TEACHING PHYSICS INNOVATIVELY

New Learning Environments and Methods
in Physics Education

Proceedings of the international conference
Teaching Physics Innovatively (TPI-15)
New Learning Environments and Methods in Physics Education
Budapest, 17-19 August, 2015.

PARRISE

Roland Eötvös
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YEAR OF LIGHT

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GREETINGS TO THE READERS

Physics is one of the most important branches of natural science and a field of research deeply affecting our daily life through its practical applications. This discipline is also at the core of many scientific achievements of chemistry and biology that are based on physics. Still, learning Physics in public or even in higher education nowadays seems to be less than popular among students. A general aversion of society towards this field is another unfortunate phenomenon of our times.

Among the various possible reasons of this problem, a major one is certainly the fact that learning Physics is difficult indeed. Nature is complicated and exact descriptions of its phenomena and processes are necessarily complicated, too. Many students, however, dislike, and, if possible, avoid difficulties and complications – unless scientific problems are presented in a relevant, authentic and inspiring manner.

Therefore, the conference “Teaching Physics Innovatively” was crucial for the future of science in society, it had an important mission accomplished successfully in August 2015 in Budapest. We were privileged to have hosted the TPI-15 international conference at Eötvös Loránd University, and congratulate the organizers and participants for all of their efforts and results presented in these Proceedings.

Péter Surján
Dean, Faculty of Science,
ELTE Eötvös Loránd University

PREFACE TO THE PRINTED EDITION

Within the framework of the prestigious conference series entitled "Eötvös Workshops", the conference, "**Teaching Physics Innovatively** – **New Learning Environments and Methods in Physics Education**" (TPI-15) took place at the Faculty of Science of Eötvös Loránd University (ELTE), Budapest, in 17-19 August 2015. The main organizer of the conference was the Graduate School for Physics of ELTE, in particular, its Physics Education program.

The history of this program goes back to 2007, when as a possible measure against the continuous decrease of interest in physics among high school students, the Graduate School for Physics decided to launch the Physics Education doctoral program. Earlier, teachers had the possibility to earn a PhD degree in Physics by carrying out scientific research only, or a PhD degree in Education, a field where Physics plays a minor role. The new program declares that establishing a novel, inspiring way of teaching modern or classical aspects of physics in a class is an achievement equivalent to traditional research results. The program is open for active high school teachers, or for lecturers at BSc study programs who do not possess a PhD degree. The Budapest Program is special since is tailored specifically for the needs of teacher-students. Candidates carry out their research at their own school.

Results of the candidate's research in physics education should be published during or right after their studies. We request at least one publication in a peer-reviewed international journal (for instance, Journal of Physics, Physics Education, European Journal of Physics, Physics Teacher, Physik in der Schule). We urge therefore (and support as much as we can) their participation at international conferences. Three other publications are requested in appropriate Hungarian journals. The participation at local physics teacher conferences is also strongly recommended.

To support the need for intensive exchanges of ideas, we organized a sequence of three conferences in the past years. Interestingly, even these turned out to be international meetings, though with Hungarian as the working language. This is due to a rather special situation we have to face: a physics teacher teaching Physics at a school in Hungarian language might be a citizen of Hungary, or any of the seven neighbouring countries with Hungarian-speaking minorities. TPI-15 was our first international conference in the traditional sense, with English as the working language. We received an overwhelmingly positive reaction to our call, and TPI-15 was attended by about 100 participants, from 18 different countries. Our Physics Education Graduate Program was represented by 29 PhD students, most of whom gave contributed talks.

The event was organized in co-operation with the Hungarian project team of the European project entitled Promoting Attainment of Responsible Research and Innovation in Science Education (PARRISE). ELTE is a member of the Consortium which is led by the Freudenthal Institute for Science and Mathematics Education (FIsme), Utrecht University and consists of 18 teams representing distinguished institutions from 11 countries (for details, see the project's webpage: http://www.parrise.eu/).

PARRISE has developed a framework for Socio-Scientific Inquiry-Based Learning (SSIBL), a novel pedagogical approach based on four interacting concepts and approaches: Responsible Research and Innovation (RRI), Socio-Scientific Issues (SSI), Citizenship Education (CE) and Inquiry-Based Science Education (IBSE). A detailed summary of the approach is given in the introductory presentation written by Andrea Kárpáti, on the next pages. The consortium regularly reports about important related events: the 2015 December issue of the PARRISE Newsletter included a one-page summary of our conference, which we reprint as a page attached to this preface. The choice of some of the main topics of the conference (as can be seen at its webpage: http://parrise.elte.hu/tpi-15/) were developed as a cooperative efforts of the two partners.

The same spirit is reflected in the choice of the sectioning of this proceedings. All the keynote speakers kindly provided us with a written version of their talk. They appear here along with almost all the contributed presentations. The effort and positive reaction of our participants expresses the fact that there is an increasing international interest in novel approaches. The benefit of the meeting for the teaching community in Hungary is shown by the fact that new directions, never existing before, seem to have been established, such as the inclusion of novel socially sensitive issues in physics teaching and experience based Science Centre physics. Parallel to this, we may also witness the strengthening of the inquiry-based learning approach, and an increasing interest in environmental aspects, as reflected also by the contributions included in this volume.

We would like to thank all our contributors for providing insightful and well-written articles, and our referees who increased the professional quality of this volume. (All contributed papers were seen by one referee at least.) The members of the Scientific and the Local Organizing Committees (cf. http://parrise.elte.hu/tpi-15/) helped us not only in the preparation and running of the meeting, but also in organizational problems arising during the editing process.

Special thanks are due to the Paks Nuclear Power Plant for organising a guided tour with detailed scientific explanation and discussion of related social issues to all accessible parts at their Maintenance Centre, at a rather late time, after the closing of the conference. Another partially related event at the meeting was the Expert Roundtable on socially sensitive issues. We are thankful to László Egyed, science communicator and founding Director of the Palace of Miracles, the first Hungarian science centre, for organizing and moderating this important discussion. The report about the visit to the power plant, and a written version of the roundtable are special highlights of this proceedings.

The technical help in the organizational issues of the conference provided by the Hungarian Physical Society is acknowledged, as well as the financial support from the Hungarian Academy of Sciences (HAS), the program of International Year of Light 2015, the Pázmány-Eötvös Foundation, and the ELTE Eötvös Loránd University.

The printing costs of this book, which follows the e-book edition published online in 2016, was covered by a special program of HAS. In the present volume a number of misprints have been corrected and some links to online sources have been updated. The editorial preparation of this book was funded by the Content Pedagogy Research Program of HAS.

We hope to provide you with an insightful and enjoyable conference proceedings, the editors,

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project team

Tamás Tél
Head of the PhD program for
Physics Education

July, 2017.

Teaching physics innovately

by Márta Jávor & Andrea Kárpáti

Eötvös Loránd University, Hungary

An international conference was organized at the end of the summer in Budapest about how to teach physics innovatively in secondary education. Nowadays physics is not the most popular subject in high school –a fact that makes discussions about how to best teach physics more important. At the conference, teachers from several countries shared their ideas about the modernization of physics education.

The highlight of this conference was the presentation of environmental and socially sensitive issues, and innovative teaching methods using the most recent IT technology in formal and informal learning environment, such as science centres, museums and research sites. Contributions were organized around themes with direct relevance to socially sensitive issues in science education and recent findings from physics education research. The SSIBL Framework was introduced in a plenary presentation and discussed in paper sessions. A roundtable discussion on socially sensitive issues, e.g. on nuclear energy, and a visit to the Paks Nuclear Power Plant was also used to highlight the importance of a SSIBL approach to science education.

The exchange of ideas during the conference by 101 participants from 18 countries was inspired by invited speakers, who included well-known researchers. *Marisa Michelini*, President of *GIREP (International Research Group on Physics Teaching)* was the first speaker about how to develop modern physics' thinking in secondary schools. *Hannu Salmi*, from the University of Helsinki, a member of the PARRISE External Advisory Board, presented relationships between formal education and informal learning via science centres. *Ulrike Feudel*, professor of theoretical physics of the Institute for Chemistry and Biology of the Marine Environment in Oldenburg gave insights into introducing students to complex systems in nature and their socio environmental consequences.

Witty experiments by *Miha Kos*, the founder director of House of Experiments in Ljubljana, Slovenia showed how "*doubtology*" helps you avoid misconceptions when illusions trick you common sense. *David Featonby* from the UK, physics teacher and ambassador of "Science on Stage Europe", presented the *Science on Stage* international network of innovative and socially targeted science education and its biennial festival, which will next take place in Debrecen, Hungary in 2017. *Zoltán Néda*, a Hungarian professor of the University of Cluj-Napoca, and external member of the Hungarian Academy of Sciences, demonstrated how light and kinematics experiments lead students to a deeper understanding of the basics of the theory of relativity, as part of the celebrations of the "*International Year of Light*" in 2015.

Participants enjoyed an exciting lecture by *György Szabó*, researcher of the Wigner Research Centre for Physics in Budapest, about game theory and its applications to the understanding of social and scientific phenomena. *Miklós Vincze*, a member of the von Karman Laboratory of Environmental Flows at Eötvös University, demonstrated that fluid dynamical experiments can faithfully model phenomena, even phenomena related to climate change. The researchers of the Institute for Nuclear Research at Debrecen developed an entertaining adventure game which can help students to understand nuclear systems and processes. *Zsolt Fülöp*, the director of the Institute, showed participating teachers how to use this game for developing a firm knowledge base as well as sensitizing students about social issues around the use of nuclear energy. In connection with this crucially important issue for the Hungarian society, *Attila Aszódi*, professor at the University of Technology and Economics in Budapest, discussed the scientific, economic and social issues of the enlargement of the Nuclear Power Plant in the town of Paks, also explaining the problems regarding its public acceptance.

Figure 15. Round-table discussion, participants (from left to right): Hannu Salmi (University of Helsinki, Finland), Zsolt Fülöp (Institute for Nuclear Research, Debrecen, Hungary), Attila Aszódi (University of Technology and Economics, Budapest), David Featonby (Science on Stage Europe, United Kingdom), László Egyed (moderator of the discussion)

In the conference sessions, speakers presented their favourite educational project in nine areas. There were several content areas that have not yet been included in the actual curriculum of physics, however their social and scientific relevance would make an inclusion justifiable. We had 60 contributing speakers, and most of them were high school teachers of physics. Many of the Hungarians among them have learnt about the SSIBL Framework during a course offered by the doctoral programme on Physics Education at Eötvös University.

The conference reached its pinnacle at the *round-table discussion about nuclear energy use*, a socially sensitive issue in Hungary that has to be reflected in science education (see Figure 15). An excursion to the town of Paks, where participants visited the *Training Centre of the Nuclear Power Plant*, completed this debate and showed how teaching Physics is relevant for shaping public opinion through providing authentic scientific information.

SOCIALLY RESPONSIBLE SCIENCE EDUCATION – A CONTEMPORARY PEDAGOGICAL CHALLENGE

INTRODUCTORY PRESENTATION

The majority of European public is *actively interested in, but does not feel informed* about the developments in science and technology, although at least half of all Europeans are interested in these issues, according to Eurobarometer. In this survey, 59% of respondents claimed that they had read articles and 47% talked to friends about recent results of scientific research in printed press or on the internet. Civic activities related to issues of social relevance were, however, rather limited: only 13% signed petitions or joined street demonstration, 10% attended public debates about scientific issues of social relevance. Hungary is also among those countries whose citizens claim not to be adequately informed about developments in science and technology. This fact emphasizes the importance of science education in our country. Science teachers are perhaps the most important shapers of the minds of young citizens, and, through them, their families. They do not only distribute knowledge, – they also share values and attitudes about the role of science in solving problems that define the ways we live and shape our future.

The results of science education, therefore, are far more than attainment on knowledge tests. Scientific knowledge may support political decisions and challenges of private life – or else, its lack may result in public and private crises, even catastrophes. At this conference, speakers have taken up this challenge and shown us ways to reconceptualise and retool science education. *Reconceptualization* means being current: integrate new results in school curricula and modify those that have become outdated. *Retooling* enables us to use cutting-edge technology to experiment, explain and test knowledge and educate for discussions that further scientific inquiry. Most educational models presented in this volume are interactive and encourage participation in knowledge construction and also in discussions about the use of research and innovation. Experimentation has always been at the core of Hungarian Physics education, but the social issue-based approach presented here may be new and relevant in turbulent times like the first decades of the 21th century.

Science has primarily been taught in Hungarian schools as a knowledge system separate from values and social justice, in which deduction is used to apply theoretical knowledge to solve problems. We joined the

Promoting Attainment of Responsible Research and Innovation in Science Education (PARRISE)

project, a Seventh Framework Program (Grant Agreement No. 612438, duration: 2014-2017) in order to expand our perspectives and enrich our repertoire of socially responsive teaching and education. The PARRISE team has developed and is now piloting a framework for *Socio-Scientific Inquiry-Based Learning (SSIBL)* based on four components: Responsible Research and Innovation (RRI), Socio-scientific Issues (SSI), Citizenship Education (CE) and IBSE (Inquiry Based Science Education), − this last being its core element. The PARRISE Project believes that science is intrinsically social and its products and processes are mediated through power relations. Science education needs to address issues of social relevance and encourage students to become responsible adults, able and willing to influence political decisions influenced by scientific research. For Hungary, communicating socially sensitive issues through science education – a group of disciplines highly successful till the 1990s and fighting problems of student disinterest and scarce funding for inquiry based approaches today – is especially relevant. This conference was also a training opportunity where presentation, a round-table discussion and an informal learning event (visit to the Paks Nuclear Power Plant) has provided new insights about educational methods of presenting perhaps the most disputed social issue related to science in Hungary: the expansion of the Paks Nuclear Power Plant. The SSIBL Framework and other models introduced by our speakers have one idea in common: in order to educate responsible citizens, we must make them aware not only of the potentials, but also the challenges and risks of scientific discoveries and show how they were solved. A deeper understanding may lead to changing mind sets and embracing solutions that had been considered unacceptable before.

This conference was dedicated to the encounter of teachers and scientists – mediators and promoters of Physics. Science teachers seem to have an inclination to identify themselves with scientists as role models – however, their mission reaches far beyond the interpretation of results. Teachers have to possess *affective skills and social competences that make them more than science communicators and assume the role of science educators*. Mapping controversies in social debates about the utilisation of research and innovation (like the use of nuclear energy) and providing authentic standpoints (impartial representation of scientifically valid viewpoints) are basic requirements for responsible science education. Promoting reflection and collaboration in resolving disputes and developing arguments based on facts and laws taught are educational targets that are crucial for developing democratic citizens. Criticality and willingness to listen, respecting the viewpoints of others with openness and honesty, engaging in discussions of controversy without injecting own biases, and the ability to reflect present alternative viewpoints where necessary are attitudes much needed for responsible citizenship – and often lacking in our contemporary society.

When manifesting the responsible researcher as role model, teachers of Physics often have to face challenges that educators of liberal arts are likely to be spared of. Developing an understanding of science-as-practise and show how scientists co-operate with each other and with lay stakeholders for a common goal in research and development often involves identifying controversies in how science is produced and applied, and sophisticated presentation of the risks of never fully predictable technological and social outcomes. Students should appreciate science as a human endeavour and construct with its limitations, constraints and opportunities. Vivid discussions that characterised the conference sessions where teachers faced researchers whose findings they were supposed to interpret at school, showed concern on both sides to promote evidence based policy making through educating the young to understand and appreciate scientific endeavours. The *inquiry-based model of Physics education that* has been the dominant Hungarian educational paradigm for decades, kept reoccurring during the conference. Detecting problems, developing hypotheses and predictions, collecting and interpreting data and communicating results: this model is based on experience of scientific procedures and ethics and is therefore a solid foundation for s*ocially responsible science education*.

Andrea Kárpáti
on behalf of the Hungarian PARRISE
project team

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I. INQUIRY BASED SCIENCE EDUCATION

BRINGING SPACE SCIENCE TO LIFE WITH MOBILE APPS, SPACE AGENCIES AND HOLLYWOOD

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ABSTRACT

Some media for teaching space science and astronomy are introduced to show how they can provide a hook for gaining interest as well as providing authentic physics instruction. Four specific examples are chosen: smartphone star-gazing, the use of European Space Agency earth-monitoring satellite data, NASA exoplanet exploration and clips from some recent Hollywood films.

INTRODUCTION

Astronomy and Space Science sit on the edge of many Physics curricula, an option rather than centre-stage. However their appeal to young minds is strong and growing with the advent of new space missions to discover alien life, dark matter, the origin of the universe, etc. The possibilities for school-based experiments in this area may seem limited. A little imagination and stretching of the school experiment concept reveals what can be done to engage secondary students in a very active way.

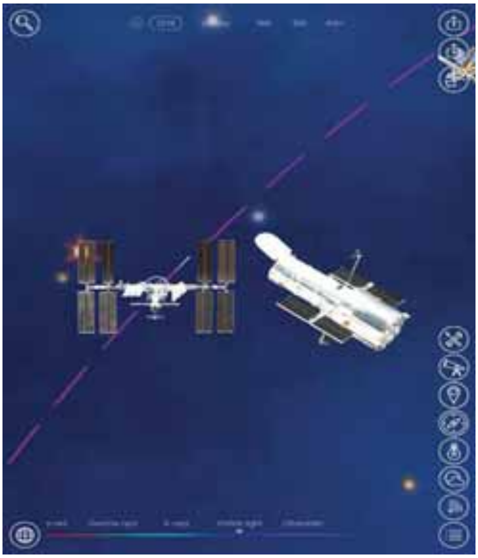

Fig.1. Screenshot of Night Sky Lite mobile application showing the real-time path of the International Space Station, ISS (dashed line) and the position of the Hubble Space Telescope

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* *Editorial note: the author was invited to give a keynote lecture at TPI-15, but unfortunately was unable to attend. We are happy to publish the written version of his talk here.*

APPS FOR ASTRONOMY

Night-school would have been a good option for the astronomy teacher. The unfortunate obstacle to astronomical fieldwork for day-school students – where lessons are given during daylight hours – is easily surmounted with the student's smartphone: simply download one of the many gps-enabled star-watcher apps and you have in your hand a tool to see the stars behind the glare of blue sky or cover of grey cloud. Orientating a phone loaded with free or a low-cost app such as "night sky" [1] allows the student to view planets, stars, galaxies and satellites as if in their actual positions. Immediate access to information about a plethora of astronomical objects is granted. This accessible tool gives an excellent starting place for the various topics studied in secondary school astronomy. For example, the topic of orbital path may be approached via discussion then location of the International Space Station. The app reveals real-time position and orbital path of the ISS in the sky. Fig.1. shows a screenshot of this app, tracking ISS with Hubble very close by. For older secondary students, orbital speeds may be estimated, then orbital altitudes.

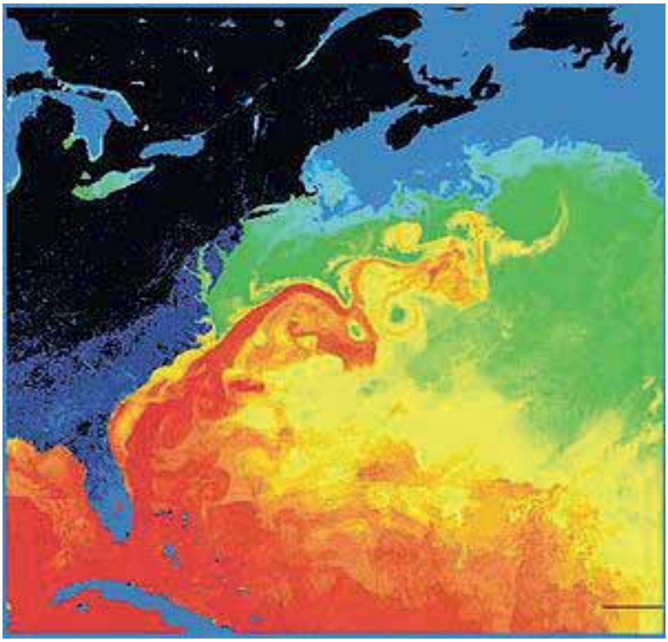

Fig.2. Composite image of the sea surface temperature of the Atlantic Ocean (the continent of North America and Cuba in dark colors) which can be analysed by ESA softwares

USING SATELLITE DATA

For students with a stronger interest in the human condition, we can look the other way, down from space to observe Earth. The European Space Agency (ESA) allows access to data from its fleet of earth-monitoring satellites. Students may download a software tool, "Leoworks" [2], in order to analyse the data. The ESA education department produces tutorials [3] to guide students through image analysis in a range of contexts. As an example we look at a set of images of the Atlantic Ocean taken in infra-red over a six month period. Fig.2. shows one such composite image for one month in 2012. Wavelength is related to sea surface temperature and colour-coded in the images, approximate range blue 275K to red 300K. Thus ocean currents and seasonal changes are made visible.

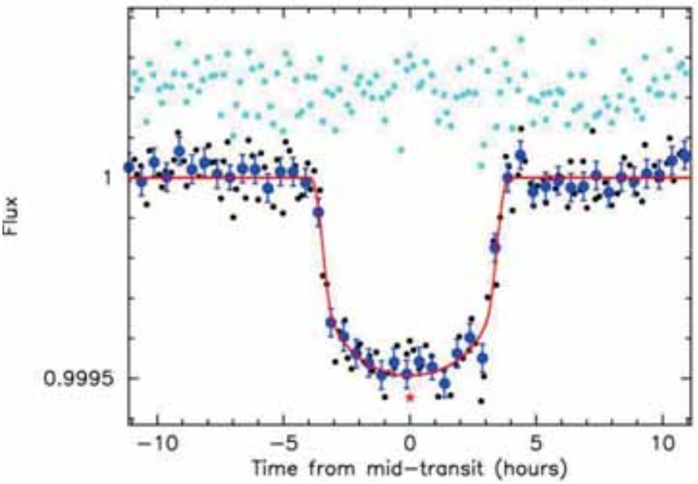

Fig.3. A centered transit light curve of Kepler-22b (dark blue dots), the first known exoplanet in the habitable zone of a Sun-like star. Light blue dots indicate the difference between the measured data and the fitted light curve (red line) on arnitrary scale.

