- [4] <http://phet.colorado.edu/en/simulations>
- [5] Kopasz K., et al (2011), Edaq530: a transparent open-end and open-source measurement solution in natural science education, *European. Journal of. Physics*, Vol. 32, pp. 491-504.
- [6] <http://www.noise.physx.u-szeged.hu/edudev/EDAQ530/>
- [7] http://cache.freescale.com/files/sensors/doc/data_sheet/MPX2010.pdf
- [8] www.honeywell.com/sensing
- [9] <http://accessories.picotech.com/ph-sensor.html>
- [10] Imholz B.P.M., et al (1998), Fifteen years experience with finger arterial pressure monitoring: assessment of the technology, *Cardiovasc Res.*, Vol. 38, pp. 605-616.
- [11] Imholz B.P.M., et al (1988), Continuous noninvasive blood pressure monitoring: Reliability of Finapres device during the Valsalva manoeuvre, *Cardiovasc Res.*, Vol. 22, pp. 390–397.

Authors

Katalin Kopasz, Ságvári High School and Department of Optics and Quantum Electronics, University of Szeged, Szeged, Hungary, e-mail: kopaszka@titan.physx.u-szeged.hu

Péter Makra, Institute of Medical Physics and Medical Informatics, Szeged, Hungary, e-mail: Makra.Peter@med.u-szeged.hu

Zoltán Gingl, Department of Technical Informatics, University of Szeged, e-mail: gingl@inf.u-szeged.hu

Acknowledgement

This project is supported by the European Union and co-funded by the European Social Fund through the TÁMOP 4.2.2/B-10/1-2010-0012 grant.

