THESIS OF DISSERTATION

ANALOGIES IN PHYSICS EDUCATION

Zoltán Csernovszky

Supervisor: Dr. Ákos Horváth

ELTE TTK

Physics Doctoral School

Leader: Dr. Tamás Tél

Physics Education Doctoral Programme

Programme leader: Dr. Tamás Tél

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Introduction

Nowadays, physics education research confronts new challenges. The explosion of scientific knowledge and information leaves less and less time to get to know new ideas, their importance and their integration in physics education. The application of digital devices for scientific and educational purposes is a complex and long-time process, but the main challenge is to use informatics devices for scientific experiences in physics education. We use informatics devices to collect data (microcontrollers, sensors), to represent, iterate and analyse experimental data (software), to fix, analyse and edit images of natural phenomena (camera).

We see several times that scientific thinking is thrown into the shade, plus results received by scientific reasoning are queried. The reject of scientific knowledge and method, based on modern Descartes-rationalism, signifies a real danger in everyday life. I think, using and developing physics educational resources, we can fight off these tendencies, The physics education have to introduce the basis of scientific knowledge, practising scientific method as soon as possible, and integrate the presented scientific knowledge-elements in a well-structured system.

The everyday use of digital devices and mobile internet offer new possibilities in physics educational research. We think here first e-learning possibilities, which can replace classical exercise and activity book with online possibilities. It can offer an alternative method with its interactive activities and aid to practise and apply scientific knowledge.

Objectives

High-priority purpose was the didactic introduction of solar cell topic. We can find solar-cell topic on physics bac, even if its development not detailed. For this reason, my first intention was to organise a solar cell project to observe and test our home-made solar cells in operation. On further investigation we wanted to form a model of the solar cell operation, especially based on energy levels and bands. In according to my plan, the students can become active participants of a scientific research process in solar energy conversion topic. We wanted to examine the absorption of light by organic pigments, applied in new type of solar cells. We hoped that this research will open a way for modern physics applications, and that the project activity form fits to the expectations of students.

As we noticed the expansion of informatics devices and culture we wanted to simulate a non-linear phenomenon. In this project the participant students already had a good knowledge in mechanics classic. Therefore, we searched a non-mechanic system, which the detailed description can be found in the secondary physics curricula. On one side the objective was finding the analogy between the two systems, on the other side we wanted to follow the systems by computer iteration. We tried to find a ready-to-use software, demonstrating the basis of iteration process, but usable without programming. In this project, first we followed the conservative motion types and then we related energy and motion types. Mapping out the dissipative motion-types of system, we hoped to find the notion of deterministic chaos, comprehensible and applicable in secondary school. Before the organisation of the project, I introduced the basis of mechanical analogies in normal physics courses, according to curricula.

The demand of the new generation for new approached curriculum on mobile devices is evident. Using the possibilities of an e-learning surface, I tried to satisfy this demand and I created mostly non-conventional activities. I paid special attention to group activities to facilitate the application of scientific method in secondary school. I describe the topics of activities within physics curriculum as precisely as possible and I offer interdisciplinary connections to take advantage didactically from these activities.

Doctoral thesis

Solar cells analogies in physics education

We find a test of a solar cell in Hungarian physics baccalaureate (2015, upper level, experience 20). It was the primary reason to construct a solar cell with my students in project activity. I choose a new type of solar cell, called organic solar cell, because the investigation of its working principle was very promising. We constructed organic solar cells ourselves in secondary school laboratory, and then we tested them, in according to the description of experience 20 of baccalaureate. It worth to organise laboratory work, because the construction of solar cells was the first autonomous step of most of students in their scientific career. The constructed devices, their operational principle and experimental data were presented on different conferences and articles. See Table 1.