PLANET-HUNTING

With the launch of the Kepler planet-hunting space telescope in 2009, the science fiction of other worlds has been brought crashing into science reality. The hard data beamed down from Kepler makes splendid material for the imaginative astronomy student. NASA provides tutorials [4] to get students started on analysing the light curves of stars as their planets transit, the tiny dips in brightness of the star being the starting point for a detective-trail to discover the nature of these other worlds. Although not yet appearing in many syllabuses, exoplanet work allows a new perspective on standard schoolwork about our own solar system: discussion of the “Goldilocks Zone” and a link with life sciences through criteria for habitable planets. Fig.3. shows a processed light curve for the famous Kepler 22b, the first known exoplanet in the Goldilocks Zone of a Sun-like star. Students may use measurements from such light-curves in detective work to deduce more information about the planet.

USING FILM CLIPS

Space has always been a popular theme for Hollywood. With the border between science fact and science fiction always on the move and the familiarity of students with this medium from the ease of online access, there are increasing possibilities to make good use of these films in science lessons. Whether it is true-to-life drama as in the rescue of the Apollo 13 mission (Fig.4.) or more speculative cinematography such as the visual representations of black holes as in “Interstellar” (Fig.5.), by careful selection of appropriate clips we can tease out physical principles. There are many good examples, but 2 suffice here.

Fig.4. Screenshot from the movie "Apollo-13" [Universal Studios]

First the 1995 Universal Studios film “Apollo 13” [5] for which a series of short clips is readily available online. The clips suffice both to indicate the plot and to give a sense of the growing tension of the rescue mission. A “problem-solving” lesson may be constructed whereby class viewing of the clips is interspersed with sessions where short problems related to each clip are posed for the class groups. The problems cover a range of topics such as simple kinematics, fuel consumption and current electricity via battery life. Fig.4. illustrates such a possibility with the clip in which Ground Control solve the problem of fixing the CO_2 scrubbers with limited materials.

Fig.5. Screenshot from the movie "Interstellar" [Warner Bros]

A second example is furnished by the 2014 Warner Brother’s film “Interstellar” [6], a film in which the astrophysicist Kip Thorne [7] was intensively involved in order to sustain the scientific integrity of the more speculative aspects of black-holes, worm-holes and time-travel! Again, via a series of short clips, a lesson may be constructed that satisfies young people’s thirst for discussion of matters at the very borders of scientific enquiry whilst still fulfilling some curricular requirements. Younger students may be posed simple physics calculations (density, gravitational field strength and weight, speed, distance, time) and older students may consider the problems thrown up by planets orbiting black holes. In Fig.5. the interstellar crew have arrived on the watery “Miller’s Planet”, in orbit around a black hole. Time dilation is huge, local gravity is 130% of Earth’s.

CONCLUSIONS

These four examples of how relatively new media may be used in the secondary school Physics classroom are the tip of the iceberg of possibilities for engaging young minds with this area of the curriculum. Although some imagination and time is required for teachers to design the lessons and starting points for projects, help is at hand from space agencies and app developers. The benefits for student motivation and enthusiasm far outweigh the investments.

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COLLABORATIVE, ICTS SUPPORTED LEARNING SOLUTIONS FOR SCIENCE EDUCATION BASED ON THE SSIBL FRAMEWORK

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ABSTRACT

PARRISE ("Promoting Attainment of Responsible Research and Innovation in Science Education", 2014-17) is a project of the 7th Framework of the European Union, involving a transnational community of science teachers, trainers, communicators, and curriculum experts from 18 institutions in 11 countries. Its major objective is to engage young people in learning science through experiencing its societal impact. The paper introduces the educational framework for socio-scientific inquiry-based learning (SSIBL) and shows results of its implementation in a teacher professional development course series at ELTE University, Faculty of Science, to enhance the pedagogical repertoire and increase affective components of science literacy of teachers.

INTRODUCTION

In Hungary, student performance in national as well as international science surveys keeps declining while best students still excel at International Student Olympics and other competitions. Educational efforts seem mainly to target high performers and transmits knowledge and skills necessary to embark on a scientific or technological career. We hope to modify this situation through developing an awareness in science teachers towards socially relevant issues – an aspect that is emphasized as increasingly important all over Europe, according to a recent study by the European Commission [1]. When engaging in socially relevant topics, a wider range of students may be motivated to learn science and eventually become a better informed and more engaged citizen.

We joined the EU-supported *Promoting Attainment of Responsible Research and Innovation in Science Education (PARRISE)* project to take part in the development and adaptation of its new framework in collaborative, ICTs-supported learning environments for use for establishing new in-service training programs for Physics teachers. Our major objective is to provide alternatives for traditionally hierarchical, driven by methods transmission in-service training and create a network of knowledge-builders –a community of teachers supported by resources shared through digital technology (the Moodle e-learning environment and social computing tools). A training course for experienced and innovative teacher communities like those applying for admission to one of Hungary's leading research universities, seem to the best environment for presenting and adapting new models through networked learning methods [2]. In this paper, we introduce the SSIBL concept and show how it is being used for the professional development of Hungarian teachers.

THE SSIBL FRAMEWORK: A NEW MODEL FOR INTRODUCING RESPONSIBLE RESEARCH SCIENCE EDUCATION

The SSIBL Framework is being developed by the PARRISE project, a European community of science teachers, teacher trainers and educational researchers whose actitivies centre on integrating current issues of science and society at school. Through experiencing the societal impact of research and innovation, this approach intends to increase the agency and motivation of young people for pursuing studies in science. By becoming more scientifically literate, young citizens are better equipped to participate in the process of science innovation. PARRISE also intends to improve pre- and in-service science teacher education through sharing best practices of professional development for primary and secondary teachers in Europe.

The project objectives are as follows (cf. [3] for details and publications):

1. Provide an overall educational framework for socio-scientific inquiry-based learning (SSIBL) in formal and informal learning environments;
2. Identify examples of best practice;
3. Build transnational communities consisting of science teachers, science teacher educators, science communicators, and curriculum and citizenship education experts to implement good practices of SSIBL;
4. Develop the SSIBL competencies among European primary and secondary science teachers and teacher educators;
5. Disseminate resources and best practice through PARRISE website, digital and print-based publications online and face to face courses authored by national and international networks;
6. Evaluate the educators' success using the improved SSIBL materials with pre-service and in-service teachers.

The project team collects and shares existing best practices in European science education and develops learning tools, materials and professional development courses for based on the SSIBL approach. *Socio-Scientific Inquiry-Based Learning* (SSIBL) is meant to address the need for a heightened awareness of the role of research in contemporary society through expanding teachers' perceptions about the aims and objectives of science education. The model is based on the concept of Responsible Research and Innovation (RRI).

> *"At the moment, Europe faces a shortfall in science-knowledgeable people at all levels of society and the economy. Over the last decades, there has been an increase in the numbers of students leaving formal education with science qualifications. But, there has not been a parallel rise in the numbers interested in pursuing science related careers nor have we witnessed enhanced science-based innovation or any increase in entrepreneurship. Science education research, innovation and practices must become more responsive to the needs and ambitions of society and reflect its values. They should reflect the science that citizens and society need and support people of all ages and talents in developing positive attitudes to science. We must find better ways to nurture the curiosity and cognitive resources of children. We need to enhance the educational process to better equip future researchers and other actors with the necessary knowledge, motivation and sense of societal responsibility to participate actively in the innovation process" [4].*

The SSIBL framework [5], [6] connects RRI with three pedagogical concepts. *Inquiry-based Science Education* (IBSE): this model has always been at the core of Hungarian Physics education, and is being gradually adapted by other science disciplines as well. It focuses on empowering students to act as researchers and them not only facts also problems and solution scenarios to experiment with. Case studies, field-work, investigations in the school laboratory or even complex or research projects can be involved in this educational approach. Teachers who employ it believe that ideas are fully understood only if they are constructed by students through reflections on their own experiences. For STEM (Science, Technology, Engineering and Mathematics), this approach is especially important, but may be successfully used in the arts and humanities as well (EC-FP7 projects promoting an IBSE approach are, for example, PROFILES, SAILS, Pathways, PRIMAS or Fibonacci) [7]. This model has proven useful also in teacher professional development [8].

Socio-scientific Issues (SSI) are open-ended science problems which may have multiple solutions. Most of them involve controversial social issues as well, which are closely connected to research and innovation in science. SSI may be successfully utilised in science education to enhance the ability to apply both scientific and moral argumentation and develop solutions in relation to real-world situations like climate change, genetic engineering, advertisements for increased consumption of unhealthy food, animal testing for cosmetic purposes, or the use of nuclear power as cheap and clean energy resource. SSI is highly efficient in promoting scientific literacy and increasing students' understanding of science in various contexts. Involvement with controversial scientific issues also enhances argumentation skills and, through developing empathy, contributes to the acquisition of moral reasoning.

Citizenship Education (CE): “can be defined as educating children, from early childhood, to become clear-thinking and enlightened citizens who participate in decisions concerning society. ‘Society’ is here understood in the special sense of a nation with a circumscribed territory which is recognized as a state” [9]. It involves an awareness of the rules of law and other regulations that concern social and human relationships. CE also provides an orientation for the individual on ethics the rights inherent in the human condition (human rights); and those that are related to being the citizen of his country, civil and political rights recognized by the national constitution of the country concerned. Recent research on citizenship education in science shows that focusing on civil rights and responsibilities can be efficiently integrated with teaching about responsible research and innovation [1]. The interrelations of these four pillars of the model are represented in Fig.1.

Fig.1. The Socio-Scientific Inquiry-Based Learning (SSIBL). Source: [6]

METHODOLOGY

In our first teacher professional development (TPD) course for teachers of Physics, based on the SSIBL framework and delivered in the second half of the academic year 2014-15, we organised a networked system of learners who developed active, collaborative agency around shared knowledge objects, according to the trialogical model of learning [10]. Teachers as knowledge builders worked and learnt together in a mentored innovation setting [11]. This setting is meant to introduce teachers new methods through investigating their pedagogical needs and offering new strategies that suit them best. The learning triangle involves the teacher as learner and peer tutor at the same time, a mentor who also acts as role model for teaching and research, and a knowledge object: in our case, a new learning unit to be developed (Fig.2.).

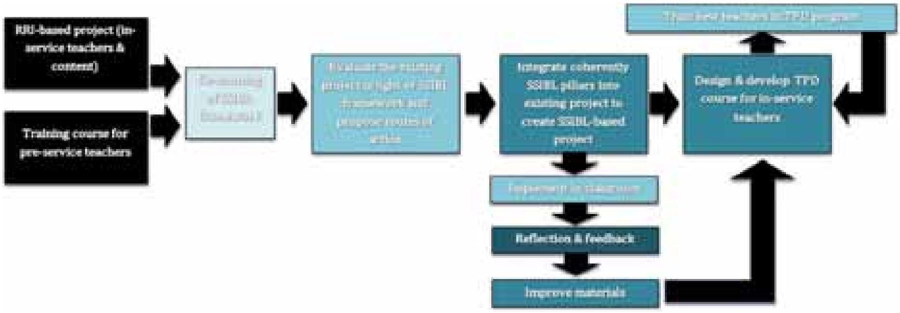

Fig.2. Model for the Hungarian in-service teacher training program based on the SSIBL framework

One of the goals set for the teacher network was to investigate a socially sensitive scientific domain, namely, the use of nuclear energy. We used the Moodle e-learning environment for sharing good practice and discuss issues of adaptation, and also employ social computing (Web 2.0) tools like science blogs and interactive science portals – a format especially important to meet changes of science media consumption [12].

Teachers were expected to introduce the SSIBL framework in their teaching as they felt most appropriate (in the form of an interdisciplinary lesson, a project week, an informal learning opportunity in a science centre or museum, or in a lesson sequence addressing socially sensitive research issues). TPD participants delivered a pedagogical essay and digital teaching materials on strategies of teaching about one of the four main subject areas of the course: modern physics, microphysics, astronomy, and chaotic dynamics and manifest how they adapted the educational framework explained in this paper. Community driven inquiry learning based on progressive inquiry and collaboration was especially suitable for involving students in disputed, social issues related to science [13]. The four pillars of SSIBL were employed in structuring course content:

1. RRI: traditionally, scientific discoveries are described as a final product of research. In this course, they were presented as *an interrelated complex of research endeavours and relevant social processes*. First, the conception of the research idea and (potential) social needs manifest in it was presented, then phases of the research where social issues were at stake were highlighted. Finally, a discussion of related innovations that raised social issues.

2. IBSE: *presentations were followed by experimentation,* where teachers acquired new scientific investigation skills. For example, they learnt how to apply information and communication technology (ICTs) tools for modelling processes and exploration of data. Teachers were also informed about still unresolved issues and encouraged to enhance student skills to develop different explanations.

3. SSI: most of the topics included in this course have *high social relevance for Hungary* (e.g. the generation and use of nuclear energy, “Big Bang” and Creation “theories”, the butterfly effect and other naïve beliefs and scientific explanations, etc.). Media

coverage of these issues were discussed and the moral implications of science communication – a field bordering on science education – was revealed.

4. CE: teachers were expected to act like responsible citizens (and trainers of such) and identify connections among current research in the field of Physics, critically reflect on curricula and propose means for future improvement, involving the inclusion of the results of New Physics.

CONCLUSIONS

The first iteration of the course, with nuclear energy and related social issues in focus, suggests improved social skills and heightened interest in the public understanding of science and research based policy making – both necessary for developing responsible researchers and citizens as well. We hope to have *introduced social and ethical concepts* that promote teachers' reconceptualization of their teaching content and do beyond teaching, towards the education of morally responsible, ethics-driven citizens [14]. Teachers have retooled their teaching processes through the *employment of ICTs solutions* as simulations, measuring tools or communication devices that facilitated the creation of an interactive science education environment. ICTs solutions should not replace real life experiments, but are inevitable for widening access and also for introducing experiments that were impossible to deliver otherwise in a classroom setting.

A second iteration currently undertaken centres around climate change – another crucial issue for Hungary where agriculture is a major factor in national economy. In this iteration, we intend to *increase the collaborative aspects* of our TPD. Collaborative knowledge building in teacher education is planned to relate to learning that occurs partially in an informal setting, the Moodle virtual learning environment that supports situated cognition and situated learning in knowledge building communities. In its ideal form, such a collaboration involves the mutual engagement of learners in a coordinated effort to solve a problem together or to acquire new knowledge together [15]. We intend to use cooperative learning methods based on cognitive apprenticeship that result in knowledge-building communities that offer peer tutoring and support [11]. In these collaborative learning models, mature communities of practitioners participate in inquiries at the frontiers of knowledge. Their activities with their mentors during the TPD process will be characterised as a transformative communication for learning.

Through collaborative methods [16], we hope to embed social issues relating to science in Physics education while retaining its major merit: its hands-on, experiment-based character. We also hope to empower Physics teachers to realise the goals of *The Framework for Science Education for Responsible Citizenship*. Its 5th objective: "Greater attention should be given to promoting Responsible Research and Innovation (RRI) and enhancing public understanding of scientific findings including the capabilities to discuss their benefits and consequences", Its 6th objective: "Emphasis should be placed on connecting innovation and science education strategies, at local, regional, national, European and international levels, taking into account societal needs and global developments" [1]. Both are in line with the SSIBL Framework and the methodological repertoire currently under development by an international team with the membership of the authors of this paper.

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HANDICRAFT AND AESTHETIC EXPERIENCE IN TEACHING CHAOS PHYSICS

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ABSTRACT

Our aim is to raise awareness of the importance of getting acquainted with chaos physics in the frame of teaching modern physics. We would like to present a good practice of a series of lessons with a focus on handicraft activities. Apart from raising interest, experiencing the joy of creating something, the activities may help students understand and deepen their knowledge of chaos physics.

INTRODUCTION

We examined the opportunities of getting acquainted with chaos physics within the framework of secondary school physics education, as I presented in a Hungarian language article [1]. We researched the methodology of inserting chaos physics within the secondary school curriculum, presented chaos experiments, introduced IT opportunities and also reviewed the use of art as a ’motivational tool’.

In this article we present how art workshops inserted in a series of chaos physics lessons are capable of raising interest in physics and the chaotic phenomena within thereof, and shall provide opportunity to explore the features of chaos. Our aim is to raise awareness of the importance of getting students acquainted with chaos physics within the framework of modern physics education, we shall provide ideas thereto and present some good practices.

We encounter chaotic phenomena not only in our everyday life [2], but also in nature: at the change of ocean plankton colonies in space and time (see e.g. [3]); or fluid layers mixing in turbulent sea, or in meteorology [4] the spread of clouds of pollutants. We can also take the shooting stars across the sky at summer nights as examples, which trace out the final phase of the chaotic motion of small asteroids. Another example can be the oscillation of the heart and brain activity, or the oscillating chemical reactions.

As we notice, chaotic motion is not exceptional but typical. It is the complex behaviour of simple systems [5]. The main characteristics of deterministic chaos are: the equations describing the motion are known; these equations are nonlinear; the motion is irregular and unpredictable; there is order in the phase space: the fractal [6] structure. As these phenomena are so typical for physics and everyday life, chaos physics should belong to the physics curriculum.

THE PLACE OF CHAOS PHYSICS IN SECONDARY SCHOOL PHYSICS EDUCATION

In a former research we investigated how the possibility of teaching chaos physics may be implemented in secondary school physics education [1]. We examined two education systems: a Romanian model and a German model. Teaching the elements of chaos physics is part of Modern Physics in the examined Romanian model, whereas similar elements are integrated in the relevant chapters in the other model.

Chaos physics can be defined as modern physics in a non-conventional sense. Currently, chaos physics is not part of the official documents of the Hungarian secondary education. In a series of lessons, we examined the possibility of implementating chaos physics and our recommendation was given in a syllabus prepared on the basis of the national curriculum (NAT): we concluded that it should be connected to topics related to environmental physics. We may encounter several environment-related topics within the syllabus, which is rich in terms of different phenomena; however, the depth of understanding is rather low. We think that chaos physics should have an important role in the preparation and academic founding of these topics.

I have developed a teaching unit that I have implemented in different classrooms. This unit includes complementary contents to the already existing curriculum. As a first step the teacher familiarizes students with chaos theory and its characteristics throughout simple mechanical examples (e.g. magnetic pendulum, double pendulum, double slope [6]): the unpredictability, the order appearing in phase space, the fractal structures. As a second step, students are familiarized with mathematical fractals. As a next step the teacher demonstrates that fractal structures become visible during chaotic mixing. Students can observe fractal patterns during mixing (mixing cream in coffee, syrup in water, ink in water, or during mixing different paints). The main hands-on activity of this teaching unit is marbling. During handicraft activities students experience the process how patterns develop. After the hands-on activities we return to the topic of environmental flows. Students will be able to recognize similar patterns when encountering environmental contamination.

The method of inquiry-based learning is applied. Inquiry-based learning includes problem-based learning. Most of the PBL-defining characteristics listed by Schmidt [7] appear during the teaching process I implemented: problems are used as an activator for learning; students co-operate in groups for part of the time; learning takes place under the supervision and guidance of the tutor; this curriculum of chaos physics consists of a limited number of lessons. In certain situations learning is student-initiated, and we often provide time for self-study.

It is important to know what competencies the students develop while getting acquainted with chaos physics. Cooperation among the students is improved with team work. The group activity provides a good platform for collaboration and the development of friendships among students in addition it facilitates making closer contacts between the students and the tutor [7]. The interdisciplinary concept of the students is largely strengthened during these lessons. On the one hand, the aesthetic experience is suitable to raise interest and to motivate, whereas the classroom activity itself develops visual and aesthetic viewpoint. The students have the opportunity to observe, compare and interpret the phenomenon. Their competency of thinking in pictures is developed; they will be able to recognise similar patterns in different situations. It is very important to note that these are not fictional and virtual pictures, but pictures occurring in nature.

WHY SHOULD WE USE HANDICRAFT TO FAMILIARIZE STUDENTS WITH CHAOS PHYSICS?

In the above-mentioned series of lessons handicraft activities play an important role. The reason for this is the peculiarity of chaotic mixing. Fractal structures always appear in chaotic processes, but regularly in an abstract space, in the phase space [5], therefore they do not become visible under direct observation. Chaotic mixing, for example the spread of contamination in a drift, or the cream poured in the coffee, the mixing of paints, is an exception. In these cases fractal structures become visible also in real space. This is the reason why we have chosen to utilize it in teaching chaos physics with the aid of handicraft. The photo in Fig.1. shows an example of chaotic mixing pattern: oil on the surface of water.

Fig.1. Oil on the surface of water (Photo: Traian Antonescu)

APPLIED TECHNIQUES (BASED ON CHAOTIC MIXING)

The following handicraft activities have been involved in teaching: painting paper, candles and eggs with marbling technique. The most important technique is marbling [8], which is chaotic mixing in two dimensions.

The steps of marbling technique are the following: 1. Small amounts of two or three different marbling paints are poured on the surface of water. 2. Marbling paint is mixed (Fig.2.a)) presents the mixing of paints). 3. A sheet of paper is placed on the surface. 4. The sheet is flattened against the surface using quick but definite movements so that it can get in full contact with the surface and the paint as Fig.2.b) indicates. 5. The sheet is grabbed and lifted up carefully as it is shown in Fig.2.c). 6. As a result, marvelous fractal structure becomes visible with nice Cantor-filaments.

