University of Szeged
Faculty of Science and Informatics
Doctoral School of Physics

Computer-based measurements in natural science education

PHD THESIS STATEMENTS

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Scientific background and research methods

One of the most promising possibilities for renewing science education is to use inquiry-based methods. 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 and focusing on knowledge constructed by the students themselves as opposed to teacher-transmitted information.

Combining this learning method with the application of computers, we get a very efficient tool in motivating students. Using computers and other modern devices can open up new horizons in demonstrating natural phenomena and the laws that describe them. This area becomes more and more prominent in the literature of natural science education; recently, there are separate journals receiving studies in this topic (e.g. Journal of Computer Assisted Learning, Computers in the Schools etc.).

Applying computers is not restricted to showing only presentations, videos or simulations in science classes. It is also possible to carry out computer-aided experiments (as an implementation of IBL), which can help students to discover concepts and their context. Today's advanced, widely available and economic electronic solutions allow us to use sensors, digital equipment and personal computers to build a wide variety of instruments and experimental setups, as well as measure and display various physical quantities in real time.

There is a wide range of computer-controlled experimentation tools, data acquisition devices and software on the market; at the same time, these sets are usually very expensive. In many cases, these tools have the additional drawback that they are not flexible and efficient enough, so usually they can only be used for demonstration experiments. On the other hand, it would be very useful if students could make experiments by themselves in the classroom or even at home, where they could do experimental homework or come up with some new experiments – this would mean much more room for creativity, motivation and efficient learning.

Another goal is to enable users to set up and use the devices and the software quickly and easily. While some physics teachers are also experts in informatics and electronics, most of our colleagues would need low-cost measuring sets which they can use without special skills.

Based on the statements mentioned above, our research group developed different measurement solutions to help the propagation of computer-based measurements in schools.

Our developments can be divided into two main groups. The first group is based on Edaq530, a low-cost, compact and easy-to-use digital measurement solution consisting of a thumb-sized USB-to-sensor interface and a measurement program. The hardware contains a single 12-bit analogue-to-digital converter unit and a three-channel multiplexer, which allows connecting three sensors to Edaq530 simultaneously. The wide range of sensors (photogates, termistors, Hall sensors, accelerometers, pressure sensors, pH electrodes) that can be used attest to the versatility of the device. The software collects the data in the background, and can display them either on an online chart or in a numerical indicator. Edaq530 is open-source: the full documentation is available on the website of the research group.

The other path in our development work is the application of sound cards as the key components of measuring systems. Sound cards, which count as standard equipment in today's computers, can be turned into measurement tools, making experimentation very efficient and cheap: their outputs can play the role of signal generators (digital-to-analogue converters), while their inputs can be used as data collectors (analogue-to-digital converters). While using sound cards to renew measuring techniques is a common idea, in many cases, the programs applied were originally developed for other purposes; therefore, the results of the measurements might be misleading, didactically poor or even unacceptable.

Our group developed various dedicated open-source programs and measurement solutions to utilise sound cards; these developments are optimised to conform to the aims and circumstances of high-school education. The high sampling frequency (44 kHz) of the sound cards enables using them instead of oscilloscopes in certain experiments. To highlight an example of these developments, we constructed a virtual measurement solution to study resonances.

My main contribution to the work of the group was to develop specific measuring experiments and exercises in several fields of physics, and also in biology and chemistry education. I have held several student labs and teacher trainings where I could test the measurements; then I could use the experience to carry out further developments. As a teacher, I think it important to mention that I usually apply my developments in classes or teacher trainings; therefore, I also present several measurement results recorded by my students and teacher colleagues in the thesis.

As my results and experiences attest, the IBL method and its implementation with computer-aided measurements help students to improve their own analytic thinking and many other skills. The applications of our measurement solutions enhance the connection between science, mathematics and informatics. The developments that will be presented below are in use both in high-schools and in higher education. My thesis could also be a good handbook to the teacher colleagues who want to use these measurement solutions or similar ones in their work.