Year	*Institute*	*Number*	*Form*	*Activities*	*Presentation(s)*
2015	*KFG, ELTE*	*5*	*project*	*Construction, electrically test*	*TPI-15, MPTL-15*
2016	*KFG*	*4*	*project*	*absorption test of dyes*	*KFG project-presentation*
2017	*KFG*	*4*	*project*	*Construction, electrically test, absorption test of dyes*	*Hungarian physics teacher camp, Gödöllő*
2018	*BDG, ELTE*	*4(2)*	*project*	*Construction, electrically test, absorption test of dyes*	*EJP article, EJP video-abstract*
2018	*BDG*	*4*	*project*	*absorption test of dyes*	*BDG Physics camp*
2018	*BDG*	*8(4)*	*project*	*Construction, electrically test*	*BDG Physics camp*

Table 1. Summary of organic solar cell projects and activities
TPI = Teaching Physics Innovatively, conference on new learning environments and methods in physics education, ELTE, Budapest
MPTL = Multimedia in Physics Teaching and Learning, conference on physics education, LMU, Munich
KFG = Kölcsey Ferenc Secondary School, BDG = Berzsenyi Dániel Secondary School
EJP = European Journal of Physics, IOP science, journal of European Physics Society

With the activities described here below, even the theoretical description of solar energy conversion and colour vision become possible, at secondary school level. I underline that experimental data of students complete the theoretical description and environmental physics applications of the topic fit to new international physics education trends.

1. Unified division of electron-cycles in solar energy converters

In secondary school projects we constructed solar cells containing pigments, so called organic solar cells. I recognised that we can understand the simplified operation principle of solar cells by organic solar cells. One of the basis of this recognition was the separation of electron-cycle representation from energy-level and band representation. According to the demand of secondary physics education, the other basis was the division of electron-cycle, which take place as photon absorption, This electron-cycle division was also the basis of the analogy with which we can follow up traditional solar cells, organic solar cells and light dependent reaction of photosynthesis.

The appluication of above all can facilitate the description of solar cells at secondary level physics education. In scientific litterature we can find a more complex division of electron-cycle of organics solar cells, and the separation of energy levels and bands representation of light dependent reaction of photosynthesis from its spatial-cycle. But up to now, a unified and analogical application for all types of solar energy converters doesn't exist.

I demonstrated that using secondary school physics education knowledge, we can follow the electron-cycle of organic solar cells. A comparative analysis open a way to the unified description of electron-cycle of all types of solar energy converters. To help students in sytematic comprehension, and following spatial electron motion in electron-cycle according to the division as above, we offered representations and equations of reaction.

Publications, conference presentations, related to thesis 1: [1] [2] [3] [6] [8] [9]

2. Teaching solar cells and photosynthesis with a new type of energy-diagram

In order to examine solar energy converters and to demonstrate their analogous operational principle, I have constructed a generalised, new type energy-diagram. This method of illustration proved effective, since with the awareness of energy band structure it makes more comprehensible the operations of above mentioned systems, because it originates in the electron-cycle of organic solar cells. **Another advantage of this new type energy-diagram is that it shows energetic relations according to the divisions of thesis 1 and it illustrates the use of energy of absorbed photon(s) on each component of the system.** With the new type of energy-diagram we can localise the energy level or the changes of energy-level in each step of electron-cycle. Thus, we have the possibility to apply and to strengthen the notion of energy in a modern physics case. Using experimental results of students, we can represent on energy-diagrams the energy levels of excited states.

On new type of energy-diagram we receive analogous representations of electron cycles, in many ways, both of solar cells and of light dependent reactions of photosynthesis. This type of representation underlines the importance of organic solar cells in physics education, because its energy-diagram simplifies in analogous way the energetical description of conventional solar cells and light dependent reactions of photosynthesis. In latter case, we considered two photon absorptions and an external process, called photolysis which results a supplementary electron.

Publications, conference presentations, related to thesis 2: [1] [2] [3] [6] [8] [9]

3. Absorption properties of organic dyes

We examine light absorption of some organic dye extracts, using in organic solar cells construction to understand their spectroscopic properties. The students produced the absorption spectra of organic dye extracts with a home-made diffraction grating spectroscope using a CD. For this purpose we used a freeware data analysis software, called spektro2012 (software of Károly Piláth: http://pilath.fw.hu/lapok/efiz.php?LF=k23.htm) and a webcam. For each dye we determined the absorption maxima and their wavelengths. Later, we completed our researches with a chlorophyll-extract measurement to describe better the light dependent reactions of photosynthesis. The maximal absorption wavelength results, received by home-made spectroscopes, were controlled by a professional spectroscope.