Fig.2. a) Mixed paints on the surface of water, b) Sheet flattened against the surface of water, c) The painted sheet lifted, fractal filaments become visible on the paper

HOW HANDICRAFT ACTIVITIES HELP STUDENTS UNDERSTAND THE ESSENCE OF CHAOS

Chaotic mixing is the most essential, the most familiar and the most spectacular phenomenon of chaos. In one of the introductory classes we examined the spread of a paint drop or a drop of contaminant in a tank with two drain holes which is also an illustration of chaotic drifting. It is surprising that the drop changes its original shape in a very short time in a way that a well-defined fractal structure becomes visible meanwhile each particle describes its own chaotic path [6]. This structure is very similar to the patterns made by the students during the handicraft activities. Therefore, the aesthetic experience during handicraft activities is suitable to raise interest and to motivate students.

During painting with marbling technique students have the opportunity to gain experience with chaotic mixing phenomena. It is a guided experience: they observe with attention for the first time how fractal structure evolves during chaotic mixing. In Fig.3.a) we can see paints on the surface of water, which is actually the result of chaotic mixing, in Fig.3.b) we can see a part of a fractal filament patterned sheet made by the students. This is the imprint of chaotic mixing, which makes students understand this aspect of chaos physics.

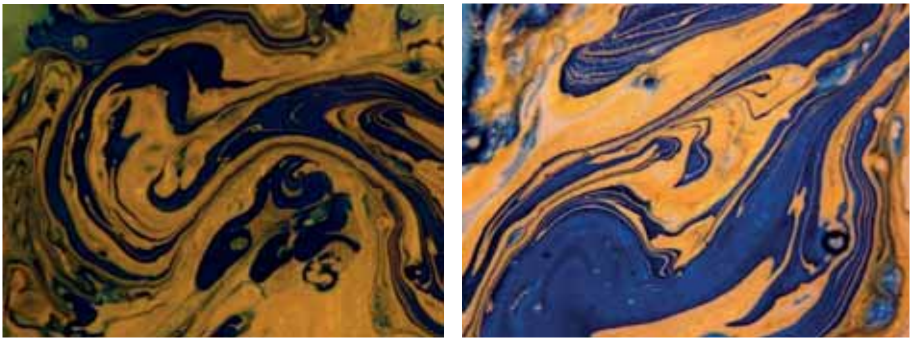

Fig.3.a) Paint on the surface of water: chaotic mixing, b) Fractal filament patterned sheet: imprint of chaotic mixing obtained by the students with marbling

Structures similar to the fractal structures that become visible during the marbling activity appear in environmental flows, for example in the case of spread of contaminants. Students have the possibility to compare the pattern of their pieces of arts and the pattern of oil contamination on the surface of water (Fig.4.a)) or the pattern of foam pollutants before the dam as we see in Fig.4.b).

Fig.4.a) Oil contamination on a puddle (photo by Antonescu Traian),
b) Foam pollutants before a dam (photo by György Károlyi)

We aim to enhance students' competence of thinking in pictures: they will be able to recognize similar patterns in different phenomena. It is very important to note that these are not pictures of a virtual world, but patterns occuring in the natural environment.

The interesting experience related to the phenomenon will motivate students to get more deeply involved in the subject: if the experience is interesting, it will raise the curiosity of students to develop a computer program to model the phenomenon. This experience might raise motivation in students to gain the knowledge required for a deeper understanding of the phenomenon.

PAINTING EGGS, CANDLES AND PAPER WITH MARBLING TECHNIQUE

Other handicraft activities related to chaotic processes are the painting of eggs during Easter and the painting of candles during Christmas time. The steps of painting eggs are the following: 1. A stick is fixed inside a white egg so that it stays stable (blown eggs, or white plastic eggs are used); 2. The egg is fully immersed under the water. 3. Small amounts of paint (two or three different colors) are poured on the surface of water then mixed in order to have a beautiful pattern with fractal filaments. 4. The egg is taken out immediately but very slowly so that the paint is evenly distributed on its surface. 5. Care should be taken while drying the eggs (as you can see in Fig.5.a). As a result, marvelous fractal structures become visible with nice filaments as can be seen in Fig.5.b).

Fig.5.a) Drying the eggs, b) Fractal-patterned Easter eggs made by students

Before Christmas we paint candles with Cantor-filaments. The steps of painting candles with marbling technique are similar to that of painting eggs (Fig.6.).

Fig.6. Candles with fractal filaments painted before Christmas

CONCLUSIONS

The summary of the teaching unit described above that I have implemented and I find worth sharing is the following: First the teacher talks to students about chaos theory, the order appearing in phase space, the fractal structures. Then, students are familiarized with mathematical fractals. As a next step the teacher raises students' awareness that fractal structures become visible during chaotic mixing. Students have the chance to observe fractal patterns during mixing. During appealing handicraft activities students experience the process how the patterns develop and connect handicraft with chaotic phenomena.

The benefits of the teaching method can be summarized as follows:

Firstly**,** handicraft activities are suitable tools for raising students' interest in physics, more specifically in chaotic phenomena. Marbling gives opportunity to get to know the characteristics of chaos.

The fact that the interest of students has been successfully raised is proven by the number of students choosing chaos physics for their school project after participating in my chaos physics lessons, even students who are not considering to continue their studies in physics. Another indication is that several students have chosen fractal geometry or chaos physics as the topic of their optional presentation at physics class.

Apart from raising interest, hands-on activities are motivational tools for students who desire to obtain deeper knowledge of the chaotic phenomena, who would like to be able to mathematically describe the system or write a computer program for the simulation of the phenomenon.

Secondly, as we have already mentioned above, the aesthetic experience during handicraft activities is suitable for raising interest and motivating students. At the same time the handicraft activity in class, creation itself develops the visual and aesthetical view of students. Creating works of art, the process of mixing and experiencing the development of the pattern help to deepen students' understanding, and develop among others the competence of thinking in pictures. Aesthetic experience in class increases motivation in everyday school life.

Thirdly, we experienced that the students' interdisciplinary concept is largely strengthened during these lessons.

Finally, an important benefit related to the IBL method is the group collaboration where a platform is created for the development of friendship among students and the teamwork facilitates close contacts between students and tutors [7].

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LEARNING KINEMATICS THROUGH ANALYSING PHYSICS IN MOVIES

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ABSTRACT

In order to increase students' motivation of learning kinematics at senior pre-university education in the Netherlands, we developed and tested a series of five lessons in which movie scenes were used. Students had to analyse whether a spectacular stunt from a movie scene could be performed in reality. Gradually students developed conceptual and procedural knowledge and learned how to establish the physical accuracy of these stunts. However, not all conceptual knowledge was firmly rooted, and cohesion between different concepts was still missing. Therefore we advise to incorporate the analysis of physics in movies in regular lessons to increase motivation and learning outcomes.

INTRODUCTION

At the 'International Conference on Teaching Physics Innovatively 2015' (TPI-15) it became clear that Hungary has a decreasing amount of students interested in choosing science, or more specifically physics, as major subject. Due to a limited budget, teachers as well as researchers have to be innovative to reach a large audience. Next to that, popularization of science subjects has to go hand in hand with an educative component: Education should be fun but instructive as well. Dutch physics teachers face similar problems as students do not relate the different subjects covered in the physics course with their everyday life. They question why it is important to learn e.g. mechanics. This study investigates the benefits of analysing movie scenes in physics class where we try to link the three components mentioned: increase students motivation by introducing a practical and recognizable problem with an educative component.

Originating from lessons in which I used movies, cartoons and bloopers, a series of five lessons was developed in which students inquire the accuracy of movie stunts: Are the stunts potentially real? The initial idea was to let students, working in small groups, investigate the physics in movie scenes. Although the teacher should not intervene, some help could be provided using questions in worksheets. It was thought that intrinsic motivation, driven by students' curiosity, should be enough to let students develop or gain the necessary knowledge to find a solution to the problem and by doing so learn kinematics. Accordingly, the research question that arose was: *To what extent are students able to develop kinematic concepts based on the analysis of movie scenes?* While motivation is a key factor for success in this approach, known as a problem-based learning approach, the second research question that arose was: *Which components of the chosen approach are appreciated by the students?*

As this is a first exploration in a cyclic process (design research, [1]), a large quantitative study is unsuitable. Therefore we chose a small qualitative study in which small groups of students were intensively monitored. The outcomes of this study reveal whether it makes sense to further develop this teaching strategy.

THEORY

At the heart of science lie the inquiries in which existing knowledge is used and new knowledge is acquired. Inquiries in which students work in small groups on problems where they still lack the prior knowledge to solve the problem directly is known as a problem based learning (PBL) approach [2], [3]. By investigating and discussing the various problems, the necessary knowledge to answer the questions is developed along the way [4]. This creates a shift in responsibility for learning: The teacher does not tell students the relevant information but the students investigate themselves what is necessary to know to solve the problem. This approach is often used at university level with medical students. However, not much is known about the potential success of this approach at secondary school level. Still this approach can be useful as many benefits are known to exist, among them [2],[5],[6]: (1) PBL aligns with how people learn science; (2) PBL stimulates active engagement and responsibility for one's own learning; (3) PBL fosters the acquisition of lifelong learning skills; (4) PBL increases problem solving abilities; (5) PBL motivates students to learn; (6) PBL improves conceptual learning; (7) PBL positively changes students' attitude and interest in physics.

However, opponents of this approach suggest that this teaching method leads to incomplete and disorganized knowledge. Students can acquire misconceptions [7]. It is questioned whether there is any room left for students to inquire themselves and students often lack motivation to continue an inquiry for longer times. So the question is whether this approach is suitable for less independent secondary school students.

One way to motivate students is to use movies, as these tend to appeal to a large audience. This certainly follows from the fact that students spend more and more time in front of the TV [8]. We could use this interest to teach physics as many physical phenomena can be seen in movies and even physical phenomena which cannot be seen in everyday life are produced within movies [9]. Many examples of using movie scenes have been mentioned in e.g. '*The Physics Teacher*' [10], [11]. Questioning whether the shown event is potentially real could arouse students' curiosity. This question is answered in many different ways by several TV programs such as '*The big bang theory*' and '*MythBusters*' to involve the viewers [12], [13]. Whether it is possible to use the same approach to bind students to the various science subjects for a longer time and instantaneously teach them to solve problems, remains a question for now.

Next to the potentially appealing way physics is presented, the visualisation of physical phenomena can also enhance student learning as they are able to see the phenomena over and over again, analysing them in detail. In this way, the mathematical equations for e.g. parabolic orbits, difficult for students, could come to life and could gain meaning and relevance to students. This could support them in a further analysis of the physics involved.

METHOD

In this design research we investigate possible affectional effects and the development of procedural and conceptual knowledge through analysing kinematic phenomena in movie stunts using a PBL approach. In order to do so, we developed a series of five lessons using recommendations on conceptual development in physics teaching and strategies for effective use of a PBL approach.

This series of lessons was tested in a single 5 VWO class (senior pre-university education) of 18 students. These students (aged 16/17) were divided into groups of three to four persons with the same academical abilities. Three groups were video recorded, the other two groups were audio recorded. After each lesson transcripts were made and subsequently students' activities, including chosen solution strategies and given answers, were analysed. In addition, we studied the development of kinematical concepts during the small group discourses. In order to do so, first the different kinematical terms were highlighted and subsequently we investigated how these terms came forward: e.g. by discussing or questioning and whether these terms were given the right interpretation of physical meaning.

DESIGN

A literature study on the use of an effective PBL approach in class yielded many recommendations. A PBL problem should at least [5,6,14]: (1) not have a single solution or solution strategy; (2) be authentic, concrete and have value; (3) match the students' level of prior knowledge; (4) engage students in discussions (5) lead to the identification of learning issues; (6) stimulate self-directed learning and (7) be interesting to students. As we use a PBL approach in a physics class, recommendations on effective physics teaching should be used in the design as well. Knight [15] summarizes that physics lessons are more effective when: (1) students are actively engaged; (2) lessons focus on phenomena rather than abstractions; (3) students have to explicitly deal with alternative conceptions; (4) students develop problem solving skills and strategies and (5) problems with a quantitative and qualitative character which go beyond symbol manipulation are used. The combination of these 12 recommendations has led to a series of lessons where:

1. Forrest Gump [16] is running across the countryside at a constant speed. In various instances, his speed can be determined and compared with that of an average jogger, showing that he is fairly slow. Students' prior knowledge was activated (uniform linear motion) and they gain experience in using the interactive whiteboard (IWB) in combination with movie scenes.
2. Criminal Bohdi is chased by agent Johnny [17]. With a 15-second interval they jump out of an airplane. Still Johnny overtakes the felon in mid-air by minimising his frontal area. Again, prior knowledge (free fall) was activated but their knowledge was extended by introducing friction.
3. Trinity [18] escapes from agent Smith by jumping from one building to another across a two-way street. Her trajectory is fairly well shown in slow-motion, making a proper analysis of the jump possible and therefore this lesson served as start on projectile motion, where step by step the independency of motion in horizontal and vertical direction was introduced.
4. Four boys find themselves trapped with their car at a collapsed bridge, see Fig.1. [19]. They dare to jump across as one is certain that physics tells them it is possible to do so. They get across, although the car disintegrates. All necessary variables (and more) to solve the problem are mentioned in the conversation between the boys. Therefore, this lesson served as a practice on the topic of projectile motion.

Fig.1. The car jump in Road Trip (2000)

5. Raines escapes from the police by jumping over a bunch of stationary cars using a ramp loader at 100 mph [20]. All necessary variables to analyse the jump are 'hidden' in the scenes, students had to find these variables. This lessons served as a formative assessment where students showed their gain in procedural and conceptual knowledge during the series of lessons.

Questions in the worksheet served as stepping stones. Although these questions provided some help, there was enough room to discuss and inquire the different kinematical concepts.

RESULTS

As students worked in small groups, in each lesson and with each question a same process of inquiry was observed. We call these phases of inquiry: the *orientation phase*, the *analysis phase*, and the *solution phase*. These phases are elaborated consecutively.

In the *orientation* phase students discussed what the actual problem was and how to, qualitatively, describe the event shown in the movie, i.e. they made the problem understandable for themselves. In this phase, kinematical terms automatically came forward, although these were not always given the right physical meaning, as the following excerpt from lesson 2 shows, where students S1-S3 discuss a fall with friction:

1 S1: But it is not like he is falling slower?
2 S2: No, he falls constantly. You have to fall constantly otherwise you would smash into the ground.
3 S1: But that is the case. Only the parachute will save him.
4 S2: The acceleration isn't increasing? Is it?
5 S3: No, not increasing.
6 S1: Why not?
7 S3: No, the acceleration is not increasing, while…
8 S1: S9… Is the acceleration increasing when you jump out of a plane? Or is the acceleration constant? You will fall harder, isn't it?
9 S3: You fall constantly, right?
10 S1: The velocity increases.
11 S9: The velocity increases, but not the acceleration.
12 S1: So… You don't accelerate?
13 S10: At a certain moment you won't accelerate anymore. You just fall with 150 mph downwards.
14 S2: So, the gravitational force is constant.
15 S9: The acceleration is getting smaller.
16 S10: If you did not accelerate at the start you would float in the air.

As students reached consensus about the interpretation of the different kinematical terms, they proceeded to the *analysis phase* in which they investigated the relations between the different terms. In lessons 3, e.g. they explored how Trinity's vertical displacement depends on time. Stimulated by the movie, some groups displayed the movement to each other by gesticulation, see Fig.2. The movie stunt was shown over and over again, where students discuss the different relations between variables. In some cases they used a digital ruler to determine lengths or areas. Each time when this was done, they compared their answers with their prior-knowledge: Does the measurement make sense to what we already know?

Fig.2. One student trying to relate the actual jump with the velocity of the jumper. Her hand showing the jump

In this phase, discussing and questioning each other are the main types of communication. Most struggles in understanding the physics showed up in this particular phase, as students still lacked the necessary knowledge and had only each other, a formula sheet and the movie to develop new knowledge. Especially with transferring formulas and events to graphs was difficult for them. This is not surprising as this is a well-known problem in literature [21], [22]. However, when they reached an analysis that satisfied them, they moved on to the *solution phase* in which they formulated their final answer to the problem. It is worth noting in this phase that students evaluated their answers with their common everyday knowledge and the event shown in the movie, shown e.g. with this excerpt from lesson four:

1 S3: 104 km/h! That's fast.
2 S1: But it is logical that they make so much speed.
3 S3: Okay, but on such a small road…

As a teacher, we like to have students evaluate their answers, but often they do not see their own mistakes, even when answers diverge on the order of 10^6. In these tasks, students evaluated their answers spontaneously and referred to daily observables, i.e. link the physics with well-known events.

In the final assignment, students show what they learned as demonstrated in Fig.3. (Appendix) This student clearly shows which variables are necessary to analyse the jump, calculates the airtime and the jumping distance. This distance (127 m) is clearly greater than the jumping distance as shown in the movie.

Motivational aspects

As students started with a kind of eagerness to work with the movies, they quickly lost some of their interest during the series of lessons as they felt it was rather a matter of repetition. According to them, each lesson resembled the previous one. Although students said to lose some interest, this was hardly reflected in the lessons: most of the time they were cooperatively working on the problems. In the questionnaires as well in the interviews, students mentioned that working together on a problem that had a practical relevance appealed to them, illustrated by a quote of one of the respondents: "*It is more fun because you understand what it is you are actually doing*." Working in small groups provided direct feedback and students appreciated the possibility to discuss several problems. Similar problems embedded in a series of lessons with instructional lessons would appeal to them even more as they were uncertain whether their approach was the right one.

DISCUSSION

During the various lessons we saw the same solution process over and over again. Students did not stick with only an analytical analysis but also tried to include the movie scene itself to solve the problem, e.g. by measuring jumping distance or airtime. Although not always successful in terms of giving a scientifically satisfying answer, students developed the procedural skills to analyse a movie scene in terms of physical accuracy. This was shown particularly in the formative assessment in which students directly knew which variables had to be determined and how in order to solve the problem. Furthermore, we see that the conceptual knowledge was extended during the various discussions held. During these discussions kinematical terms come forward and gained meaning for the students. However, not all kinematical terms obtained a scientific interpretation and the relationships between the various concepts and kinematical terms was missing. Students would like to obtain a summary of all the kinematical concepts involved. However, this can also be seen as a benefit from using this approach, as students know their own knowledge deficits, they ask more profound questions during instructional lessons and they have an intrinsic motivation to pay attention as they know why the instruction should matter to them.

CONCLUSION

The developed series of lessons has proven to offer interesting practical problems for students at the age of 16/17. The problems provide a link between physics and the context in which physics is present. Integrating these ideas in different lessons would lead to enthusiastic teenagers eager to debunk Hollywood movie stunts, who instantaneously learn physics.

ACKNOWLEDGMENTS

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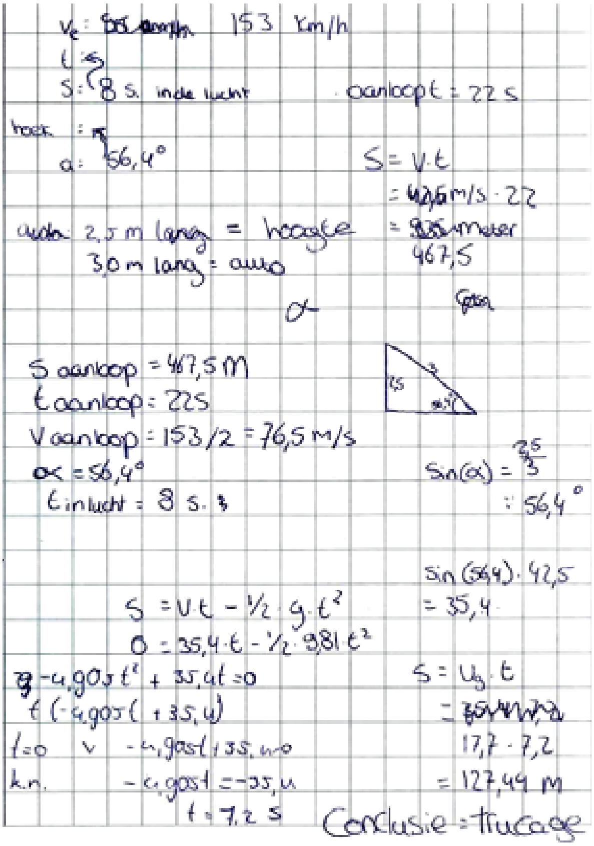
APPENDIX



V_t : 153 km/h

t: s

S: 8 s. inde lucht

hoek :

a: 56,4°

auto: 2,5 m lang = hoogte

3,0 m lang = auto

α

S aanloop = 467,5 m

t aanloop = 22 s

V aanloop = 153/2 = 76,5 m/s

α = 56,4°

t in lucht = 8 s.