Results:

The aim of my thesis work was to develop and test computer-based measurement methods which are applicable to support experimental natural science education in high-schools. After a continuous development process, I worked out a group of special experiments and exercises that apply the Edaq530 measurement system (http://www.noise.inf.u-szeged.hu/edudev) or sound-card based measurement solutions. These developments help students to acquire the principles of measurements and allow them and their teachers to measure experiments in different science classes.

I tested the measurement solutions and the experimental set-ups in student labs in the Ságvári High School for three years, applying IBL methods.

The references listed after the thesis statements are organised as follows. [T]: refereed publications associated with the thesis; [E]: non-refereed conference material associated with the thesis; [K]: teacher trainings.

1) **I developed measurement exercises in the topic of *classical mechanics* applying Edaq530; these developments help students to work in an IBL environment.**

[T2.], [T5.], [T7.], [E1.], [E2.], [E5.], [E6.], [E7.], [E8.], [E10.], [E12.]

― An exercise, applying the method of structured discovery, is to study *collisions*. The students worked in pairs using our self-developed photogates. They were able to discover the concept of momentum and the law of the conservation of momentum via their own measurements, in both elastic and inelastic collisions. The study of collisions is usually presented carrying out demonstration experiments; my development enablesteaching this topic via student measurements.

― Studying *pendulum motion* implements the highest level of the Herron model of the IBL method. From their measurements, the students were able to determine the parameters affecting the period of the pendulum, and they also verified the conservation of mechanical energy in an unusual way.

— Attaching an accelerometer to an object on a spring, we can illustrate *harmonic oscillations*. The software displays the acceleration versus time plot online, and, switching level-crossing detection on, we can instantly read the period of the motion. I could also apply this measurement solution in student experiments. While the topic of harmonic oscillations is usually hard to understand for students, it is particularly important to enable them to make own measurements. (To get acquainted with accelerometers is a further motivation for students, because they can learn something about how their phones work).

— *Hall sensors* are widespread devices to measure velocities in our everyday devices. I developed an experiment in which students are able to measure the rotational frequency of a simple DC motor. They can also study whether the frequency depends on voltage or not.

— To study the properties of fluid pressure we applied *relative pressure sensors* whose operation is based on the piesoresistive effect. The measurement solution is able to measure the pressure in the fluid relative to the air pressure. Therefore, pressure differences can be determined also at low fluid levels, which is a very difficult task using traditional measuring methods. With our solution it is also possible to show that hydrostatic pressure does not depend on the orientation, and it is also applicable in measuring the density of fluids.

2) **I developed exercises based on *temperature measurement*. These exercises can be applied not only in teaching thermodynamics but also in environmental education.**

[T5.], [T7.], [E5.], [E7.], [E10.], [E12.], [E13.], [E14.], [E15.].

— Connecting thermistors to Edaq530 we can demonstrate the *decrease of temperature* during *evaporation*. Although it is a common experience, its quantitative study is difficult in traditional ways. My simple measurement solution also gives a chance to study the sensitivity of thermistors. The students are able to study heat equalisation between liquids and phase changes by analysing the real-time curves generated by the software.

— With this measurement solution the students are also able to study the *propagation of thermal waves*, *thermal insulation*, and *heat preservation*. These exercises help students to acquire the basic research methods in natural sciences and to become environmentally aware.

— The measurement solution also allows the measurement of temperature changes of heated gas bottles containing different *greenhouse gases*. It is a good model of greenhouse effect, which help students to understand this phenomenon.

3) I developed measurement solutions to study phenomena in electromagnetism.

[T2.], [E8.], [E10.], [E11.]

— I developed a measurement solution to study the *magnetic field of coils* at different current levels. Using a Hall sensor it is possible to record the Hall voltage as a function of the current in the coil (which yields a direct proportion between the two quantities).