These results show that the maximal absorption wavelength results of organic dye extracts, received by home-made spectroscopes, were closes to professional wavelength values. Moreover, these results were useful to understand the structure of dyes and chlorophyll. **With experimental results of students, we can determine the wavelength of absorption maxima of organic dye extracts, constructing organic solar cells, and of chlorophylls. Build upon our experimental results, we have introduced the notion of complementary colours, and we interpreted the colours of fruits and leaves. Using the experimental results of students, we have completed the new type of energy-diagrams of doctoral thesis 2, with electron excited states values of dyes and chlorophylls.** From point of view of physics education, our experimental data of the topic fit to Hungarian education trends in optical and modern physics.

Publications, conference presentations, related to thesis 3: [2] [3] [6]

4. Test of solar cells in electrical circuit

We tested conventional solar cells and organic solar cells according to Hungarian physics baccalaureate (2015, upper level, experience 20). In this series of measures, the candidate determines optimal intensity of current of cells as their maximal power. We analysed data, according to the description of baccalaureate. To prepare for baccalaureate, we have the students to do measures in supplementary physics courses and in project activity. We examined the dependence of electrical properties of solar cells on one hand to the type of light absorber pigments (raspberry, blueberry, mango, blackberry) and on the other hand to the type of light sources (incandescent bulb, LED, halogen, neon, mercury-vapour lamp). We also determined maximal power of cells with graphic method and theoretical calculation.

As compared measurement values of organic solar-cells to conventional solar-cells, we find the raspberry solar cell as the most photo-stable, the most analysable and the most solid organic solar cell. The raspberry solar cell is applicable as good as conventional solar cells, at least for experiences above described. The experimental values received by using mercury-vapour lamp were the best fitted to theoretical values. **I underlined that a secondary school student group, based on their own experimental results, be able to choose the most stable organic solar cell and the best fitted to theoretical values light source, and it is possible to compare conventional and organic solar cells. According to my measuring experiences with student groups, I recommend to test raspberry solar cell, exposed to a mercury-vapour lamp in electrical circuit, as individual work as project activity.**

Publications, conference presentations, related to thesis 4: [1] [6]

Analogous description of a pendulum and a compass in different fields of force

The analogies have accentuated importance in physics education. For illustrate this statement I introduce here an analogous description of a pendulum and a compass, developed by secondary school physics knowledges, which are built up gradually. Using analogous quantities, we can describe the rotation of magnetic dipole or a compass, in more and more complicated fields of force, which open a way to secondary school applications (Budapest, Kölcsey Ferenc Secondary School, 2017/ 18). The original purpose was the development of a series of project activities, which introduce students in research work by computational modelling. Finally, the creative ideas of students are integrated in the development of topic and with their own results, they also formed the topic itself. It is the first Hungarian scientific literature of the topic.

5. Pendulum-compass analogies

We described conservative pendulum and compass motions in uniform standing, uniform rotating and their superposed fields. **I demonstrated that, with the followed analogy, the description of a magnetic dipole rotation is possible, even we use only secondary school physics knowledge.** Up to now, the scientific literature of this topic describes the magnetic dipole rotation by using higher mathematics tools (p.ex.: Bergé,P., Pomeau,Y., Vidal,C.: L'ordre dans le chaos, InterEditions Herman, 1984).

We created a uniform standing magnetic field by a Helmholtz-coil, constructed in a secondary project activity. To follow the motions of systems in uniform rotating and superposed fields, we applied a freeware iteration software of J.M. Aguirrebeiria, called Dynamics Solver. We represented these types of motions on a phase-plan angle-angular velocity, which facilitated conservative motion analysis and comparisons. **I demonstrated that the introduction of phase-plan angle-angular velocity facilitates the comprehension of students, because on phase-plan representation we can easily relate energy and motion type Thanks to phase-plan angle-angular velocity representation and to reference frame fixed to rotational field, we lead back the description of compass motion in uniform rotating field to uniform standing field.**

The introduction of phase-plan notion in secondary school and the computational analysis of systems above described, prepared the notion of stroboscopic projection, which was indispensable to further analysis. The representation of compass motion in superposed field results such a complicated and non-analysable image on phase plan angle-angular velocity, that its analysis requires a new representation type, called stroboscopic projection, which utilize the period of rotating field. **We applied the stroboscopic projection to search motions where or the uniform standing or the uniform rotating field was dominant, called quasi-periodic motions. I demonstrated, that this method can raise the interest of students for researching quasi-periodic motions.** Up to now, the scientific elaboration of the topic is only known in French (Croquette,V: Systemes Non Linéaires et Introductions au Chaos, ESPCI Signaux et Images, 2009), pedagogical purpose publication is not known.