$S = v \cdot t - \frac{1}{2} \cdot g \cdot t^2$

$0 = 35{,}4 \cdot t - \frac{1}{2} \cdot 9{,}81 \cdot t^2$

$-4{,}905t^2 + 35{,}4t = 0$

$t(-4{,}905t + 35{,}4)$

t = 0 v −4,905t + 35,4 = 0

k.n. −4,905t = −35,4

t = 7,2 s

aanloop t = 22 s

$S = v \cdot t$

= 42,5 m/s · 22

= meter

467,5

$\sin(\alpha) = \frac{2{,}5}{3}$

= 56,4°

sin(56,4) · 42,5

= 35,4

$S = v_x \cdot t$

17,7 · 7,2

= 127,44 m

Conclusie = trucage

Fig.3. A student's answer on the question whether the jump could be made

HOW TO MERGE TECHNOLOGY WITH METHODOLOGY IN MATHEMATICS AND SCIENCE EDUCATION – THE GEOMATECH PROJECT

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ABSTRACT

The GEOMATECH Programme is a large-scale EU funded project which aims to develop high-quality teaching and learning materials for all grades in primary and secondary schools in Hungary. These materials (1200+ Mathematics, 600+ Science) will be embedded into an on-line communication and collaboration environment. The portal is to be used as an electronic textbook, a homework system, and a virtual classroom environment. In this paper we present the details of the Project and give some examples how to use it in the classroom.

INTRODUCTION

Looking around the world there is no question that technology turns into the essential part of the everyday life. A proper combination of pedagogical methods and cutting-edge technology must be, therefore, the primary goal for the education system at all levels. As one might expect, the successful integration of technology into mathematics and science education depends on several factors. It is also evident that the teacher plays the most important role in this process. That is, no essential change can be done only by integrating new technologies into science education. Teachers' preparation and motivation is indispensable. Moreover, as Hennessy and Osborne [1] state, teachers have to be responsible for evaluating appropriate technical resources and designing the learning activities.

Several large-scale projects around the world [Argentina, Thailand, Uruguay, USA] attempted to hand out millions of laptops and/or tablets to students. However, various studies pointed out that these actions only are not enough to have a breakthrough in science and mathematics education. Parallel to the integration of the novel technology, a training is also needed for teachers in order to be able to use new devices in their everyday practice [2,3].

Luckily, we had the opportunity to develop a programme called GEOMATECH. It was funded by the EU and the Hungarian Development Agency to integrate the STEM (Science, Technology, Engineering, and Math) subjects and digital technologies based on an open-access web portal [4]. The basic purpose of this short paper is to present the main ideas and the novelty of the GEOMATECH Project.

PROJECT OVERVIEW

There is a consensus probably not only in the teacher community but also among the parents, policy makers and students that the mathematical and science education needs refreshment. Looking at our children there is no doubt that they are "digital addicts". To reach any success in their education we cannot ignore this fact. The GEOMATECH Project serves professional and peer-reviewed digital materials that can be connected to the everyday-used electric devices.

The basic idea of the Project is to develop 1800 digital materials (1200 mathematics and 600 science) for all grades in primary and secondary schools. These materials are embedded into an on-line communication and collaboration environment that can be used as an electronic textbook, a homework system, or a virtual classroom. An important feature of the portal is that beside the teachers and students the parents might also have an access to the materials and, thus, they can follow the educational progression continuously.

During the realization of the Programme six different groups worked closely together. In what follows, we summarize the main tasks of these groups in order to give an insight on what segments were synthesized to build up the GEOMATECH Portal.

- Material development: This part of the Project brought together traditional pedagogies and new curricula in order to have more efficient methods
- Software development: For better visualization and supporting the physical experiments GeoGebra [5] got several new features. The 3D part of the software become more versatile. The real-time data collection is already a default built-in function. It means that various software (e.g. Tracker) and/or hardware (mobile phones, data capture devices) can be connected to the GeoGebra software and use it in data acquisition and reduction. An android application has also been developed in order to make the physical experiments more accessible to students.
- Piloting: 25 mathematics and 20 science teachers were involved into the pilot study. The main purpose of this program was to get valuable feedback from those teachers and students who already used the GEOMATECH in their classrooms. The information collected in this work was extraordinarily important not only from theoretical point of view but also in practical sense for other parts of the Project.
- Teacher training: A total of 2400 mathematics and science teachers were involved nation-wide in this part of the Project. We offered a 60-hours training with innovative curriculum that fully matched the basic objective of the Project. During the training teachers learnt the basics of the GeoGebra software, modern methods in education, use of the GEOMATECH portal, WEB2 techniques, file sharing, mobile phones in science courses, etc.
- Student competitions: Multi-round competitions were also part of the Project. A large number of teams (more than 200) joint these cheerful events every month. More than 1000 students from all grades solved the interesting mathematics and science exercises based on GeoGebra.
- Teacher community: After the Project was completed, a very important issue was the information sharing between teachers who participated the Programme. Therefore, an on-line site has been created which offers a common platform to discuss the experiences, to share new and innovative ideas, or just think together about the possible further applications offered by the Programme.

About 200 people were directly involved in the Project. The next section is devoted to the results of their contribution.

MAKING USE OF GEOMATECH

First we want to emphasise that GEOMATECH is meant to be not only a collection of digital materials but rather a platform that includes all the methods we use in classes or, in general, the possible ICTs (Information and Communication Technologies) that are used in mathematics and science education. In this section we present some applications and methods of GEOMATECH.

GeoGebra. All digital materials in GEOMATECH Portal are based on the dynamic mathematics software GeoGebra [5] developed by Marcus Hochenwarter in 2001. The software is basically designed for elementary and secondary school teachers and students in order to clarify the abstract mathematical concepts and methods. In the last 15 years the software became one of the most common mathematical software around the world. It is completely free and open source. Thanks to the continuous developing nowadays GeoGebra can be used on-line on several different platforms (PC – Mac, Linux, Win; Tablets, smart phones – Android, IOS) and also various features for STEM subjects are built in. Last but not least, in the last decade, Hochenwarter and his team established a world-wide community including the GeoGebra tube, a collection of more than 200,000 public materials. In addition, the International GeoGebra Institute brings together more than 150 local GeoGebra Institutes in all five continents.

What to teach and how to teach? No matter what kind of class we want to give, the basic aims of GEOMATECH suggest to use at least one computer and a projector. Therefore, the teacher must be familiar with using such devices. The same is also true in the case of team-work or a class in a computer room (e.g. we should take care that the appropriate number of laptops are available or consult to the system administrator about possible experiments in a computer room).

We can decide what portion of a class is going to be covered by GEOMATECH. One possibility is to present just a few materials while introducing a new topic. The other choice can be a chain of materials (related to the same subject) at various parts of the course. Furthermore, digital materials can be used during the entire 45 minutes. This latter is quite easy, since, as mentioned above, the materials are based on GeoGebra and, therefore, the students can be strongly involved into the work. So, they should not just be watching the canvas but doing something profitable on their machines. In other situations, say, exams and/or homework GEOMATECH can also be utilized.

The GEOMATECH materials are essentially designed for visualization and for redeeming certain experiments. However, in fact, they do not replace the equipment in the physics laboratory. Next, we classify the digital science materials.

The first class contains "computer simulations" of easy demonstrations. These applications are more or less the same as we can present in a classroom but, of course, they cannot replace the original experiments (for example, harmonic oscillations, conservation of angular momentum, Lorentz force in fluids, etc.). Nevertheless, we can argue in favour. These "experiments" can be repeated any time with several different parameters. Moreover, students can take them home and play with them. (This is true for the other two groups below as well.)

The second class includes materials that are related to experiments difficult to present (due to the available time or space) or impossible to make because no components are accessible in the laboratory, e.g. complex electric circuits, elaborated optical arrangements.

In third group one can find materials which describe physical processes/experiments that are unworkable (due to the timescales or measures) in a classroom. For instance materials in atomic physics, environmental flows, astronomy, etc. Simulations like these might help to draw students' attention to the less graphic experiments or to the hot topics of modern scientific problems.

Methods and materials resulting in more interesting and impressive in-class experiments. The most challenging task in the 21st century education is probably to keep pace with the fast improving digital technology and to give valuable and usable knowledge to the students. Teachers play an important role in creating motivation. It cannot be done only by knowledge transfer. Using the current available technology is also necessary. Therefore, it is extremely important that teachers should be able to use ICT during their classes, and not just for presentation. These days the IT is already not about ppt presentations only, but much more.

Teaching science is unimaginable without measurements and demonstrations either for teachers or for the students. It is clear that students remember a mathematical function describing a natural phenomenon better if the measurements are done by themselves. It also does matter what kind of devices they use. The motivation can be missing if the students feel that the equipment around them left back from long ago.

Smartphones take over the mobile market. One can buy a smartphone roughly for the same price as a classical mobile. Another important fact is that the cheapest smartphones are as good as the most expensive devices in the sense of classroom use. In other words, all students can have the same potential to perform physical measurements during the science courses.

But what actually a smartphone means? A loose definition might be: a device that runs an operating system (OS) independent of the hardware used. A second important criterion is that the manufacturer of the OS offers an on-line application store and the owner can download various programs from this market to customize her/his smartphone. Moreover, having the suitable programming skills, people can also write such applications.

Another remarkable phenomenon of smartphones is that they contain various sensors. By using these sensors one can broaden the applicability of the phone. For example, by putting the phone face down the silent mode is activated, or by firmly shaking the device an incoming call can be rejected. Several years ago innovative physics teachers already involved smartphones into science education. [6,7,8] The GEOMATECH offers a professional way to use the mobile sensors as innovative applications in physics classes.

In what follows, we will present a possible use of the mobile phone for data mining and real-time data processing. Using the sensors and the mathematical skills of the GeoGebra software together the students might have complex digital measuring equipment in their hand.

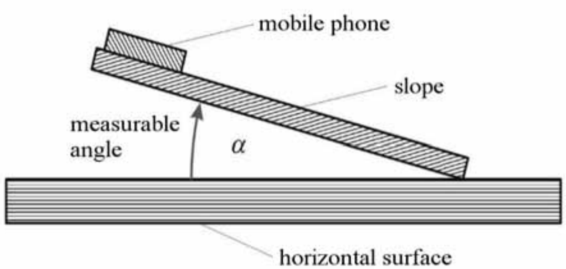

Fig.1. Using a smartphone in an experiment to determine the static friction between two different surfaces

Fig.1. depicts the experimental design for measuring the static friction using mobile sensors. We need a surface with alterable slope, a smartphone, and the Geomatech Sensors application from the Google Play store. For more details how to download and set up the program (and other requirements) please visit the website [9]. In addition, one can prepare

various boxes with different kinds of surface to measure the material dependence of friction. In this experiment the varying quantity is the angle alpha. The smartphone application tells us the acceleration of the phone for each value of the inclination of the slope.

Fig.2. shows the GEOMATECH material related to this experiment. On the upper part of the screen several questions can be found related to the experiment. For example: "*Sometimes the objects do not slide on the slope. What is the reason? What kind of force keeps the smartphone in place? What is the angle when the object starts to move? What physical parameter can be obtained from this tilt?*" The main window shows the GeoGebra application with four buttons (start, stop, new measurement, and data evaluation). In order to connect the smartphone sensors and perform the actual measurement a code is required. This code is generated by the Geomatech Sensors application and should be typed into the text-box. The co-ordinate system depicts the gradient vs. time. From the graph the angle can be obtained when the mobile phone starts to move. (In this plot the acceleration is not shown.) The experiment can be repeated using different materials between the phone and the slope.

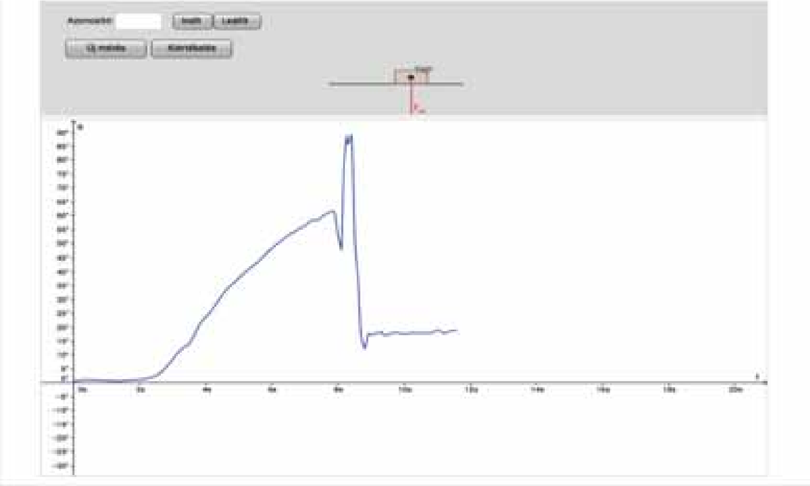

Fig.2. Real time data plot with GeoGebra and Geomatech Sensors

CONCLUSIONS

The GEOMATECH Project, i.e. the material and software development, the teacher training, etc., finished in September 2015. It is too early to assess the impact of this package on the science education at the elementary and secondary levels. The success of the Project depends on many factors. Nevertheless, taking into account the results of the pilot program, the feedback of the teachers' who participated in the trainings, and the positive media communication, it seems that the idea has a great number of potentials. We will see where the GEOMATECH evolves over the next few years and how it influences the mathematics and science education at the elementary and secondary school levels.

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LIGHT POLLUTION MEASUREMENT: A PROJECT WORK FOR SECONDARY SCHOOL STUDENTS

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ABSTRACT

Our student group on environmental physics in Garay János Grammar School in Szekszárd started to show interest in light pollution, by reason of necessity of dark sky for our astronomical observations. In the frame of a project work we made measurements with a special portable photometer (SQM) in a nearby area in Tolna county called Hegyhát. We obtained very good data, approaching those of Hungarian International Dark Sky Parks' values.

INTRODUCTION

The Zselic National Park was the first in Europe to win the title of International Dark Sky Park on 16 November 2009. This title was founded by the International Dark Sky Association after realising that there are fewer and fewer places on Earth where the starry sky can be seen in its full beauty.

A hundred years ago every child could naturally experience the Milky Way, falling stars or constellations. However, gaining such experiences today is impossible without outings to places free from light pollution (Fig.1.).

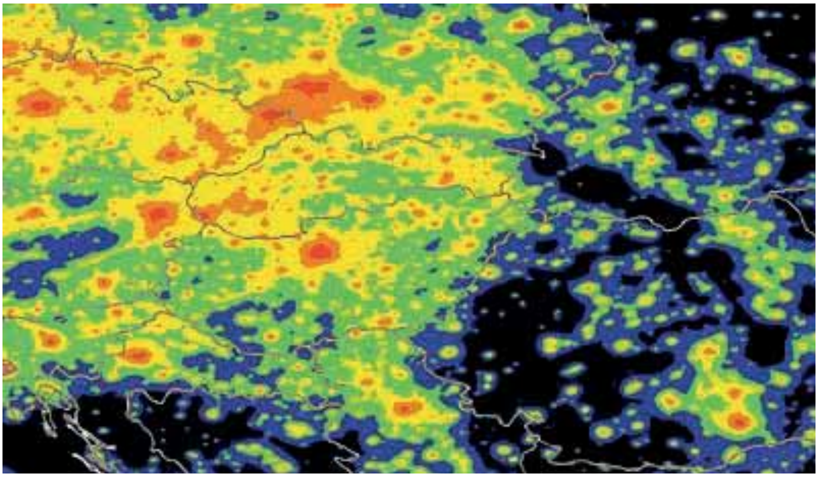

Fig.1. The map of light pollution in Hungary.

Together with some enthusiastic students we wanted to find out about and objectively justify by measuring whether there are places either in the neighbourhood of our school Garay János Grammar School or in Tolna county where the sky can be seen the way it is in Zselic. Our school successfully applies for micro researches and the necessary financial support every year within the frame of "Út a tudományhoz" (The Way to Science), which is a part of "Útravaló" (Provisions) Scholarship Programme. Due to our latest research programme (Shooting with Astrophotographic Mechanics) we got a good quality astrophotographic stand (EQ-6) with the help of which we were able to take highly aesthetic scientific photos of objects in the sky. For photos rich in details we had to find places with dark skies because the darker the sky is, the longer exposition time the photo requires and the more details can be seen in it. Finding such places was our reason for starting to measure sky brightness. Meanwhile, on the Internet we found a map showing light pollution in Hungary (see Fig.1).

The International Starry Sky Parks of Zselic and Hortobágy can be seen well in it and so can the sandy area of Illancs and the hills of Tolna the object of our measures. The lighter the colours are in the map, the shinier the sky is, and the darker they are, the higher quality the sky has (the darker it is) in that area. In the map we could see that the hills of Tolna may have sky similar to the quality of those of Zselic and Hortobágy the two International Starry Sky Parks. We planned to get ground-based measurements to prove this hypothesis.

LIGHT POLLUTION

Light pollution is in fact a skyglow, an increased light density on the nocturnal sky which originates from the artificial light at night scattered on the aerosols and molecules in the atmosphere. Fig.2 indicates that the incorrectly designed and installed lighting devices can be sources of light pollution if their light goes not on the right place, right time and not with the right intensity.

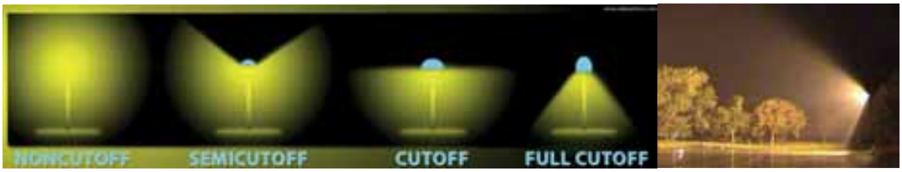

Fig.2. Light pollution sources. Left panel: possible design of the public lighting.
Right panel: badly installed lamp

These light sources have a high ULOR (upward light output ratio) value meaning that they spill light above the horizon. The wasted luminous flux causes energy loss, artificial skyglow, panorama destroying, undesired effects on health (including humans and other species) and dazzling.

Artificial light at night increases skyglow, that is why the astronomers and anyone else cannot observe less intense objects and phenomena of the nocturnal sky. Nocturnal artificial light sources (public lamps, illuminated flat houses and church towers etc.) disturb the flying insects', birds' and turtles' ability to navigate or to reproduce properly. Some nocturnally active species (for example bats or owls) or inversely, the daytime active species (for example the songbirds in the cities) cannot live their natural lifestyle because of the light pollution.

Nowadays most of the human beings live in unnatural light conditions. We spend our daytime period at less illuminated indoor places than natural outdoor illuminance, in addition, at night we cannot experience complete darkness. Our endogenous circadian rhythms are affected, for example body temperature, heart rate and melatonin production. With the artificial light we have altered the natural 24-h light-dark cycle, thus we can observe serious pathophysiological repercussions. Disorganization of our circadian system and perturbations in melatonin rhythm (caused by sleeping with artificial light, use of LED screens at night, shift work, jet lag etc.) denote an increased probability of the development of diabetes, obesity, heart disease, premature aging and some types of cancer [1].

Dazzling represents risk mostly for the traffic and for employees working in dangerous scopes of activities. If the light sources with high ULOR value emit too much light directly to the pupils, it causes temporary sight decrease because of the eye's inability to adapt to the new lighting level. Light pollution can be disturbing in one's property, for example if the incorrectly settled public lighting causes too much brightness in one's room so one can not sleep properly.

OUR MEASUREMENTS

We used a UNIHEDRON Sky Quality Meter instrument to measure the luminance of the sky. This small portable instrument has been used in Hungary for measuring the sky brightness since 2007. The device measures the average luminance of a 1.5 steradian solid angle towards the zenith. The unit of measurement of sky luminance is mag/arcsec^2, which can be converted into cd/m^2 (SI units) using the following formula:

$$\text{Value (cd/m}^2\text{)} = 10.8 \cdot 10^4 \cdot 10^{-0.4[\text{value(mag/arcsec2)}]} \qquad (1)$$

The temperature-calibrated device works with the precision of 10 percent in linear luminance (cd/m^2) units [2]. There are two types of this instrument (SQM and SQM-L) used in practice. The difference between them is in the angle of collecting light (see Fig.3).

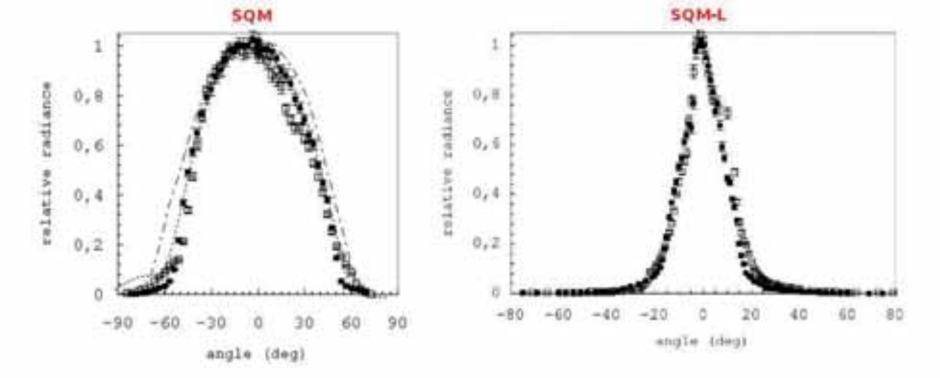

Fig.3. Solid angles of the two types of SQM.

An SQM works with a bigger angle, measures and counts the average of the thickness of the incoming light quantity. An SQM-L does the same but with a smaller angle. All of our measurements were taken with the device pointing to the zenith with an SQM-L to avoid the effect of the disturbing lights of Szekszárd on the horizon.

The favourable conditions for measuring are complex. It can be started when the night sky is clear without the Moon and the Sun is 18 degrees under the horizon, and should end before the Sun approaches the horizon up to 18 degrees again during its way at night. As long as it is possible, artificial sources of light should be avoided. When measuring in the town this condition is imperfect in some cases. Places with objects in the area such as trees that can disturb the detector of the instrument must also be avoided. Directing the instrument towards the zenith five measurements are made, the first two of which are ignored when evaluating them. These are less accurate data due to the time necessary for the instrument to warm up. The other three data are then averaged. The co-ordinates of the venues of the measurements are fixed by a GPS.