— Since Edaq530 is applicable to measure very small voltage differences, we are able to demonstrate the presence of *induced current in a conductor in a magnetic field*, e.g. in the field of a horseshoe magnet. It allows us to study the properties of the Lorentz force in the classroom. With a measurement solution based on the idea that had come up at one of the teacher trainings, we are able to demonstrate the phenomenon easily and spectacularly; students can see a graph on the screen which shows the changes of the current real-time.

4) **I developed measurement exercises which help to *harmonise knowledge in different areas of science*. These experiences can be also used in teaching chemistry or biology.**

[T2.], [T5.], [E12.]

— Temperature change is one of the most important parameters in chemical experiments. Using Edaq530 is possible to measure it in real-time, which I demonstrated with studying *exothermic dissolution*. I tested the measurement exercise in teacher trainings where chemistry teacher colleagues participated.

— There is also a possibility to connect a pH electrode to Edaq530. pH measurements are very important in chemistry, but they can usually be carried out with expensive and fragile electrodes. At the same time, indicator papers can only be used once, and they allow doing measurements only with very limited precision. I found a cheap pH sensor whose robust epoxy body makes it safe to be used also 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 (after calibration). The measuring system became one of the standard set-ups in the Regional Science Laboratory of Szeged in the Ságvári High School.

— Using Edaq530 as a *photo-pletysmograph* could be also an interesting physical and biological experiment, but, at the same time, a medical measurement, too. 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. The Valsalva manoeuvre, another interesting phenomenon, could also be studied with our plethysmograph. We cooperate with some colleagues at the Institute of Medical Physics and Medical Informatics to incorporate our measurement solution in medical student labs at our university.

5) **I developed and tested different measurement exercises based on the *application of sound cards*, whose main advantage is the high sampling frequency (44 kHz). We use special software to the measurements, which allows students to work in a simple and transparent environment. To explore this measurement system, I studied a known phenomenon in another way: I measured the rotational frequency of a simple DC motor using an optical method.**

[T1.], [T3.], [T4.], [T6.], [E3.] , [E9.], [E10.]

— The high sampling frequency allows us to study *free fall* and measure the value of the local gravitational acceleration in the classroom. The precision of our measurements makes it possible to show the influence of the drag force and the buoyant force on the value of fall time.

— I modernised a classical measurement method to study *rotational motion*. Using a sound card based measurement set-up instead of a stopper, the students were able to measure the quadratic dependence of the moment of inertia on the distance from the rotational axis. This exercise also gives a chance to students to practise linearisation.

— Using sound cards we can also study *resonances*. Our virtual measurement solution displays the relevant results real-time on the monitor. We can apply it to determine the natural frequency of a tuning fork, or study electrical resonances.

6) **To promote the incorporation of my developments in public education, I created *a syllabus for a teacher training programme*, which prepares the teachers participating (who may have only minimal information technology or electronics skills) to carry out**

computer-based experiments and measurements in their classes. I have held training courses three times to teachers with my colleagues, and, additionally, I was also an invited trainer in the Regional Science Laboratory of Szeged.

[T5.], [E4.], [E12.], [K1.], [K2.], [K3.], [K4.]

As a short summary, I was one of the main contributors in developing a set of widely applicable, modern measurement solutions, which allow the teacher colleagues and their students to carry out computer-based, personalised exercises in the classroom or also at home.

Some of our developments were built into the repertoire of Regional Science Laboratory of Szeged at the Ságvári High School.

Within the confines of an international tender ("Non-Standard Forms of Teaching Mathematics and Physics: Experimental and Modelling Approach", MathPhys-Bridge, HUSRB/1203/221/024), some of our measurement solutions will be incorporated in the education of medical and other students at the University of Szeged and the University of Novi Sad.

The integration of the Edaq530 system into Geogebra, a world-wide used mathematics education software, is also in process. The goal of this cooperation is to develop learning materials to natural science education.