Publications, conference presentations, related to thesis 5: [4], [5], [7], [10]

6. Chaotic motion of a compass

The dissipative compass motion in superposed field can become chaotic. To find chaotic motions it requires parameter values, where chaotic attractors, the signs of deterministic chaos, appeared on stroboscopic projections. To search chaotic attractors, the students realised many stroboscopic projections with different parameter values. To start the analyse, we fixed two parameter values and made stroboscopic projections at every whole number of the third parameter value. But if we found chaotic attractors, we focused on this value, and changed parameter-scale to realize other projections. Finally, we made a video, where every picture was a stroboscopic projection and then we summarized the results by a video. During common work with students, **I recognized, that with the stroboscopic projections, prepared systematically, we can form a video. where each stroboscopic projection is one picture of the video. Using this video, we can map the parameter-intervals of chaotic motions, then we can analyse and compare chaotic attractors.**

The characterization of chaotic attractors and the analyse of the way which leads to chaos are fruitful chapters of the investigation of deterministic chaos. The pedagogical applications of chaotic motions did not come from nowhere. See doctoral thesis of Péter Nagy and József Jaloveczki (2014, 2015). Albeit, the elaboration of topic goes far beyond secondary physics curricula, however the searching for control-parameters of chaotic attractors of dissipative compass motion in superposed magnetic field was a popular project. The elaboration of the topic was a real discovery for students and teacher, too.

Publications, conference presentations, related to thesis 6: [4], [5], [7], [10]

7. Development of digital physics education resources

All of physics teachers have the same experience: we can't teach the same way than we taught the physics some years ago. For this reason, I would like to form a resource, simply accessible for teachers and students on a digital learning surface. With this resource, containing conventional and non-conventional activities, I hoped to help teachers in lesson-preparation, and helped them to organise differential class-working. It can result in a personal preparation and a more activated class-participation of students.

The digital resource activities were fitted to secondary physics curricula, and divided in chapters, distributed uniformly in the curricula. The base of each chapter is an introductory text. I organised around each text a class-activity, a complex project-exercise, a measurement, a video-activity, a test, an animation and a computational activity. At same time the activities of a chapter are related. **From point of view of physics education, it is a special digital learning-resource, containing text and remarks, fitted to physics curricula. The basically text-understanding exercises, individual and group-activities are proposed to elaboration at home and in physics-class, too. I demonstrated that using these physics-history readings, complex project-exercises, comics, animations, measurements the teacher can create open problems and questions. Its elaboration can also follow the demand of teacher and students.** The test of the resource was organised in Hermann Ottó Secondary School, Miskolc at school-year 2014/15, by educational group, called "Suliklub".

Publications, conference presentations, related to thesis 7: [11] [12] [13]

Summary, plans

With my students, I have constructed organic solar cells then, I have chosen ideal dyes and light sources. We tested the cells in electrical circuit. We would like to increase the received optimal intensity value, lifetime of cells and their stability. The relatively simple operational principle of organic solar cells and their similarity to conventional solar cells and light dependent reaction of photosynthesis open the way to interdisciplinary applications. The analogous description of systems above mentioned is the most promising pedagogical application of organic solar cells. In future we would like fix better the titanium-dioxide layer on glass-plate and hold the quickly evaporating electrolyte in the organic solar cell. Our purpose is increasing the measurable electrical voltage and current intensity values. We would like to test perovskit solar cells in project-work.

The spectroscopic analysis of organic dyes project can stand up separately from organic solar cell project. We completed the original purpose, the analysis of organic dyes by a home-made spectroscope, with an analysis of leaves and fruit-extracts to interpret the colours-seen.

The description of compass motion in uniform standing, uniform rotating and superposed magnetic field allowed more interesting pedagogical application. On one hand we can establish the pendulum-compass analogy with secondary school physics concepts, on the other hand with constructing Helmholtz-coil and varying its current intensity, we can observe compass motion in uniform standing case. As conservative uniform rotating case offers a good occasion to apply a rotating referential frame to simplify its description, the application of superposed magnetic field creates a chance to introduce the stroboscopic projection. The research for quasi-periodic and chaotic motions on stroboscopic projection is an exciting project activity. The notions of deterministic chaos, chaotic attractor or fractal appear in everyday life. It can be the reason that their analysis and characterisation are fruitful chapters of physics education, in project work. Further purposes are the realisation of complex cases and following compass motions by a high definition camera.