Fig.4. The members of our study circle while measuring.

Certification of the instrument was done with the help of calibrated SQM instruments gathering accurate data on the sand hills of Bácska in the area of Illancs, which is highly free from light pollution. We got evidence that no correction is needed as our instrument measures sufficiently accurately. We measured (Fig.4.) night sky brightness in Szekszárd at places relatively distant from each other. Later during our night outings among the vineyards we surveyed the neighbourhood of Szekszárd as well. A couple of times we drove along different routes in the hills and stopped at places to measure (Fig.5.).

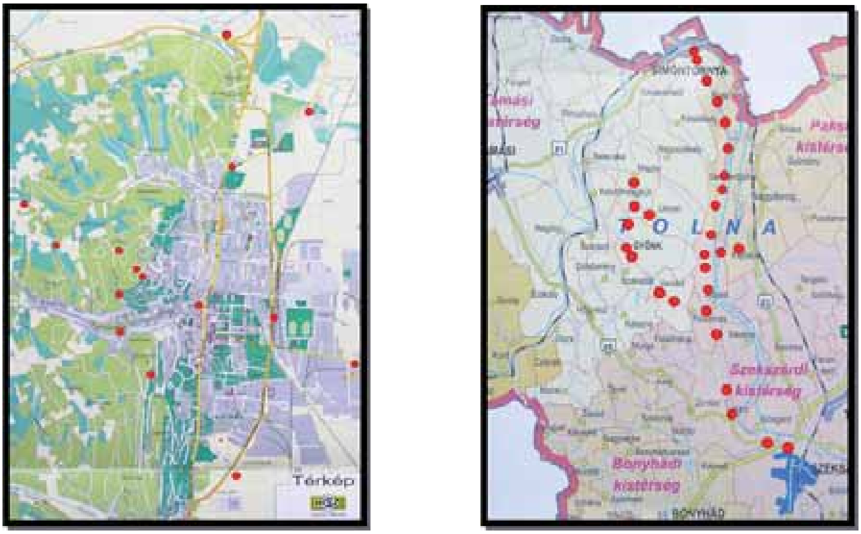

Fig.5. The venues of our measurements. Left panel: Venues in Szekszárd.
Right panel: venues in the hills of Tolna.

Quite a few factors made our measurements in the summer holiday difficult. For example, nature in the first place, the unpredictable weather, the late sunset and the early sunrise.

Because of these latter ones we had to make our measurements in the middle of the night. Besides, other tasks of the students, family holidays or the fact that getting to more distant points of the county is only possible by car also delayed our work.

DSLR PHOTOMERTY

After finishing our measurements in the summer of 2014, public lighting system has been refurbished in Szekszárd. The old high pressure sodium lamps were replaced with white energy-efficient LED lighting. Our research team from the university measured the luminance of the light dome of Szekszárd by DSLR photometry before and after the reconstruction. We used calibrated DSLR cameras with fisheye lens to get images with high ISO setting and long exposure time. Our photos in raw format can be converted to false colour images to show the distribution of sky luminance. With this method we could qualify different lighting systems and draw attention to the possible environmental effects of the changes in lighting. As Fig.6 indicates, we obtained a decrease of the sky brightness in Szekszárd [3].

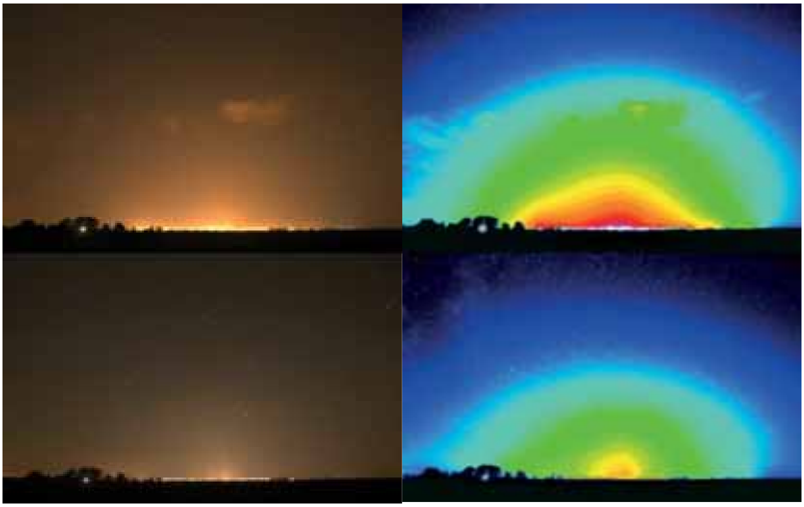

Fig.6. Light dome of Szekszárd. Top panels: before the reconstruction, bottom panels: after the reconstruction. Left panels: normal images, right panels: false colour images (Source: Z. Kolláth).

OUR RESULTS

As it can be seen from the data below our SQM measurements showed that the quality of the night sky of the hills in Tolna County is similar to those of the dark sky parks of Zselic and Hortobágy.

Table 1. The measured data.

measured areas	**SQM-value**
The average of the area of Szekszárd without the centre	20.4
The edge of Szekszárd at the vineyards	20.6
The average value of our measurements among the vineyards of Szekszárd	21.0
SQM-values in the area of Hortobágy Dark Sky Park	21.0 – 21.5
The SQM values of an all-night observation in the area of Illancs	21.0 – 21.5
The average of the measured values in the area of the hills of Tolna	21.1

CONCLUSIONS

The topic of light pollution proved to be an excellent project task. It was suitable to combine biology and mathematics, deepen the students' environmental awareness and last but not least the cooperation within the measuring team, their enthusiasm and the joy of learning playfully are all definitely serious pedagogic results. However, we find the pedagogic results more important than the physical ones. Now it is the students who want to continue measuring. We are going to take pictures of the hills of Tolna with DSLR photometry by our fish-eye lens bought with the help of application sources. It will be exciting to measure the sky brightness in the town and in its neighbourhood again with SQM after the public lighting changes.

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II. SCIENCE CENTRES AND OTHER INFORMAL LEARNING OPPORTUNITIES

SCIENCE ON STAGE: THE EUROPEAN PLATFORM FOR SCIENCE TEACHERS

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INTRODUCTION

Science on stage is a pan European **teacher network** established in 2000 as Physics on Stage which grew into Science on Stage in 2005. It is a non-profit association since 2011 with administrative headquarters in Berlin. We believe that living out its motto "From teachers for teachers" makes Science on Stage unique in Europe. By inspiring science teachers we provide inspiration for our students, and therefore will make a difference in the supply of motivated scientists in the future. The ultimate goal of science on stage is to improve science teaching by encouraging creativity in science teaching, with teachers sharing ideas that have worked for them in the laboratory and classroom. Through this we shall encourage more school children to consider a career in science or engineering by spreading good teaching practice among Europe's science teachers.

Science on Stage has an expanding network of national committees (NSCs) in more than 25 european countries (1) who are responsible for selection national representatives for its festivals and promoting the good teaching ideas from these biannual festivals and consequently reaches about 100.000 teachers and teacher trainers each year. Each National Committee works independently following certain agreed guidelines common to all, is self funding from local industry, governments and educational institutions, and is supported from the Science on Stage office in Berlin.

Fig.1. Teachers sharing ideas at a recent Science on Stage Festival

Science on Stage has organised eight European festivals from 2000-2015, the latest being in London, and the next is planned to be held in Debrecen, Hungary in 2017.

We draw together teachers of school children of all ages to share experiences and work together on joint projects. We seek to promote science for young people via enthusiastic teachers and we encourage teachers as to their own value and promote high quality teaching, seeking to demonstrate the importance of STEM to children, to the public and to decision makers across Europe.

ORGANIZATION

Science on Stage is organized through an executive board

7 members, elected every 4 years by representatives of the National Science Committees. At the present time there are representatives from Cyprus, Czech Republic Germany, Spain, Sweden, Switzerland and UK. The board meets regularly in between festivals to plan and innovate for the future.

How does Science on Stage enable the international exchange from teachers for teachers?

Many people know of science on stage though its biannual festivals which are attended by delegates SELECTED by national Committees according to a quota system for each country depending on the number of inhabitants. We therefore maintain a high standard of presentation. Science on Stage festivals have taken place every 2 years at different venues throughout Europe bringing together up to 350 science teachers (primary to secondary level) from over 25 European countries. The national contacts can be found on www.science-on-stage.eu

Fig.2. Teachers at the recent Science on Stage Festival in London (2015)

FESTIVALS

Science on Stage Festivals showcase the work of the teachers with over 200 stalls showing a huge variety of projects from all STEM subjects. The Festivals are fully funded for participants by the host country and Science on Stage Europe, so teachers simply have to reach the venue. All else is provided for the 4 day festival. Follow-up activities are then encouraged across borders. All participants are selected through national events in each country. Each festival is carefully evaluated by recognized agencies, so that we can determine how successful the programmes have been. See the science on stage website for the most up to date information.

Evaluation

- 69% of the teachers attending said participation increased their motivation and joy in teaching
- 79% of participating teachers have incorporated ideas that were presented at Science on Stage into their own lessons

- 74% of teachers appreciated the opportunity to exchange experiences with cross border colleagues
- 50% of participating teachers have incorporated ideas from Science on Stage into teacher training events

(Reference: Evaluation Study carried out by Humboldt University Berlin)

The Science on Stage Festival is a platform for the exchange of **new ideas** and **concepts** in science teaching. The **follow-up-activities** ensure the development and sustainable spreading of these ideas and concepts.

First we encourage sharing ideas within one's own country

All participants are encouraged to take ideas from the festivals back home, to share

i) within their schools and localities
ii) through teacher training events and conferences

and we know that a massive 50% of participants use ideas in training events to share with others

Then we encourage sharing ideas and working across Europe and beyond

All participants are encouraged to make lasting friendships at the festivals which in turn lead to working relationships and sharing of fresh ideas. 50% of participants maintain 5-9 European contacts after festivals

INTERPLAY: MY OWN STORY

Fig.3. The author

I first encountered Science on Stage in 2005 when I was privilege to be selected by the UK National Science Committee to attend the Science on Stage Festival in Geneva. This was for me, like others, a great eye opener, to meet with so many like mined, enthusiastic teachers from a wide range of different backgrounds and countries. After the conference, where I presented some ideas on using magic to engage children, (that is magic that is based on scientific principles rather than deceit) I came home with my head buzzing with ideas.

Two years later the festival in Grenoble gave me the opportunity to represent the UK again and present a workshop "What Happens Next?" and meet up with colleagues from the previous festival. Several took up the idea, and we shared some ways in which the workshop could be extended.

Fig.4. Large and small balloons. When joined the smaller balloon inflated the larger one.

One such idea was the "Two balloon experiment" where a less inflated balloon will blow up, (surprisingly) a connected larger on. A discrepant event to many, Zuzana Jesková, a colleague from Slovakia, used this idea with her students, and together were able to publish an article in the journal Physics Education, "Balloons Revisited". I was able to visit Zuzana in Kosice, Slovakia and present the workshop there, and this led to further friendships, and even now, in 2015, a joint article published in Physics Education with a colleague of Zuzana. The workshop has since been presented in The Netherlands, Czech Republic, Poland, Ireland, Scotland, Belgium, Italy to my knowledge, and maybe other countries too, as the ideas now feature regularly in the journal of the Institute of Physics, Physics Education. Whilst I write the column, several colleagues from Science on Stage have been able to contribute.

Fig.5. The author with students at staff in Kosice, Slovakia.

More recently I was elected to be a member of the Science on Stage Executive and this has given me the privilege of serving the community more

> *widely, helping with decision making on matters of policy, and supporting new members of science on stage, We are a growing community and I fully expect that the 2017 festival will see the largest number of participating countries so far in Science on Stage's history.*
>
> *And finally I can honestly say I have friends and colleagues all over Europe now that I didn't have 10 years ago, a greater understanding of the different educational systems, and more than that a greater insight into the current situations around our continent and history of each nation.*

In addition Science on Stage encourages its own follow-up projects alongside the education festivals.

Teacher training events and travel scholarships

Workshops with international festival projects take place in every Science on Stage country. Teachers can get scholarships for further exchange with their colleagues, to develop project ideas together.

Science on Stage Europe provides funds to encourage…

“**taking a workshop**“ to another country

19 WORKSHOPS were formally funded across borders between 2013 and 2015, and others took place informally. Many workshops were repeated in home countries and participants used the ideas from workshops at the festivals to devise their own.

“working together on teacher initiated **joint projects**“

10 travel scholarships were formally funded between 2013 and 2015 and several more have already been instigated following the 2015 festival covering a huge range of topics. These enable teachers who participated in the festival to meet again and continue their work and to develop new projects.

Development of **teaching materials**

Groups of international teachers from Science on Stage develop teaching materials together. Results are published and spread Europe-wide; e.g. **Smartphones in Science Teaching** (2014). The latest pan European is a group of 20 teachers from 16 countries developing materials and a stage booklet on **„science and football“** sponsored by Science on Stage Germany due to be published in June 2016.

Some countries produce their own publications for European distribution both in print and on line For example the Irish Science on Stage team have produced 5 booklets ,

300 in each print run and now on line, detailing some of the demonstrations shown at the festivals. Free downloads can be accessed from http://www.scienceonstage.ie/ where videos of the experiments can also be seen.

In fact since the 2013 there have been over 85 publications in different journals etc. Check your own country's website to see those in your own language!

FUTURE FESTIVAL

Countries bid with each other in order to be selected to host the next festivals, and at the recent festival in London, Hungary was chosen to host the festival in 2017. It will take place in the beautiful city of Debrecen between June 29th and July 2nd 2017.

The festival will take place at the Kölcsey Convention Centre in Debrecen, organised by Science on Stage Hungary, the University of Debrecen and the MTA Atomki Institute in cooperation with Science on Stage Europe.

Fig.6. Debrecen cathedral

Meanwhile, **selection events** are taking place in all member countries; **follow up** meetings are happening across Europe; cross border exchanges are being planned; **significant internet cooperation** is ongoing every week; **joint papers** are being prepared and published; **good practice** is being shared, and all this from practicing teachers to other practicing teachers.

We know we are making a difference to STEM teaching across Europe and beyond.

BECOME PART OF THE INTERNATIONAL FAMILY

You can check the website at

www.science-on-stage.eu

Get in touch with Science on Stage in your country

Read our Newsletter via

www.science-on-stage.eu/newsletter

The European platform for science teachers

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The European Office in Berlin is mainly supported by the Federation of German Employers' Associations in the Metal and Electrical Engineering Industries (GESAMTMETALL) with its initiative think ING.

Member Countries of Science on Stage Europe (in population size order) are:

Germany, Turkey, UK, France, Italy, Spain, Poland, Romania, Netherlands, Greece, Belgium, Portugal, Czech Republic, Hungary, Sweden, Austria, Bulgaria, Switzerland, Denmark, Slovakia, Finland, Ireland, Slovenia, Cyprus, together with Canada, (special arrangement). Further European countries with membership pending and to be ratified. Ukraine, Macedonia, Latvia, Norway, Iceland.

DOUBTOLOGY
(ABOUT COMMON SENSE, DOUBT AND CRITICAL THINKING)

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Throughout almost twenty years of experience running the Science Centre, I gradually realized that it is not a centre of science that I am running. Promotion of Science is just one of the tools used in order accomplish our main mission – inspiring curiosity and critical thinking.

Our society is facing a pandemic illness without a name but with clear symptoms of apathy in place of curiosity and learning, looking for easy but shallow ways of acquiring knowledge, no interest in seeking the answers to bothering questions, misinterpretation of dialog as being just two monologues, believing instead of having doubts, critical thinking, checking and proving…

There isn't a single country that would claim their educational system is perfect, or even that it is good. Experts are wondering when and where in the education process this curiosity is lost.

Curiosity is something every single human being is born with. Not only humans, many animals start their lives being curious. Curiosity is a driving force for the learning process. It is fuel for the trial and error process – learning by mistakes that are nothing more than personal learning experiences. Instead we have an educational system that despises mistakes rather than looks at them as a necessary learning optimisation method and encouraging them.

Imagine a curious child raising a hand in order to get the attention of the teacher and ask a question, pose a proposition or express a personal idea of the topic. This is one of the crucial moments that will define the future level of curiosity of the whole class.

There is a right and a wrong course of action. The teacher could respond with: “That’s a good question/idea! Let’s talk about it.” “I don’t know the answer. Does anyone have any ideas?” “Wow, great idea. What if we also take into account that …” “This is a question that also bothered great scientists at that time.” …

The other response (that demands less effort) might be: “Don’t interrupt the class!” “You should know that by now!” “What a crazy/stupid idea.” “We will talk about it later.” “We have already discussed this. Listen more carefully next time!” “Can someone please explain the idea to him/her. I am tired of repeating the same thing all over again and again.” …

One can guess which option is a “curiosity multiplier” and which is the “curiosity killer”. Both options directly signal to the curios person (but also to the whole class) the value of being curious, but one option is treating this curiosity as a virtue (the holy grail for creativity) while the other shows that the curiosity does not pay, that the curiosity is punished.

Curiosity is a very tangible substance that each teacher should nurture throughout life. It triggers the passion for learning and creativity. It is also important as a teacher to exercise the answer “I don’t know”. It is precious to admit the mistakes one makes while teaching (especially if the teacher is alerted to the mistake by some doubtful student). This shows that everyone makes mistakes. Moreover it gives the teacher the feedback that 1) students are curious, 2) that they do care what the teacher is communicating, 3) that they don’t just believe what they hear, 4) that they know to doubt and to think critically.

A good teacher is not a teacher at all. A good teacher is an inspirer that amplifies curiosity and encourages doubts and critical thinking. Inspired students will learn by themselves (Fig.1).

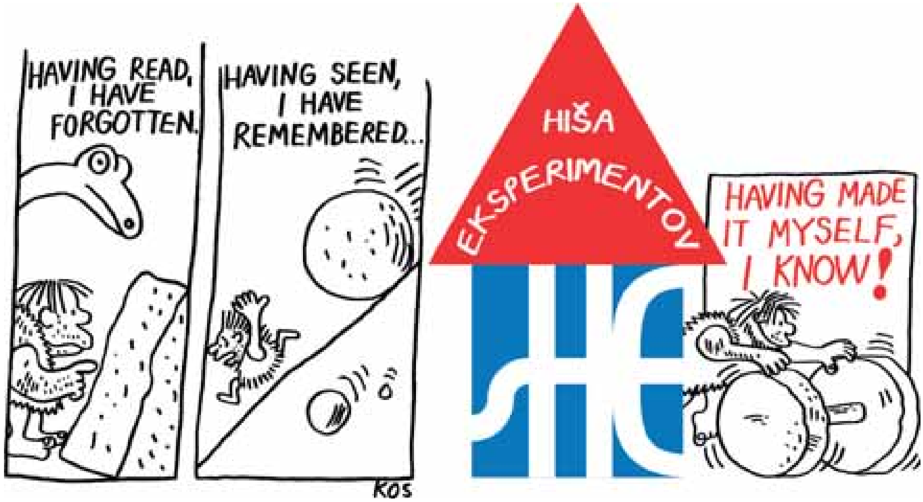

Fig.1. One can never learn from others’ mistakes, only from your own.

MAKING SCIENCE UNDERSTANDABLE AND MEANINGFUL: BRIDGING THE GAP BETWEEN FORMAL EDUCATION AND INFORMAL LEARNING

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INTRODUCTION

”Science education is not only a question of advancing technology or of demands for a scientifically qualified workforce, but is also a question of social goals. The aim is not solely to produce more scientists and technologists; it is also to produce a new generation of citizens who are scientifically literate and thus better prepared to function in a world that is increasingly influenced by science and technology” [1].

Learning and education can be defined both narrowly and broadly: they can occur either unconsciously or formally. One of the first to present this broader definition was in 1922 the German philosopher Krieck [2] who used the term "unreflektierte Erziehung" – “education by chance”. According to him, people also learn unconsciously through work, art, language and culture. The whole relationship between human beings is an educational one. Philosophically, informal education represents the ideas of freedom, in the spirit of Rousseau's tradition as manifested, for example, in the work of A.S. Neill.

Learning in informal contexts has often been regarded as the opposite of formal education. Even the names of the classic books – Deschooling Society by Ivan Illich [3] and The Unschooled Mind by Howard Gardner [4] – have been provocative. These books also contained harsh criticism of failures of schooling, which has alienated students from meaningful learning. Moreover, they argued that learning from informal sources was effective and motivating. These books have had a great effect on education and educational research.

Until the 1990s, informal learning solutions were often considered as unreachable ideals, or informal education was used only as a tool for criticising school or school reforms. To advance public understanding of science, new forms of education were actively sought. Learning does not take place only in the actual world of school but in the presented world of nature, parks, yards, science centres, gardens, and the media, as well as through the virtual worlds of the internet and social media.

Since the 1990s, however, informal education has become a widely accepted and integrated part of school systems. Despite this development, there has been less theoretical or empirical research in the informal sector. Recently, learning in informal contexts has become a more accepted part of science education.

A huge amount of information, especially about modern phenomena, is obtained in a personal way from family, friends, and peer groups. Furthermore, the roles of television, libraries, magazines, and newspapers are also essential. Museums and science centres have regularly had increased numbers of visitors during the last decades. Despite this development, there has been less theoretical or empirical research in the informal sector [5]. ICT- and web-based learning has totally changed the vision of formal education [6, 7].

The terminology of informal education is variable, due to, on the one hand, to the slight difficulties caused by differences in school systems and, on the other, some translation problems. One of the main difficulties is that pure informal learning refuses to be categorised, and the definitions are not needed until informal learning becomes institutionalised. Learning in informal contexts and open learning environments are the latest terminology in the field.