Publications

I. Publications associated with the thesis

Refereed papers:

[T1.] G Makan, **K Kopasz**, Z Gingl: Real-time analysis of mechanical and electrical resonances with open source sound card software (Eur. J. Phys accepted for publication; Impact factor: 0.644)

[T2.] **K Kopasz**, P Makra, Z Gingl: Student Experiments and Teacher Tests Using Edaq530, (Acta Didactica Napocensia, Vol. 6. (2013) No. 1., http://adn.teaching.ro/)

[T3.] **K Kopasz**, P Makra, Z Gingl High resolution sound card stopwatch extends school experimentation, (Acta Didactica Napocensia, Vol. 5. (2012) No. 2., http://adn.teaching.ro/)

[T4.] Z Gingl, **K Kopasz**: High-resolution stopwatch for cents (Physics Education, 46 (2011) 430-432.)

[T5.] **K Kopasz** et al: Edaq530: a transparent open-end and open-source measurement solution in natural science education (Eur. J. Phys. 32 (2011) 491-504. Impact factor: 0.644)

Refereed conference proceedings:

[T6.] Gingl Z, Mingesz R, Mellar J, Lupsic B, **Kopasz K**, *Efficient Sound Card Based Experimention At Different Levels Of Natural Science Education*, MPTL16 Workshop on Multimedia in Physics Teaching and Learning and HSCI2011 8th International Conference on Hands on Science, Ljubljana (Slovenia), September 15-17, 2011, pp. 507/1-507/5. (ISBN:978-989-95095-7-3)

[T7.] **Kopasz, K.,** Gingl, Z., Makra, P., Papp, K.: *Virtual measurement technology in public education (*Multimedia in Physics Teaching and Learning, 14th edition) http://www.fisica.uniud.it/URDF/mptl14/ftp/full_text/T3%20_56%20Full%20Paper.pdf (January 4, 2010)

Non-refereed conference proceedings and other conference matters (in English):

[E1.] Gingl Z, Mingesz R, **Kopasz K**, *Sensor-to-computer interfaces support experimental education,* Conference on Computer Algebra- and Dynamic Geometry Systems in Mathematics Education (CADGME 2012), Novi Sad (Serbia), June 22-24, 2012, p. 54-1.

[E2.] Gingl Z, Mingesz R, **Kopasz K**, *Real experiments with sensor-to-USB interfaces,* Conference on Computer Algebra- and Dynamic Geometry Systems in Mathematics Education (CADGME 2012), Novi Sad (Serbia), 2012.06.22-2012.06.24. p. 54-1.

[E3.] **K. Kopasz**, Z. Gingl, P. Makra, B. Lupsic, *Easy and cheap measurements with a sound card*, EUPEN's 13th General Forum: "PREPARING GOOD PHYSICS TEACHERS", Limassol (Cyprus), 28-30 August, 2011

[E4.] Z. Gingl, P. Makra, **K. Kopasz**, *Thumb-size USB-to-sensor interface supports efficient experimentation in multilevel education of physics and other disciplines*, invited presentation, EUPEN's 12th General Forum - EGF2010, "NEW WAYS OF TEACHING PHYSICS", Paris (France), 2-5 September, 2010

[E5.] **Kopasz, K.,** Gingl, Z., Makra, P.: *Virtual measurement technology in Physics Education*, interactive poster session MPTL14 (Multimedia in Physics Teaching and Learning), Udine (Italy), September 23-25, 2009

Papers in Hungarian:

[E6.] Gingl Z., **Kopasz K,** Tóth K: *Kutatás alapú tanulás számítógéppel segített mérések alkalmazásával* (Fizika Tanítása 2012/1. 22-27.)

[E7.] **Kopasz K**., Gingl Z., Makra P., Papp K.: *A virtuális méréstechnika kísérleti lehetőségei a közoktatásban* (Fizikai Szemle, 2008/7-8. 267. o.)

Conference matters in Hungarian:

[E8.] **Kopasz K.**: *IBL alkalmazása a fizika tantárgy tanításában, szakkörön* szimpóziumi előadás XII. Országos Neveléstudományi Konferencia (Budapest, 2012. 11. 8.10.)