The digital resource fitted to secondary physics curricula have completed, its test was organised in Hermann Ottó Secondary School, Miskolc by Suliklub educational group. The positive feedback signs for the demands of this type of digital resources and developments. I underline that its success largely depends on the used image, animation and video resources. It poses the question of the creation of a secondary physics specific education database with the most successful activities.

Publications

Peer reviewed articles

[1] Csernovszky, Z, Horváth, Á: Raspberry solar cell, a versatile tool in teaching physics, Int. *Conf. Teaching Physics Innovatively* ed T Tél and A Király (Budapest: Graduate Sch. for Physics, Eötvös Univ., 2015) pp 149–154 http://csodafizika.hu/fiztan/letolt/konfkotet2015.pdf

[2] Z. Csernovszky, Á. Horváth: Video abstract (Organic solar cells and physics education), *European Journal of Physics 39, 045804 (16pp), (2018)* *http://iopscience.iop.org/article/10.1088/1361-6404/aab5d1/pdf*

[3] Z. Csernovszky, Á. Horváth: Organic solar cells and physics education, *European Journal of Physics 39, 045804 (16pp),* http://csodafizika.hu/fiztan/english/student/cserno_solar_2018.pdf

[4] Csernovszky Zoltán: Iránytű kaotikus rezgésétől kaotikus mozgásáig Fizikai Szemle, LXVII. ÉVFOLYAM, 6. (750.) SZÁM 2017. JÚNIUS https://drive.google.com/open?id=0B8tzAsVf60K-SUJ4OFBaaFUwTzQ

[5] Csernovszky, Z: From harmonic oscillation to chaotic motion of a Compass, 2019 J. Phys.: Conf. Ser. 1223 012004, IOP, Open Acces https://iopscience.iop.org/article/10.1088/1742-6596/1223/1/012004

Conference presentations

[6] Csernovszky, Z Organikus napelemek, a fizikatanítás sokoldalú eszközei (Organic solar cells, versatile tools in teaching physics, Országos fizikatanári Ankét, Gödöllő, 2017 http://prezi.com/yqo13xu6j4qq/?utm_campaign=share&utm_medium=copy&rc=ex0share

[7] Csernovszky, Z Erdélyi Fizikatanári Ankét, Sztána, 2017, Az iránytű harmonikus rezgésétől kaotikus mozgásáig http://www.empirx.ro/activities/erdelyifizikatanarianket2017

[8] Csernovszky, Z, Horváth, Á: Raspberry solar cell, a versatile tool in teaching physics, *Conf. Teaching Physics Innovatively* (Budapest: Graduate Sch. for Physics, Eötvös Univ., 2015)

[9] Csernovszky Z, Solar energy converters in teaching physics, *Conf. Multimedia in Physics Teaching and Learning* (Munich, Ludwig Maximilian Univ., 2015)

[10] Csernovszky, Z: From harmonic oscillation to chaotic motion of a Compass, (21st International Conference Multimedia in Physics Teaching and Learning (MPTL 2017), The Open University, Milton Keynes, UK

Curricula

[11] Afrodita M, Balázs K, Birloni Sz, Csernovszky Z, Demeter É, Farkas B, Kis Sz, Kormos E, Nemes Nagy E, SULIKLUB, e-learning digitális tartalmak: http://elearning.suliklub.hu/materia/index.php?func=simplesearch

[12] Csernovszky Z, SULIKLUB, Fizika tartalmak pdf-formátumban: https://drive.google.com/open?id=1Tc7ujiKsuDlRUWkRrFzSDf7nD_YP84PO

[13] Afrodita M, Balázs K, Birloni Sz, Csernovszky Z, Demeter É, Farkas B, Kis Sz, Kormos E, Nemes Nagy E, Szövegértési képességek fejlesztése tantárgyi tartalmakon a gimnáziumok 9–12. évfolyamán, *Tankönyv, (IN-00001* http://www.kormany.hu/download/0/8c/51000/tank%C3%B6nyvjegyz%C3%A9k2018.pdf