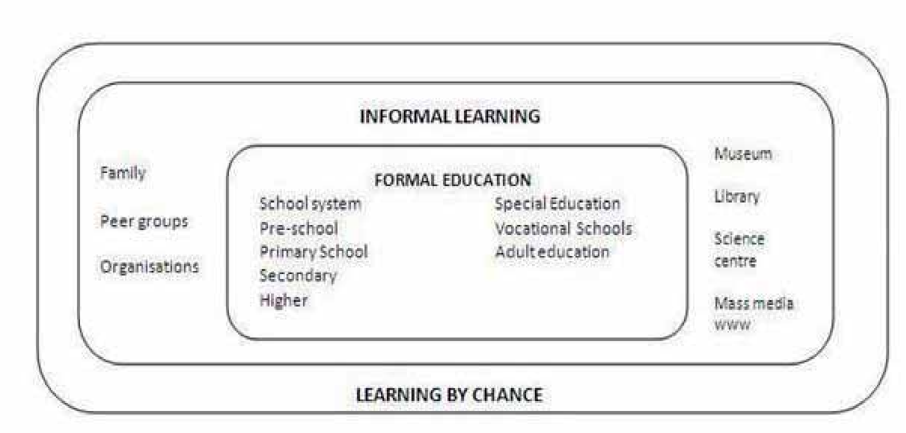

Fig.1. The relationship between the different kinds of education [8]

The relationship between the different kinds of education is shown in Fig.1, which is a combination from several sources. Originally it was the scheme for educational statistics in the UNESCO report Learning to Be – The Faure Report in 1968. It was used then for first time to show the forms of life-long education.

To promote public understanding of science, new forms of education are actively being sought. A huge amount of information, especially about modern phenomena, is obtained in a personal way from family, friends and peer groups. Furthermore, the roles of television, libraries, magazines and newspapers, and of course by ICT and web-based reality are essential. Informal learning has often been regarded as the opposite and criticism of formal education. However, since 2000s, informal education has become a widely accepted and integral part of school system.

The terminology of formal education and informal learning has been clearly defined in the literature for three decades now. The recent boom in informal learning has not changed the view on the terminological level. However, out-of-school education is yet another essential term. It means education that happens during school time and according to the curriculum, but uses settings and institutes outside the physical school building.

SCIENCE CENTRE PEDAGOGY

The numbers science centres – and their visitors – have increased regularly during the last decade. Most of these forms of education can be classified as informal learning, either focused on young people via informal, out-of-school education programmes or as clearly informal learning occurring totally outside any educational institutes for young people or adults. We have to head towards the evidence based education via teacher training. There is all too much anecdotes and every-day-experiences related to science education and informal learning. There has to be more reliable link between research communities and teacher training.

The role of informal learning is increasing in the modern societies – meaning the countries which are developing their societies by investing and creating opportunities for research, innovations, and education. The phenomenon is closely related to the growing impact of science and technology in our everyday lives. Lifelong learning needs new practical forms, and the formal education can learn something from the informal, open learning environments like the science centres.

Hands-on learning is the main pedagogical principle of the science centres. This classical "learning by doing" method is something that the science centres have been pioneering in Europe during the last decades. The multidiscipline contents of modern science centre exhibitions form a unique and reliable learning source. The most important results related to informal learning underline the role of intrinsic motivation and the learner's own activity, stimulated but not forced.

A science centre is a learning laboratory in two senses. First of all, it is a place where visitors can learn scientific ideas by themselves using interactive exhibit units. Secondly, it is a place where informal education can be studied in an open learning environment.

In the USA, the background to the expansion of modern science centres in 1960s was the Sputnik phenomenon. The crisis in national confidence that resulted from the successful launch of Sputnik had a knock-on effect on all education in the USA. The attitude towards the study and teaching of science dramatically changed. The educational system in the USA was totally reformed.

Exploratorium Science Centre started in San Francisco in 1968. In the 1970s and 1980s there was a period when nearly identical exhibitions were built by science centres just by copying exhibit units and whole exhibitions from other science centres. The main source for this was the 'Exploratorium Cookbooks', which were to a large extent published for this purpose. Many new institutes still utilise this concept for their main content which says much about the international nature of science and science centres.

However, the staff of science centres adapts their national and local features with their own ideas when choosing the content, design and programme ideas.

Frank Oppenheimer has been quoted as the creator of the science centre pedagogy. His criticism of the passive pedagogy of science education derives implicitly from John Dewey's ideas (1938) expressed in his thesis 'learning by doing'. The same approach can be seen in contemporary developments in science centre pedagogy: The famous hands-on principle articulated by Oppenheimer is a corner-stone of the principle of interaction in modern science centres. What Dewey and modern science centre pedagogy share is the accent on motivation, free will and the learner's own activity, stimulated but not forced.

The growth of science centres since the 1990s is closely related to the developments of the information society. Communicating science to the public via different media is not only a matter of giving sufficient support for scientific research and academic education in society but also a process of giving citizens their basic democratic rights in relation to scientific information.

The continuing world-wide trend is for a broadening of the subject range of science centres and an increasingly interdisciplinary approach to exhibition themes. One non-trivial problem that has been raised in the discussion of the role of science centres and universities is related to the meaning of the word 'science'. In English, science generally means the natural and physical sciences and is often limited to physics, chemistry and biology. However, in German, Swedish, Hungarian, or Finnish, the words ‘Wissenschaft’, ‘vetenskap’, tudomány, and ‘tiede’ include the humanities, history, psychology, social science and linguistics. The modern science centre must be able to present phenomena related to all academic research. Accordingly, the content of the leading science centres in Europe has been planned in an interdisciplinary way. The content of exhibitions is supported by a broad spectrum of temporary exhibition themes. Also the recent PISA-results are showing the importance of this relation and interaction between science and society.

Figure 2 presents the positions of a science centre in its relation to science, technology and education. It can be well used in order to explain and express the main goals of the European Commission Science with and for Society 2020 programme. It shows how these objectives are met through the cooperation between universities, science centres, schools, teacher education and school authorities. Science education is presented in at the point where science and education overlap. Science and technology meet in the area of research and development (R&D), within which academic research is used to develop industrial methods. Vocational education is at the intersection of technology and education.

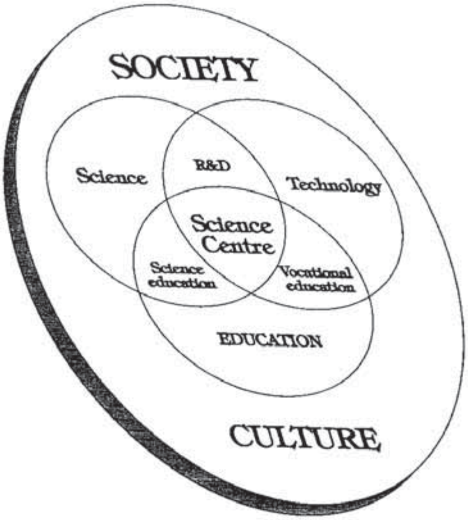

Fig.2. Education, Science and Technology in the context of Society & Culture [9, 7]

In the same figure, science centre is located where science, technology and education meet. According to this description, a science centre features all of these three fields. Any exhibition, event or educational activity like the science truck, combine these three elements and adapt them to the nature of the specific content.

Out-of school education often uses informal education sources for formal education. It forms a pedagogical link between formal education and informal learning. Science centre education is one form of out-of-school education [10].

The methods of informal learning have traditionally been used in, for example, the teaching of biology, geography learning, science education, museology solutions, and art education. To advance public understanding of science, new forms of education were actively sought [11]. Learning does not take place only in the actual world of school, but in the presented world of nature, parks, yards, science centres, gardens, and the media, as well as through the virtual worlds of the internet and social media [12]. There has been few activities related to mathematics education and learning in informal learning settings including science centre exhibitions [13,14]. The international mathematics happening BRIDGES arranged every second year is one of the few role models for this type of public understanding of mathematics exhibition and activities. Such results have been multiplied in the literature [10, 6]. However; science, technology and engineering have traditionally been tactile and become more and more visual, and many of the skills trained and taught are definitively not textual. Therefore, "here might be a mismatch between the structure of the knowledge and the structure of the print and language media traditionally used both impart and test that knowledge" [15].

Positive attitudes towards the science and technology and the motivation for science education are created at a young age both in the field of cognitive learning but also in the more affective sides of education. "Feelings, beliefs and values held about an object that may be the enterprise of science, school science, the impact of science of on society or scientists themselves" [16]. Attitudes have shown to be formed early, hard to change after elementary school. Because of this phenomenon, it is important to analyze and influence them before transition to middle school. The change of these false pre-concepts are especially difficult, if the attitudes have been formed more intuitively, automatically and on emotional basis than more consciously in process of time [17].

The big challenge is the fact, that the attitudes of girls already early ages become more negative towards science. Overall, students often tend to lose their interest by time. Therefore, analysing motivation, attitudes toward science and science education are essential in order to make predictions about whether and how the pupils will engage with science later in life and their career. It is essential not just for the individuals but also for society and the economy.

Recently some promising results have been reached in this area. How do science, technology, engineering, and mathematics attitudes vary by gender and motivation? Attractiveness of science exhibitions were carefully studied in six countries: Belgium, Estonia, Sweden, Latvia, Estonia, and Finland [18]. Science centres tend to give opportunities to hands-on experiences in an attractive learning environment. The study analysed attitudes, motivation and learning during a science exhibition visit, their relations to gender and future educational plans (N=1800 sixth-graders). Pupils' performance in a knowledge test improved after the visit. Autonomous motivation and attitudes towards science predicted situation motivation awakened in the science exhibition. Interestingly, the *scientist* attitude and the *societal* attitude were clearly separate dimensions. The third dimension was manifested in the *engineering* attitude typical for boys, who were keener on working with appliances, designing computer games and animations. *Scientist* and *societal* attitudes correlated positively and *engineering* attitude correlated negatively with the future educational plans of choosing the academic track in secondary education. The *societal* perspective on science was connected to above average achievement. In the follow-up test, these attitudes showed to be quite stable.

CONCLUSIONS

The main results of the science centre pedagogy can be stated as follows [19]:

1. Science centre education is still too much based on anecdotes and everyday knowledge.

2. Motivation is the main outcome of science centre pedagogy: how to move from situation motivation into intrinsic motivation!

3. Quality knowledge learning results can be achieved – but only by pre-lesson and/or post-materials in context of science centre visit.

4. The teachers must have courses related to science centre pedagogy to receive" cost-effective" learning results.

Also the European Commission's Rocard Report [20] has underlined the importance of this phenomenon. This report and other presentations describe the situation mostly in the pre-schools, primary and secondary schools while we also see the trends around the formal education. The role of learning in informal contexts is increasing in the modern societies – meaning the countries which are developing their societies by investing and creating opportunities for research, innovations, and education.

The digital technology and increasing computational complexity of daily practices are reorganizing our society. The quality of science education in primary and secondary schools is so rooted in the bright scientific history of Europe and so critical for its future that every effort should be made to remedy a far from optimal situation, such as that which we observe at the beginning of this 21st century. The European Union has all the necessary talents and tools to rebuild a strong educational system in science, able to communicate to every young person a taste for science, an understanding of its place in culture, and a vision of professional careers.

Science affects everyone's life. Thus, being scientifically literate is a civil right, and science education should promote accessibility to science by an attractive, inviting and not a too difficult pathway. However, both age and gender have to be taken into account. The modern movement for public understanding of science started from the Sputnik-phenomenon in late 1950s. Unfortunately, it seems that the humankind and the societies do react only after crises already have happened like the Tsernobyl accident, or are clearly treating like the Climate crisis. Scientific literate learners is one solution in the process of Science with and for Societies in 2020s.

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THE MAGIC TOWER OF EGER

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ABSTRACT

Programmes of the Magic Tower are housed in six different locations, which are the Magic Room, the Jedlik Ányos experimentarium (lecture-hall), the planetarium room, the astronomical museum, the panorama terrace, and the Camera Obscura. Having gained reputation, interest for certain programmes outside the building has increased. In the next sections, the work in the Magic Tower is presented by introducing each location one by one.

INTRODUCTION

The Lyceum of Eger was built between 1761 and 1785 as the home of a university. The key element of the building is the Specula or the Astronomical Tower (see Fig.1), where astronomical research took place after the construction. Later on, the Tower started functioning as an astronomical museum and the Eszterházy Károly College became its supporter. In 2006, the College broadened its museum activities with interactive experiments, experimental demonstrations, and planetarium shows [1]. Since then, the institute operates on four floors under the name Magic Tower. Its main tasks include the popularization of natural sciences, the scientific dissemination of knowledge, and turning young people's interest towards natural sciences within the confines of higher education.

Fig.1. Left panel: The Lyceum of Eger. Right panel: The Specula

Fig.2. Left panel: A staff member presents an exhibited device. Right panel: The Bermuda barrel at work. The black arrow shows the displacement of the toy ship

The Tower has about 24 000 visitors annually. Two third of them are primary and secondary school students, the rest are tourists. Students visit the Tower according to a pre-established schedule. Upon arrival, they are separated into parallel groups that explore the stations of the exposition in different order. The itinerary of each group includes about 20 minutes in the astronomical museum, 30-35 minutes in the Magic Room, 15 minutes in the Camera Obscura, 45 minutes in the planetarium room, 45 minutes in the experimentarium, and 20 minutes on the panorama terrace. The whole program takes almost four hours. Tourists spend less time, roughly 1 hour, in the Tower; they usually want to see only the museum, the panorama terrace, and the Camera Obscura. The guiding staff of the Tower consists of fourteen persons: nine college students, and four qualified members of the academic staff, all of them employed with part-time contracts.

THE MAGIC ROOM

The Magic Room houses more than 30 interactive experimental devices that help visitors to understand a wide scale of physical phenomena. These experimental stations do not only encourage hands-on experiments to teach the fundamental laws of physics in a playful and self-directed way, but they also give the visitors the opportunity to play scientific games. The method of demonstrations in the Magic Room is very different from those of secondary school. First, the professional staff describes the exhibited device and explains the law of nature behind its operation, then the visitors can try them themselves (see the left panel of Fig.2).

Our most popular experiments are the Bermuda barrel (see the right panel of Fig.2), the Lenz's law demonstrator (see the left panel of Fig.3.), and the hot air balloon (see the right panel of Fig.3). The Bermuda barrel is a transparent water tank with a floating toy ship (see the inset of Fig.2. right panel) whose average density is slightly less than that of water. At the very bottom of the tank, there is an aerator. When the aerator is turned on, the water becomes saturated with air bubbles, and its average density decreases to a smaller value than that of the ship. The ship goes to the bottom and stays there until the aerator stops. This phenomenon can possibly explain why ships get lost in the Bermuda Triangle.

The apparatus for demonstrating Lenz's law (Lenz cannon) can be seen in the left panel of Fig.3. It consists of an electromagnetic coil with an iron core, a switch, and a voltage source connected in series. Initially, an aluminium ring rests on the coil. When the switch is flipped on, the ring springs upward. The explanation is that the changing electric current in the coil generates a changing magnetic field in the core. This changing magnetic field induces voltage

Fig.3. Left panel: The Lenz cannon. Right panel: The hot air balloon is ready to start

and current in the aluminium ring. According to Lenz's law, the induced current will create a magnetic field in the direction opposite to the magnetic field in the core. Because of the opposite direction of these two fields, the core and the ring repel each other. In our case, the force between the "magnets" is strong enough to move the ring upward.

The hot air balloon presents the technology of the first successful human-carrying flight. The structure of the balloon is the same as usual: envelope, wicker basket, and hot air generator. The balloon can fly up to approximately 8 meters, but in this case, only the envelope flies. The basket with the hot air generator stays down, because the volume of the balloon is relatively small. The sideward movement of the envelope is prevented by a vertically extended metal wire. The scope of experiments in the Magic Room ranges from mechanical (e.g. hot air balloon, Bermuda barrel, Magdeburg hemispheres) through optical devices (e.g. laser blackboard, kaleidoscopes) to interesting features of electromagnetism (e.g. Lenz cannon). The operation of these devices gives delightful experience not only to children and students, but adult visitors as well.

JEDLIK ÁNYOS EXPERIMENTARIUM

The experimentarium is a classroom equipped with the most modern tools of educational technology where teachers of the Eszterházy Károly College give scientific lectures from fields of biology, physics, geography, mathematics, and chemistry (see Fig.4.). These lectures can be attended by classes of any primary or secondary school. The experimentarium also gives place to other programs, such as postgraduate courses for teachers, meetings of the local amateur astronomy club, and the Magic Tower Quiz, which is a scientific competition held yearly for primary school students of Heves County. The main aim of the competition is to popularize science subjects, although events are organized all year round in the Tower on poetry day, Saint Stephen's Day, and Advent Sundays. These programs are not typically scientific but science plays an important role in them.

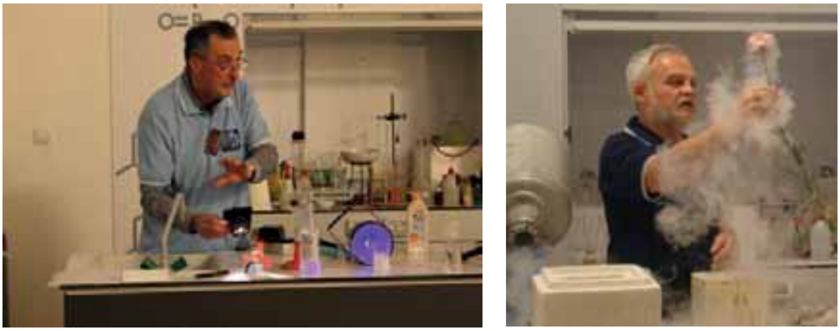

Fig.4. Experiments presented in the experimentarium. Left panel: The effect of ultraviolet radiation on a quinine solution. Right panel: The effect of liquid nitrogen on a rose

ASTRONOMICAL MUSEUM (SPECULA)

The Specula started its operation in 1776 as an observatory. It was equipped with the most modern astronomical instruments, which had been manufactured in workshops of London and Vienna. In the museum, you can see many instruments with the most different working principles: sundials, quadrants, reflecting and refracting telescopes (see the left panel of Fig.5), etc. A special sundial can be seen in right panel of Fig.5. It is a combination of a sundial, a cannon, and a burning glass. At noon, the glass concentrates the sunlight on the fuse of the cannon igniting the gunpowder and makes the cannon fire. Left panel of Fig.6. shows the great mural quadrant, which is an angle-measuring device. It is mounted on a wall oriented towards precisely the meridian. Astronomers used it to localize the position of a planet or a star. The special spectacularity of the museum is the Linea Meridionalis (see left panel of Fig.6.) or the Midday Line. The astronomical midday in Eger is marked by the moment when the shadow of a mark (see the inset of the picture) transits the Midday Line.

One of the specialties of the museum is that visitors get to see original instruments and devices at their original sites. In addition, the museum offers museum pedagogy programmes to visitors.

Fig.5. Left panel: Reflecting and refracting telescopes in the Astronomical Museum. Right panel: The sundial cannon, it can indicate noontime by a cannon-shot

Fig.6. Left panel: The great mural quadrant. Right panel: The Linea Meridionalis

PLANETARIUM

Our planetarium is equipped with a traditional planetarium projection apparatus. On the surface of the 6-meter-diameter hemisphere the copy of the starry sky can appear realistically. The planetarium programme shows the movements of stars and planets on the sky, and completes the astronomical knowledge of visitors. At the end of the show, they can ask the lecturer questions.

CAMERA OBSCURA, PANORAMA TERRACE

At the top of the tower there is the Camera Obscura architected by Miksa Hell (Maximilian Höll). Camera Obscura is a dark-room with a rotating periscope projecting the view of the city to a white, round-shaped, 266-cm-diameter table (see the left panel of Fig.7.). It is interesting because there are only two other similar instruments in the world. After the presentation, visitors can step out on the panorama terrace surrounding the building of Camera Obscura (see the right panel of Fig.7.), and can admire the beautiful panorama of Eger.

Fig.7. Left panel: The table of Camera Obscura. Right panel: The Camera Obscura surrounded by the Panorama Terrace

Fig.8. Left panel: Sun observation in Berekfürdő. Right panel: A water explosion experiment in a barrel with liquid nitrogen

The terrace is also the site of our telescopic observations and performances, which are connected to the activity of the local astronomy club as well. The Tower has three reflector and one refractor telescopes. During performances, staff members and amateur astronomers operate the telescopes and help the visitors to understand what they can see. Depending on the weather and the possibilities, the observed objects are planets, open clusters, galaxies, etc.

OUTDOOR PROGRAMMES

A couple of programmes can be taken to external sites. The staff members of the Tower are often invited as guest presenters by schools, organisations, and companies. These programmes are also very popular (see the panels of Fig.8.), the most popular one is the Astronomy Week in Berekfürdő [2].

CONCLUDING REMARKS

From the abovementioned aims of the Tower, the third one (young people's interest) is emphasised by social demand nowadays. Unfortunately, teaching of natural science subjects such as physics or chemistry in Hungary is in crisis, young people's interest is turning away from the field of natural sciences. Under such circumstances, institutes and organizations like the Magic Tower have a special opportunity and responsibility to do something in order to turn back this disadvantageous progress. This is the reason why currently our "target age-class" is the 15-18-year-old secondary school students. The numbers of invitations and visitors have been increasing recently, which implies the need for human resource development sooner or later.