[E9.] **Kopasz K.,** Lupsic B., Gingl Z., Makra P.,: *„Mérések hangkártyával egyszerűen, olcsón"* előadás („Természettudomány tanítása korszerűen és vonzóan" nemzetközi szeminárium magyarul tanító tanárok számára, ELTE 2011. aug. 23-25., kiadvány 252-256. oldal, elektronikus kiadvány: http://termtudtan.extra.hu/kotet.pdf, 2012.08.09.)

[E10.] **Kopasz K.**: *Tanulói mérések számítógéppel – egy szakkör tanulságai* műhelyfoglalkozás, II. díj, 54. Országos Fizikatanári Ankét és Eszközbemutató (Sárospatak, 2011. 03. 12-15.) (műhelyfoglalkozás, II. díj)

[E11.] **Kopasz K.**: *Számítógéppel segített iskolai kísérletezés és mérés* c. előadás, „Modern módszerek az informatika, matematika és fizika oktatásában" című konferencia, (GAMF, Kecskemét, 2011. 01. 17.)

[E12.] **Kopasz K.**: *Iskolai kísérletezés és mérés virtuális méréstechnika segítségével* c előadás, „Szakmódszertani kutatások a természettudományos, illetve a matematika és az informatika tantárgyakhoz kapcsolódóan" című konferencia (Szeged, 2010. május 20-21.)

[E13.] **Kopasz K.**: *Virtuális méréstechnika a fizika szakmódszertan laboron* c. előadás, HEFOP 3.3.3. „Új oktatási módszerek és a horizontális szempontok a kétszintű felsőoktatási rendszerben" konferencia, Szeged, (2008.09.20.)

[E14.] **Kopasz K.**: *Virtuális méréstechnika fizika szakmódszertan laboron* c. műhelyfoglalkozás, „A tanárképzés napja - I. veszprémi konferencia", (2008.04.23.)

[E15.] **Kopasz K.**: *Valódi mérések virtuális mérőműszerekkel – multimédiás PC-k a tanári kísérleti demonstrációban,* eszközkiállítás III. díj, 51. Országos Fizikatanári Ankét (Békéscsaba, 2008. 03. 26-30.) (eszközkiállítás III. díj)

Teacher trainings (in Hungarian):

[K1.] *„Korszerű, tevékenység-központú természettudományos laboratóriumi gyakorlatok vezetése a közoktatásban*" című (82/55/2012 alapítási engedély számú, 30 órás) pedagógus-továbbképzés meghívott oktatója

[K2.] *„A kísérletező oktatás támogatása, számítógéppel segített kísérletek bemutatása"* 15 órás továbbképzés szervezése és tartása (Szeged, 2012 november 16-17.) (Kimenet orientált képzésfejlesztés a Dél-alföldi Régió szolgáltató egyetemén TÁMOP-4.1.2.A/1-11/1-2011-0013)

[K3.] :*Számítógéppel segített iskolai kísérletezés és mérés* 20 órás továbbképzés szervezése és tartása (Szeged, 2011. november 18-19.) (Mentor(h)áló; TÁMOP-4.1.2-08/1/B-2009-0005)

[K4.] *Multimédiás alkalmazások a középiskolai természettudományos oktatásban* (OKM 2/11/2006 sz.) 30 órás akkreditált továbbképzés szervezése és tartása (Szeged, 2010.03.19-20., 2010.08.24.)

II. Other publications associated with physics education:

Conference matters in English:

[F1.] Katalin Papp, Anett Nagy, Katalin Kopasz (2007): *Communication strategies in Physics Education*, Frontiers of Physics Education GIREP-EPEC Conference, Opatija (Croatia), 2007 August, online matter & poster

Papers in Hungarian:

[F2.] Kopasz K., Papp K., Szabó M. Gy., Szalai T: *„Üstökös az asztalon" - Hogyan „főzzünk" csillagászati demonstrációs eszközöket?* (Fizikai Szemle, 2009/7-8., 257. o.)