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FROM FUN SCIENCE TO SEDUCTIVE SCIENCE*

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ABSTRACT

Science centres and museums have undergone a great evolution in recent decades although it seems that, lately, the science museum model has been somewhat stagnant. Since the radical changes of the mid-twentieth century, it has developed towards strategies in which visitor numbers take precedence over other considerations. Alongside a school science that still does not seem to attract a sufficient number of students to science, a trend has emerged with a focus on "fun science" in science centres and museums. We question this view and propose the idea of "seductive science" as an alternative to achieve long-term impact of museum visits, with an emphasis on scientific museology principles and inquiry based learning.

INTRODUCTION

In recent times, more and more science centres and museums are aligning themselves with the trend of presenting the visitor experience mostly as "fun", thus identifying the visit with a playful activity. A museum visit must certainly be unique and stimulating, but such an explicit identification with fun-related aspects can, in our view, leave out of the picture the wealth of other elements that a visit to a science centre or museum has to offer.

Let us first have a look at various factors that may have contributed to this trend:

- The focus on visitor numbers as a measure of success. It is indeed surprising that this is actually taking place in institutions that are meant to show how science works, with visitor numbers becoming, in practice, the only performance indicator of science centres and museums. Mission and vision statements always include a strong societal dimension, such as promoting uptake of science careers [1]. Naturally this should be also an important part of the evaluation of success, but we all know how scarce and difficult to obtain such evaluation data are (see for example [2] for one of the very few longitudinal studies available). As a consequence, there is the risk of just abandoning in practice the role of socio-cultural leadership science centres and museums can have within their communities and replace it with a focus on activities aimed at attracting ever growing visitor numbers. This is often done without the realm of museographic language, sometimes even under the disguise of bold experimenting with avant-garde museology.

- The use of business-style market studies. Institutions with a strong societal focus can certainly use market studies to gain a deeper knowledge of their public and so be able to ascertain what they can offer that is most appropriate. Unfortunately science centres and museums apply such studies in the same way businesses do – in order to learn about public demand and respond to it quickly. Paradoxically, one of the assets of science centres and museums is their ability to offer their audiences experiences previously unknown to them and for which clearly no demand will be detected via a direct and superficial market study.

- The identification of science centres and museums with leisure venues. Many members of the public identify science centres and museums as good leisure alternatives for a family day out keeping the children amused, rather than opportunities to share a creative museum experience. Whilst this approach by visitors is certainly welcome, it does not imply that museum managements have to share and cater for it as it is not aligned with the science communication aims and objectives they set themselves.

- The influence of "Braniac"-style TV shows. It may seem that science communication works well as a TV product, if one measures by the proliferation of programmes that have some degree of "science" in them, usually through spectacular science demonstrations that are fun and entertaining. Without questioning the good intentions of the producers of such shows, it has to be remembered that their main aim is not to communicate science, but to attract audiences measured by means of "shares".

- The influence of trends in schools. There is a current trend in schools which is concerned with ensuring –to a worrying degree— that pupils "feel good" and enjoy being in class, with the ulterior aim of preventing them from developing a distaste for learning, as it is proven that learning is strongly influenced by the learner's emotional state (cf. [3]). In this context, the main reason why many teachers take their classes to science centres and museums is for the pupils to have fun with science [4].

In summary, the demand both from school visits and family audiences seem to push science centres and museums to offer fun. Pairing science and fun can, however, bring about some unwanted consequences, as we will discuss in the next section.

FUN SCIENCE OR SEDUCTIVE SCIENCE?

Identifying science with fun can constitute a deceiving enticement towards science for the public, and in particular for prospective students of science careers, who constitute one of the main target audiences of a number of science communication channels, including science centres and museums.

The day-to-day work of a scientist hardly qualifies as "fun" if one looks at long lab hours, data analysis, or code programming, to mention but a few examples. A final year project supervised by one of us showed that those pursuing a career in science tend to distance themselves further and further from the concept of "fun" in science as they gather experience, and that there are numerous other adjectives they come up with to define science, such as fascinating, interesting, exciting, or important, for example [5]. In fact, assuming children will only do things they perceive to be fun could be considered a patronizing attitude towards them. Many children get involved in say, environmental or animal protection activities not because they think they are fun, but because they realize they are important [6]. However, repeatedly assuming they are only interested in fun could end up becoming a self-fulfilling prophecy.

Moreover, there is growing evidence that making science pleasant and fun for student does not go beyond improving their attitude towards science, as there is no correlation with decisions towards science careers, as reported in [7]. A recent broad study by Reach Advisors has shown that after a few years the most intense memory of a visit to a contemporary museum is often related to real objects of particular museographic value, even in the case of young visitors [8].

Focusing on fun during science centre and museum visits also leaves out of the picture educational considerations such as science centres and museums being ideal environments for constructivist, inquiry based learning [9], [10], [11]. Moreover, this can even have a backfiring effect in that it reinforces the idea that learning in class in inherently boring, the "fun" being outside the classroom.

Another often overlooked danger of the idea of "fun science" is that it dissuades scientists from getting involved in science communication, especially the most renowned and prestigious ones. In a day and age in which we are making a big effort to persuade the research community to get involved in public activities it is important to ensure they feel comfortable with it, and trivializing their work by portraying it as a show without substance certainly does not help.

TOWARDS SEDUCTIVE SCIENCE

We all know that another word for "fun" in English and other languages is "diversion", in one or other variant. In English the word "diversion" also kept the original Latin meaning of "turning away" from the intended path. This coincidence is a handy illustration of our view that overemphasising "fun" may "divert" or distract from the intended message about science, education or science centres and museums.

As mentioned earlier, there are many other adjectives that can be applied to science and which reflect much better what it represents: fascinating, exciting, thrilling… This is what "seduces" the scientists to make them willing to endure the hard and less gratifying aspects of research. They know that at the end of the process, obtaining results and drawing conclusions is an unmatched intellectual experience.

"Seducere" means in Latin "to attract" and this is exactly what should be strived to in science centres and museums – and in schools, too, we dare say—: to promote interest for science; to prevent the children's innate curiosity from fading off with time; to show pupils that a museum visit provides more questions rather than answers; to facilitate that excitement becomes fascination. To do so there are some fundamental elements a school visit should feature, which we list here with our experience and research as a basis, and without aiming to be exhaustive.

Collectively constructed science. The core of a science centre or museum is the exhibition. It should become the field where students in small groups collect data, where they observe nature, where the most exciting moments of encounter with the object or the phenomenon will take place. These data can then be analysed in the workshop rooms –their labs—, where they share ideas with their fellow students, and construct their own conclusions, which they can then communicate to the other members of their school or family group. Science is a collective human construction and in science centres and museums, there must be a constant interplay of doing, thinking and communicating, just as in real science, and as such, it is not necessary that everyone in the group does everything: there are different roles, and it is not about having done every single task, but rather about having gone through all intellectual stages and having taken part in the generation of new knowledge as a member of a team.

Science as a story. First, science needs to be portrayed as a human endeavour in constant change, embedded in culture, particularly in the culture of the visitors. To do so, science must be told as a story, scientific language has to become a narrative that links concepts with personal cultural experiences, almost like turning science into a new humanities discipline. Starting an activity as a story based in the use of different communication systems will help creating an emotional bond that can be referred to throughout its delivery.

Fig.1. Various children at the Museu Blau (Barcelona), attentively listening to a museum educator about a skull on display. Image: Museu de Ciències Naturals de Barcelona.

Science in dialogue with other disciplines. On the other hand, in a museum natural phenomena are presented out of their context. Objects displayed or exhibits that simulate natural processes need educational approaches which redefine their contexts and link them, again, to culture. This cannot be attained if science does not interact continuously with the other disciplines. Science may well be the central axis for a topic, but at the same level as, and in conversation with, other communication systems, the arts, mathematics, etc., so as to incorporate one of the key aspects of any scientific development: creativity, as reported in [12].

Consolidating learning. The museum is not a classroom, but the museum's assets can be developed to be an invaluable complement to classroom learning. In the science centres or museums we have little knowledge of how the teachers make links between the visit and the curriculum (or how the discussion will go on at home), as our contact time with visitors is brief and fleeting. Yet it is clear to us that, since two thirds of the visitors are not only looking for fun but for learning experiences, too, and 100% of teachers hope that learning will take place during the school visit to the museum [4], we must ensure this actually happens. The only way to achieve this is through a facilitated activity at the end of the visit in which participants have to apply their learning and the changes in the way they see reality that have taken place since they arrived. As we will mention below, the interplay of different communication systems and interdisciplinary dialogue will be key to this.

Calm Science. It easily follows from the previous points that, just like science itself, the whole process cannot be completed in haste. A visit to a science centre or museum has to be relaxed. Not only because science cannot be rushed, but simply because a high level of attention cannot be sustained for long periods of time, and it becomes necessary to alternate between moments of intense stimuli that require high levels of attention and other more relaxed ones that then allow to bring attention back to a high level. This implies that a museum visit, especially a school visit, needs to be as long as possible so as to include the necessary breaks. A whole morning would seem appropriate. But it is not only the delivery of the actual activity what matters, there are other relevant aspects that need to be taken care of:

a welcome at reception that is not rushed; moving through the exhibition floor quietly and without running; museum staff talking in a low voice; and everything that contributes to a calm atmosphere. This is radically different from the common scenario in which crowds of children shout and run around, press buttons without paying attention, etc., to the desperation of teachers, parents and museum staff.

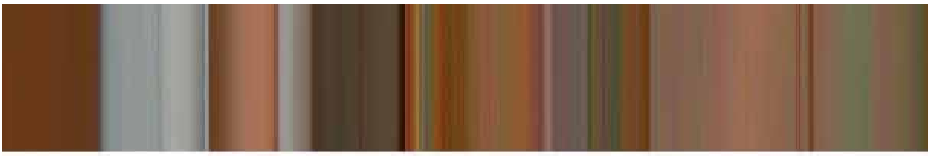

Fig.2. Exhibition "Iriscendium: the soap bubbles lab" at the Engineering College of Tarragona. A fascinated child spends an extended period of time with full attention in order to make an iridescent giant soap bubble. Image: Ruth Dolado.

All this is certainly not easy. It definitely is not in the absence of a professional education team. It is not if we do not have educators instead of explainers and guides, if we leave these activities in hands of interns without much experience –internships are something quite different— and without resources at their disposal, if we rely on temporary workforces without continuity within roles. Highly knowledgeable educators are needed –visitors hope to meet experts to help them understand [4]—, trained both in the subject matters and in education, and prepared to deal with diverse audiences and adapt any part of the activity to changing audience needs, knowing that it is their only shot with these particular members of the public. We need educators that can cater for very different visitor groups, with radically different needs and unknown expectations.

We know that in the current economic climate, advocating such a working model may seem frivolous, but education is not, and there is a lot at stake. We know that we are not doing particularly well, that citizens do not feel involved in the issues of science and technology, that fewer and fewer young students want to become scientists. We need to act now.

Otherwise we will certainly contribute to the entertainment of the population, but without effecting any change in how they see science in the long run or in their ability to recognise the essence of what we call the scientific method. In such a scenario we do not need science centres or museums – theme parks and shopping malls will suffice.

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INSPIRING PUPILS TO STUDY PHYSICS AND ASTRONOMY AT THE SCIENCE CENTRE AT-BRISTOL, UK

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ABSTRACT

An investigation was carried out to collect evidence that science centres can have a positive effect on young children's formal education in Physics and Astronomy. We explored whether the science centre At-Bristol's exhibitions and planetarium show align with the current UK curriculum guidelines in Physics and Astronomy and the point of view of pupils, a science centre educator and a teacher on whether they can increase further uptake of these particular subjects later on. The evidence gathered showed a positive alignment between science centres and curricular content and that science centres are indeed considered an adequate and effective tool in supporting learning and inspiration for subjects such as Physics and Astronomy.

INTRODUCTION

A report in 2001 stated that 'in many developed countries of the world, science education is seen to be in crisis. Pupils' attitudes to school science decline progressively across the age range of secondary schooling, and declining numbers of students are choosing to study science at higher levels and as a career' [1]. This suggested the importance to ensure primary school children are kept sufficiently interested in the study of Science. Particularly in Physics and Astronomy is interest likely to decrease at secondary school level [2]. It has been suggested that this could be due to the subjects themselves or to lack of scientific knowledge and enthusiasm from teachers [3].

As a response to this reality, many changes have been made in recent years to how Science is taught across the UK and to the subjects covered. As many of the subjects covered in the key stage 2 (KS2) National Curriculum are statutory, it is important to ensure children are engaging with the right information inside and outside of the classroom. According to the UK's Department for Education the three main changes made to the primary school National Curriculum in 2014 were towards 'More focus on learning outside the classroom', 'New content areas to be covered' and 'More types of inquiry are to be specified' [4].

In 2014 the science centre At-Bristol had approximately 35,000 visitors attending educational workshops at the KS2 level, an increase of 5,000 visitors with respect to the previous year 2013 [5]. A suggested reason for the increase of visits to a science centre could be linked to the government guidelines encouraging more focused learning outside of the classroom in Science subjects.

Science centres are often used by schools to encourage a hands-on fun approach to learning, but are also as important in supporting formal education [6]. Recent studies show that with increased visits to science centres, young pupils' existing knowledge is reinforced, allowing them to discover subjects in more depth inside and outside of the curriculum. A report entitled ‘The Effect of Science Centres on Students' Attitudes towards Science’ concluded that ‘Science centres can be used by educators as an effective way of increasing students' attitudes towards science.’ [7].

On the other hand, a recent increase of students studying in Physics and Astronomy at the level of Higher Education has been reported. The Institute of Physics published these statistics in 2012 [8]:

- The total number of full-time students in the first year of first-degree physics courses increased by 25% between 2004/05 and 2009/10, from 3190 to 3975.
- In 2009/10, 51% of physics, 52% of astronomy, and 46% of chemistry fulltime first-year students are registered on enhanced first-degree courses compared to 19% of mathematics, 17% of electronic & electrical engineering, and less than 2% of biological science students.

It is important to establish what factors have contributed to the growth in interest in subjects such as Physics and Astronomy in order to be able to further promote and inspire young children into having an interest in these and other fields. If science centres are realistically creating exhibits and workshops that are aligned with the current Primary Science National Curriculum guidelines there should be clear evidence that they are a useful supporting tool for schools and families.

METHODS

Data were collected over a period of four months in a primary school and in the science centre At-Bristol.

First, quantitative content analysis methods were used to look at the amount of significant written content relating to Astronomy and Physics in the texts displayed on exhibits and in the planetarium show script at the Science Centre. Key words were identified and their counts compared to those in the KS2 National Curricular content. Irrelevant subject material, i.e. words that were not featured in the National Curriculum, was removed from summaries to simplify the detection of key words in the text.

Second, a classroom teacher asked a number of suitable questions to the year 3 pupils of Shield Road Primary School. Their responses were analysed and quantified regarding the pupils’ knowledge of Physics and Space Sciences.

Third, a structured interview was carried out on the Key Stage 2 classroom teacher; predetermined key questions were asked, with the aim of establishing an academic opinion on the subjects taught on the curriculum and what more can be done to encourage further study.

Finally, an unstructured interview was completed with an Education Officer at the science centre, At-Bristol to gain insight into the current relevant Physics and Astronomy learning tools at the centre and explore the opinions of a professional working in education outside of the classroom.

RESULTS

The current National Curriculum at upper and lower Key stage 2 has 14 compulsory Science modules that are to be covered in the classroom. Five of these modules are based on Physical Processes and Astronomy.

The frequencies of selected key words relating to Astronomy and Physics in the 5 relevant modules are shown in Table 1.

Table 1: Frequencies of key words in Physics and Astronomy in the KS2 National Curriculum

Astronomy:	**Total**
Earth	11
Sun	8
Moon	5
Solar System	5
Planets	4
Space	1

Physics:	**Total**
Light	28
Sound	11
Magnet	16
Force	9
Electricity	7
Gravity	1

Of an overall exhibit total of 164 in At-Bristol, 36 exhibits are directly related to Physics and Astronomy. This is 22% overall. Key words correlating with the Physics and Astronomy subjects covered in the KS2 National Curriculum were searched for in the exhibit texts as an indication of how many are related specifically to the National Curriculum at KS2 (Table 2).

Table 2: Physics and Astronomy key word frequencies in exhibit texts

Astronomy:	**Total**
Earth	22
Sun	9
Moon	2
Solar System	0
Planets	7
Space	20

Physics:	**Total**
Light	41
Sound	31
Magnet	21
Force	9
Electricity	11
Gravity	11

It can be seen that practically all the key words are covered with several occurrences in the exhibit texts.

From the transcript used in the show ‘Exploring the Solar System’ in the Planetarium of At-Bristol we identified the key words that align with the relevant National Curriculum content (Table 3).

Table 3: Physics and Astronomy key words in the planetarium show

Astronomy:	**Total**
Earth	39
Sun	28
Moon	16
Solar System	21
Planets	21
Space	6

Physics:	**Total**
Light	7
Sound	0
Magnet	0
Force	0
Electricity	0
Gravity	0

Whilst the absence of Physics key words is understandable given the topic of the show, a Chi-Squared test shows that the distribution of words in the National Curriculum relating to Astronomy is not significantly different from that of the planetarium show transcript (Chi-square= 0.95), the P-value of 0.97 suggesting that the two distributions are equivalent.

The KS2 Planetarium show transcript covered 75% of statutory requirement topics that pupils should be taught in the Earth and Space module at upper KS2, including:

- Describing the movement of the Earth and other planets relative to the Sun
- Describing the movement of the Moon relative to the Earth
- The Earth’s rotation to explain day and night and the apparent movement of the Sun across the sky

Further, 50% of the non-statutory guided learning topics recommended in the Earth and Space module are also covered in more depth throughout the Planetarium show, including

- That the Sun is a star at the centre of our Solar System and that it has eight planets.
- A moon is a celestial body that orbits a planet (Earth has one, Jupiter has many)
- Pluto is now a dwarf planet

Responses to questions asked by the teacher at Shield Road Primary School to 30 KS2 pupils show that only one third have a knowledge of what Physics is, that two thirds have knowledge on Astronomy and Space that is not taught in school and that all would like to learn more about these topics. Also, two thirds have already had the opportunity to pursue this interest by visiting a Science Centre. (Fig.1).

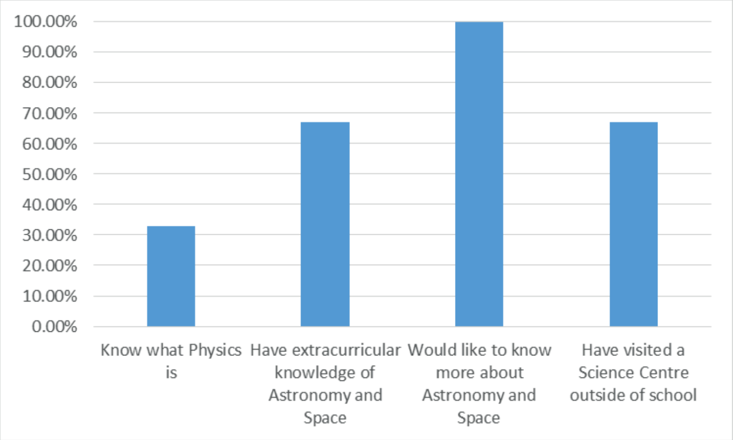

Fig.1: KS2 Pupils' responses to questions asked by the class teacher

The interview of the teacher showed that she and her colleagues agreed that the pupils would benefit from covering more topics in Physics/Space related subjects from a lower age, to give a better basis for the subjects and open up a potential interest even before upper KS2. Regarding interest in subjects that are not necessarily covered on the curriculum, especially in Science subjects such as Physics she pointed out the need for appropriate facilities such as science centres, museums and libraries, as it is sometimes difficult for parents to teach their children Physics based topics outside of the classroom as they are often not educated in these particular subjects themselves. Regarding school trips to At-Bristol and other opportunities to get hands-on with science, feedback was overwhelming and many pupils came out with solid knowledge of subjects they may not have been so confident in before, as well as expressing less of a dislike for subjects they labelled as 'boring' beforehand. So she would largely recommend more use of hands-on learning and encourage more trips.

The Education Officer of At-Bristol pointed out that Science Communication research suggests that if teaching and understanding of Science early in Primary Schools is sufficient then pupils are more likely to study the subject with confidence in later years. Ensuring pupils are getting the correct teaching is key, using Science Centres or other tools is sometimes necessary to support this. Visits to At-Bristol are designed to excite interest and build enthusiasm in Science as well as support learning in school. Many students have the opportunity to ask expert scientists questions that teachers do not cover and may not be able to answer in schools. It also gives students the chance to experience hands-on learning in laboratories and resources that are limited in schools. At-Bristol also encourages parents of children to come along and get involved with their children so they are able to engage about subjects that they can learn together when they have left the science centre.

DISCUSSION AND CONCLUSIONS

The evidence gathered shows a clear alignment between exhibits and planetarium shows at At-Bristol and the content taught on the Key Stage 2 National Curriculum, and that science centres are indeed perceived by pupils, teachers and science centre educators as an adequate and effective tool in supporting the content taught in school, particularly in difficult subjects such as Physics and Astronomy.

A study published in 2000 explores children's ideas in science. It explains that children, even when very young, draw different scientific conclusions and each have personal ideas and concepts when studying Physics based subjects. The study states 'students approach science in classes with previously acquired notions and these influence what is learnt from new experiences in a number of ways'. The study goes on to explain that students acquire information from several sources including texts and experimentation outside of class. It concludes that using supporting resources is paramount to ensure all levels of students attain a basic knowledge of Physics [9].

The views of the teacher and At-Bristol's Education Officer are consistent with a recent study on primary school children's developments in Astronomy concepts in the Planetarium. The results showed 'significant improvement in knowledge of all areas of apparent celestial motion covered by the planetarium program'. As well as results demonstrating that 'The value of both kinaesthetic learning techniques and the rich visual environment of the planetarium for improved understanding' [10].