[F3.] Kopasz K. Papp K.: *Aktív tanulói eljárások a fizikatanításban II.* (Fizika Tanítása, 2008/3. 18. o.)

[F4.] Kopasz K., Papp K.: *Aktív tanulói eljárások a fizikatanításban* (Fizika Tanítása, 2008/2. 20. o.)

Conference matters in Hungarian:

[F5.] Kopasz K.: *„Fizikatanítás az iskolán kívül”* előadás („Fizikatanítás tartalmasan és érdekesen” nemzetközi szeminárium magyarul fizikát tanító tanárok számára, ELTE, 2009. aug. 27-29., kiadvány: 427-432. oldal elektronikus kiadvány: http://fiztan.extra.hu/konferencia/proc/szekcio-poszter/KopaszKata.pdf 2010.01.04.)
[F6.] Kopasz K.: *Tanárjelöltek felkészítése az iskolán kívüli aktivitásokra* c. előadás, „A tanárképzés napja - II. veszprémi konferencia”, (2009. április 29.)
[F7.] Kopasz K.: *Üstökös az asztalon* c. műhelyfoglalkozás 52. Országos Fizikatanári Ankét (Kaposvár, 2009. április 15-18.)
[F8.] Görbe M., Jójárt P., Kopasz K., Osvay K.: *Impulzusüzemű és frekvenciakétszerezett Nd:YAG lézer vezérlőprogramjának fejlesztése*, poszter, Felsőfokú alapképzésben matematikát, fizikát és informatikát oktatók XXXII. Konferenciája, Kecskemét (2008.08.25-27.)
[F9.] Papp Katalin, Nagy Anett, Kopasz Katalin (2007): *Kommunikációs stratégiák és a fizikatanítás,* Fizikus Vándorgyűlés, Programfüzet p. 64. (poszter)
[F10.] Kopasz K.: *Aktív tanulói eljárások a fizikatanításban* – előadás műhelyfoglalkozáson, 50. Országos Fizikatanári Ankét (Szeged, 2007. 03. 18.)

Other professional talks in Hungarian:

[F11.] *Hogyan készítsünk kísérleti eszközöket... (optika, mechanika, hőtan)* Apáczai Nyári Akadémia (Újvidék, 2013. júl. 10.)
[F12.] *"Játékszerek a kísérletes oktatásban"* Apáczai Nyári Akadémia (Újvidék, 2013. júl. 10.)
[F13.] *Új módszerek a természettudományok oktatásában* Interdiszciplináris és komplex megközelítésű tananyagfejlesztés a természettudományi képzési terület mesterszakjaihoz című projektben (Szeged, 2013.03.28.) (TÁMOP-4.1.2.A/1-11/1-2011-0025)
[F14.] *Környezeti nevelés lehetőségei a természettudományos oktatásban (egyszerű kísérletek)* előadás, Apáczai Nyári Akadémia (Újvidék, 2012. júl. 18.)
[F15.] *Számítógépes mérések a középiskolában* előadás, Apáczai Nyári Akadémia (Újvidék, 2011. júl. 13.)
[F16.] *Környezeti nevelés a természettudományos órákon* c. előadás „Tisztább Dunamentéért, Európáért” című pályázat nyitó konferenciája (Almásfüzitő, 2011. 03. 24.)
[F17.] *Szerethető-e a fizika?* c. előadás, „Komplex szervezetfejlesztés, a munkaerő-piaci és a nemzetközi alkalmazkodóképesség növelése a Kecskeméti Főiskolán” pályázat keretei között (Kecskemét, GAMF, 2011. 03. 22.)
[F18.] *Számítógéppel segített iskolai kísérletezés és mérés* c. előadás, XX. Schwartz Emlékverseny (Nagyvárad, 2010. nov. 13.)
[F19.] *Valódi mérések virtuális műszerekkel* c. előadás, Apáczai Nyári Akadémia (Újvidék, 2010. júl. 15.)