This is further supported for example by a longitudinal study entitled 'Factors influencing elementary school children's attitudes toward science before, during, and after a visit to the UK National Space Centre' [11], which tested 10- and 11-year-old pupils from four schools regarding attitudes toward Science and Space before and after visiting the UK National Space Centre. The report concluded that nearly 20% of the pupils showed an increased desire to become scientists in the future and that immediately after the visit all pupils showed a more positive view on Space and a moderate increase in their views about the value of science in society. It also stated that the pupils that visited the centre 'showed a positive advantage over the other children with regard to science enthusiasm and space interest' and that 'Two months later, they continued to be more positive about being future scientist'. Again evidence shows there is a clear positive change in young children's attitudes toward science subjects when involving interactive and hands on learning spaces.

Although many improvements have been made to the science curricular content overall in recent years, this study suggests there is still a need for the inclusion of more Physics and Astronomy subjects at early primary school level to encourage future study in science based subjects, given that there is interest in such topics in KS2-aged pupils and that resources are available to schools and parents to support the pursuit of this interest.

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PROMOTING ENVIRONMENTAL PHYSICS ISSUES IN SCIENCE CENTRES AND AT SCIENCE EVENTS

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ABSTRACT

We consider that environmental physics issues could be interesting for students, but these topics are not included in the school curriculum. Organizing extracurricular physics events is of great importance as they present aspects that are related to everyday life and environment. We make an overview of experiments related to environmental physics displayed throughout different European science centres. We present experiments related to this topic performed during the annual event "Saturday of experiments" organized at the Babeş-Bolyai University – tsunamis, weather fronts, cyclones – and make suggestions for the possibility to display at science centres without the help of an animator.

INTRODUCTION

For students the process of learning physics is a very complex one, partly because of the abstract nature of many scientific concepts and of their mathematical representation. Topics of different curricula are related to simple physical models which in most of the cases do not relate to real-life situations. Because of their complexity, everyday life and environmental phenomena are difficult to be represented mathematically, so they are avoided in high school curricula. The other challenge of teaching these topics is to have an experiential approach to help better understanding. As for the moment we cannot have an influence on national educational policies, we try to summarise some informal learning activities to provide learning situations about our environment. Such informal learning activities are offered by science centres, different science events and student research projects. As an example of a science event we present the Saturday of experiments organized by the Faculty of Physics of the Babeş-Bolyai University and the EmpirX Association.

ENVIRONMENTAL PHYSICS IN SCIENCE CENTRES

Museums and science museums in special have a special educational role. In the case of museums the main motivational tools are intrinsic factors – such as curiosity, enjoyment in learning and mastery of challenge. Thus, learning in museums has a different character from that at schools, where extrinsic factors such as examinations, grades, approval of teachers are common motivators [1]. Mihaly Csikszentmihalyi has studied different intrinsically motivated activities [2]. He points out that this kind of learning is successful only when the challenge is close to but slightly greater than the skill level of the person and when feedback is immediate.

In the best museums, learning is a multisensory activity. Exhibits are visually exciting and most have a text to help explain the phenomena. But they also produce sounds and encourage touching. Because of this richness, museums and exhibits have the opportunity to connect with many different learning modes that people use.

We have made a short inventory – some of them by personal visits, some from the information provided by the scientific boards of the museums – of environmental physics exhibits in different European science museums. We have gathered information from the following ones: MUSE Trento, Italy, Phaeno Wolfsburg, Deutches Museum Munich, Germany, At-Bristol, Techniquest Cardiff, Wales, Science Museum London, UK, Technisches Museum Wien, Austria, NEMO Center, Amsterdam, Netherlands, Hiša Eksperimentov, Ljubljana, Csodák Palotája Budapest, Hungary. The playful atmosphere of science centres leads many people to think of them as places only for children. But "playing" is a serious matter in science education. It leads to the development of skills in observation and experimentation and the testing of ideas, and it provides an opportunity to independently discover order in nature.

Fig.1. Flow tank at Techniquest Cardiff [3]

We have found a diverse presentation of environmental physics related experiments, being hard to summarize them in one paper. Phenomena related to fluid dynamics have a special interest for us, as this is one of the topics which is avoided in our curriculum in high schools, not only in the Romanian educational system, but in the Hungarian as well. The most often presented phenomena are: turbulent and laminar flow, the Bermuda bubbles, vortices and tornados. The flow tank appears in many museums in the form of a tank of fluid with shiny mica crystals, inside which the visitor can move and rotate objects of different shapes with the help of a magnet, like the one shown in Fig.1. from Techniquest in Cardiff. With the help of these objects the visitor can experience the occurrence of turbulent flow and make connections with phenomena experienced in everyday life. In some cases turbulent flow is presented in connection with the atmospheric movements through a semi-spherical dome which can be rotated by the visitor (NEMO Center Amsterdam).

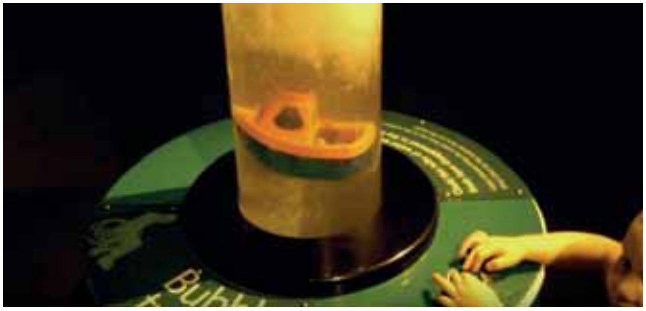

Fig.2. The Bermuda bubbles experiment in At-Bristol museum [4]

The mystery of the Bermuda triangle is a commonly known phenomenon where a number of aircrafts and ships are said to have disappeared under mysterious circumstances. We can argue about the accuracy of the data but our goal is just to find a possible explanation. Laboratory experiments have proven that bubbles can, indeed, sink a scale model ship by decreasing the density of the water [5]. Based on this, in many science museums the experiment is presented with the name: Bermuda bubbles, which consists of a large cylindrical tank filled with water and the visitor can adjust the amount of air released into from the bottom of the reservoir. The visitor can observe (Fig. 2.) how the model ship sinks to the bottom of the tank (At-Bristol). If the water is full of bubbles it is a much lighter fluid then ordinary water, so water full of bubbles cannot hold the ship.

SATURDAY OF EXPERIMENTS AT BABEŞ-BOLYAI UNIVERSITY

In our town, Cluj-Napoca, we do not have a functional science museum, but as one of the major cultural, academic and industrial centres of Romania there is a real need to have a science museum. We have tried to achieve something similar with the one-day event called *Saturday of experiments* which is organized once a year. It is organized by the Faculty of Physics at Babeş-Bolyai University in partnership with the EmpirX Association in the main building and the courtyard of the university every spring in April or May. In comparison with science centres it is a low budget event, as the exhibits are low-cost ones, they cannot be used individually, so each exhibit is presented by a guide. Even so, most of the exhibits are hands-on, thus the presence of an animator represents an advantage facing science centres, as the visitor has a person to ask his questions, to discuss the observed phenomena in detail, reaching a higher level of understanding. More than 60% of the visitors are high school students, as our aim is to keep their interest in physics alive. The animators are selected from among the students of the Physics Department, who are prepared in advance by their tutors, to present in pairs or teams a certain experiment and to reply to the visitors' questions. This is an excellent way to provide teaching practice for them. At each edition of the event, we present around 40-50 exhibits, many new ones as well, but there are some much enjoyed by the public, presented regularly. The visitor has free choice in both the experiments and the order of visit, similar to the science centres. We print out leaflets with the map of the event site and the location of each experiment. The event is with free entrance and it has become one of the main scientific events of the city, attracting more than 1000 visitors not only from Cluj County, but some schools are organizing trips for their students even from a distance of 300 km. The project *Saturday of experiments* was supported by grants from Bethlen Gábor Foundation, Cluj County Council and sponsorship from SKF Romania.

As first impression is always important, at the entrance to the event we project one of the main attractions of the day, like experiments with smoke rings or experiments with liquid nitrogen. Smoke rings are produced by a card box (about 80x80 cm base) with a hole of about 30 cm on the top. The bottom of the box is replaced by a membrane. The box is filled with smoke and rings are produced by hitting the membrane. We have used two boxes at the same time to observe the collision of the smoke rings, too. Liquid nitrogen is used for several experiments, like levitation of a magnet above a superconductor (Meissner effect), rapid freezing and crushing of different plants or placing inflated balloons into liquid nitrogen to observe the thermal contraction and expansion process of the air.

We have carried out a survey among the visitors about the most attractive exhibits in order to have a feedback of the event. Visitors were requested to complete a questionnaire at the end of their visit. They were asked to name the five most attractive exhibits. Among the most cited was the one called tsunami, which consists in a long water tank (dimension of the water tank: 297x12.8x35 cm), which is separated in two with a plexi glass. If at the beginning we make a difference of water level in the two sides, at the removal of the separator a soliton wave is formed which travels along the surface, as shown in Fig.3. A soliton is a wave-packet which maintains its shape while it propagates at a constant velocity. A remarkable quality of these solitary waves is that they collide with each other and yet preserve their shapes and speeds after the collision.

Fig.3. Soliton wave in a water tank, after the removal of the separator, presented at the Saturday of experiments event in 2015

In attracting talented students towards the study of physics, a significant role have the research projects realized by them. Inspired by the soliton waves, Vivien-Emőke Bartha and Botond Biró, students in Apáczai High School ran a project (simulation of known physical systems) using the experimental setup presented above to prove the relationship ($c = \sqrt{gH}$) between the travelling velocity of the soliton wave (c) and the depth of water before the separating glass is released (H), where g stands for the gravitational acceleration. They have found a very good correspondence between the theory and the measured data. They performed a two-dimensional computer simulation as well, which proved the formation of the soliton wave in such conditions [6]. In this project they were helped by a supervisor, a PhD student, Dávid Deritei, a former student of the high school. This project shows that science centres or science events may have long lasting influence on the interest in studying physics.

With the same setup we have presented weather fronts as well. For modelling the cold front we put cold water in the left side of the tank, and warm water into the right hand side (left panel of Fig. 4.). When releasing the separating glass, the water from the two sides mix together like in the right panel of Fig 4. The difference between cold and warm water can be highlighted by colouring the water in the left hand side. These experiments were inspired by the fruitful collaboration between the Physics Department of Babeş-Bolyai University and the Kármán Laboratory from ELTE University in Budapest. About similar experiments in this laboratory you can read in detail in the paper of Miklós Vincze: *Modelling climate change in the laboratory*, published in this same proceedings book of the conference.

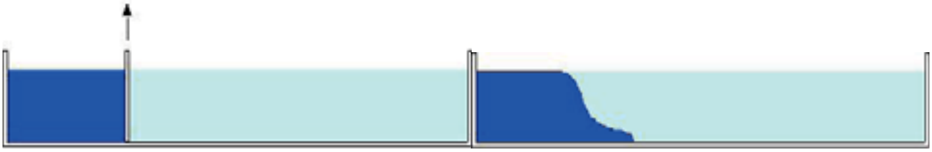

Fig.4. Left panel: Water tank separated in two by a glass with cold water in the left and warm in the right. Right panel: After removing the separator, the cold water moves similarly with the cold front [7]

Some atmospheric phenomena are intriguing, such as the von Kármán vortex street (Fig.5.). It is a repeated pattern of swirling vortices behind objects in a stream of a fluid. They appear on the two sides rotating in opposite direction and are caused by the unsteady separation of flow [8]. In order to save water, we use a cylindrical vessel with water on a rotating disc. We introduce the needle of a syringe that stands as an obstacle in the stream of water created by the rotation. The red ink released from the syringe is for visualizing the vortex street (left panel of Fig. 6). The syringe is moved slowly from the margin to the centre of the vessel, as the vortices can be seen for longer time. The von Kármán vortex street is visible behind the syringe as in the right panel of Fig. 6. Animators used to explain that vortex street is observable in our direct environment around a stone in a stream of water and could be tested with the help of some leaves dropped into the stream. Another example is the fluttering of a flag generated by the flagpole.

Fig.5. Landsat 7 satellite image in September 1999 above Selkirk Island, off South America. Credit: Bob Cahalan/NASA, USGS

Fig.6. Left panel: rotating disc with cylindrical vessel with water, Right panel: von Kármán vortex street visible behind the syringe

According to our information, the latter two experiments presented above are not displayed in science museums, but because of their expressivity we propose them to be adapted in a hands-on manner. As for the case of the von Kármán vortex street experiment, the visitor could adjust the rotational velocity of the vessel, and to manoeuvre the syringe. With a robust construction, the experiment could be run safely even by a young student, in order to be displayed in a science museum.

CONCLUSIONS

Science museums have a diverse field of experiments, and in each case we have found a huge number of exhibits related to environmental physics: energy production and conversion, fluid dynamics, pollution, waste management. In this paper we presented only those related to fluid dynamics, as we think they are of great interest, because this topic is missing from the school curriculum, and related to it some new phenomena could be presented in science museums as hands-on experiments. We propose two experiments to be presented in this way: the tsunami and the von Kármán vortex street.

The *Saturday of experiments* science event has the following advantages: possibility for the visitor to ask questions about each exhibit, to have a discussion on the observed phenomena with a young scientist, it is a low budget event, the explanations can be adapted according to every age group and to the level of the individual knowledge. The event is a proper way to give the university students practice in both teaching and team building. Disadvantages of these events to the science centres: a lot of volunteers are needed, sometimes it is overcrowded at some exhibits, so some visitors could miss out some experiments, it is organized only once a year. The *Saturday of experiments* is a very good way to promote science in general and physics in particular, thus completing the formal educational tools and even leading to engage high school students in demanding research projects.

There are cases when science centres try to promote science in a more direct way. This is the case of Hiša Eksperimentov from Ljubljana, where each year a three-day long science festival is organized with a lot of volunteers engaged reaching outside the walls of the museum, and engaging the entire town centre into exciting science lectures, presentations and events. This way physics can reach the general public.

Science museums and science events as well, regard learning in a minimally guided approach, described under a variety of names: discovery learning, inquiry based learning or experiential learning. Formal education can use these methods only rarely, thus these events and institutions are excellent for deepening some existing structural competencies and knowledge [9].

ACKNOWLEDGMENTS

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THE MOTIVATING ROLE OF THE FULL DAY EXPERIMENT PROGRAMME CALLED “PHYSICS SHOW” IN TEACHING PHYSICS AND CHEMISTRY

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ABSTRACT

Our school organized an experiment show day for the eighth time in 2015 where students demonstrated and explained experiments in physics and chemistry (in the last two years in biology, too) to their fellow students. In this article I will provide a short review of the history and organization of the full-day experiment programmes held for the public annually. I am going to report the way how the composition of the visitors, their number, and their opinion have developed during each programme. My accompanying students demonstrate a few physics and chemistry experiments chosen from the former show programmes, which can motivate learning physics and chemistry.

INTRODUCTION

In this article I am going to introduce our “Physics show”. The show is a round-the-clock presentation of physics experiments. It takes place in our school, in Szent László ÁMK, in the city of Baja, usually in late April. The first show was held by students from the study group of physics in 2001. The renewed shows have continued since 2007 with attached chemistry and later biology experiments. The shows are organized year by year by study group and science workshop students with the help of their teachers.

THE PREPARATION FOR THE “SHOW”

After selecting the experiments, we choose the members of the groups for presentation. They practise in study groups, in science workshops, in the afternoons and sometimes in class if the experiment fits in the curriculum. We advertise the show in schools in town and in nearby villages, in newspaper ads, in the local radio and TV and on the Internet. Fig.1. shows the number of students carrying out experiments

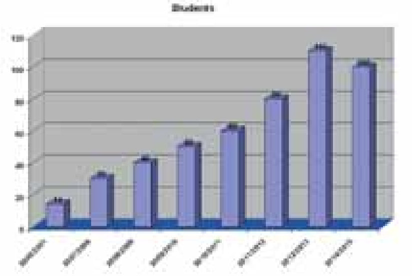

Fig.1. The very first show was held by only the study group students in 2001. Since 2007 volunteers also have been able to take part along with the study group students

VISITORS

The visitors of the show consist of our students, students from the schools in the area, their teachers, and children from the nursery school. We have very positive feedback. They expect to have it every year and encourage us to organize it again. Fig.2. shows the estimated numbers of the visitors of our show.

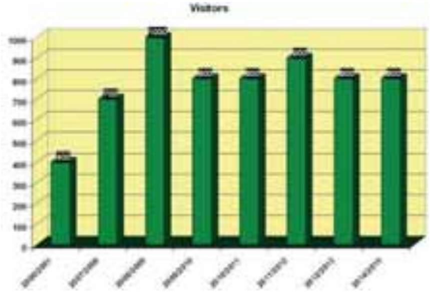

Fig.2. The estimated number of visitors based on preliminary registrations. In 2008 the show was held in two mornings

EXPERIMENTS

We selected experiments from books and from the internet. We have already demonstrated mechanics, electricity and magnetic phenomena, light and heat phenomena, nuclear physics together with chemical and biological phenomena. Fig.3. shows the increasing number of experiments in the shows. In 2011 on the anniversary of the discovery of the nucleus we carried out exactly 100 experiments [1].

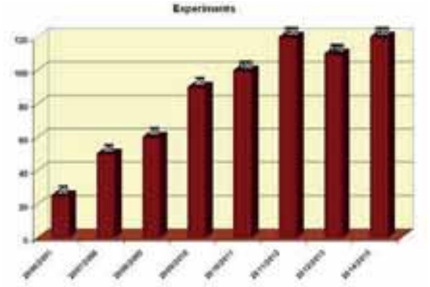

Fig.3. The increasing number of the physics show experiments

THE FIRST EXPERIMENT: ELEPHANT TOOTHPASTE

In this experiment, 30% or 35% hydrogen peroxide is mixed with some liquid soap, and then a catalyst is added (potassium iodide), to make the peroxide break down rapidly. As the peroxide breaks down, it releases a lot of oxygen. It results in a very showy outpouring of tiny soap bubbles. Hydrogen peroxide contains a lot of oxygen. The more concentrated the peroxide is, the more oxygen it releases. The oxygen gushing out is what makes the soap bubbles move. As the peroxide breaks down the soap that was mixed in will also combine with the water and turn into foam. A burning match reveals the presence the oxygen. Often some food colouring is added before the catalyst, which makes the resulting column of foam gushing out look even more like toothpaste. Fig.4. shows a student dropping a match into the foam [2, p.638].

Fig.4. A burning match began to glow dazzlingly because of the oxygen.

THE SECOND EXPERIMENT IS: HYDROGEN GUN

Our hydrogen gun is made from a plastic film box attached to a plastic tube. We filled the film box with air mixed with hydrogen. Hydrogen gas is produced by reacting an active metal, zinc (Zn), with hydrochloric acid (HCl). Having fixed the top, the compound is blown up with a sparkle made by a piezo-lighter. This exothermic reaction yields 286 kJ/mol of water formed. The rapid release of a considerable amount of energy causes the surrounding air to expand suddenly, resulting in a sharp explosion. The best 'pop' is usually achieved with a mixture containing 20 - 40 % by volume of hydrogen. Fig.5. shows the ignition of the mixture by a piezo-lighter [2, p.461.].

Fig.5. By pushing the piezo lighter Dóri starts the combustion of hydrogen-air mixture

THE THIRD EXPERIMENT: A LAMP FROM PENCIL REFILL

A thin pencil refill is placed between alligator clips fixed to a stand. It is connected to the power supply and the current is slowly increased. The thin graphite starts glowing due to the Joule-heat and then the carbon goes into reaction with the oxygen. At this time the pencil refill begins to glow dazzlingly. We cover it with a glass shade. The light goes out when the graphite burns away and cracks. Fig.6. shows the glowing refill when current flows through it [3].

Fig.6. The pencil refill starts glowing dazzlingly because of the Joule heat. The reaction between the carbon and the oxygen increases temperature

THE FOURTH EXPERIMENT: CONDUCTIVITY OF GLASS

Bulbs are set up in serial connection, one of them is broken and the tungsten filament is removed. This light bulb is heated in the closed circuit. When all the glass has melted permanently the other lights starts glowing again. Glass is in fact is a high viscosity liquid. During heating its viscosity decreases and it is able to flow (ductile over 600 °C). Cations can always be found in glass (Na^+, Ca^{2+}, $Mg^{2+)}$ as well as anions (HCO_3^-, BO_3^{3-}), which are able to move due to the electric field resulting from an electric current. If it cools down, it will stop. Fig.7. shows heating the glass of the broken bulb and the other one beginning to glow [4].

Fig.7. Tünde heats the glass of the broken bulb to melt it

THE LAST EXPERIMENT: BURNING MONEY

Prepare a water-alcohol mixture by combining rubbing alcohol with of water. Make sure to stir the mixture thoroughly. We used 50 ml of 95% ethyl alcohol with 50 ml of water. Borrow a bank-note from your friend. Dip it into the mixture of water and rubbing alcohol making sure it is completely soaked. Remove it using the tongs - squeeze out any excess liquid. Hold one end of it with tongs and light the bottom of it. The bank-note will *seem to be* burning, but it should not burn (famous last words). When the flame is completely extinguished, it is safe to touch the money... you will find that the money is even cool to the touch. Alcohol burns with an almost invisible blue flame. One trick is to add a little table salt to the water-alcohol mixture to make the flame more visible. The water from the water-alcohol mixture absorbs much of the heat energy that is generated when you light the bank-note. If you reduce the amount of water in the mixture, the paper money is likely to be charred or even catch fire. Fig.8. indicates the girls burning my 5000 HUF [5].

Fig.8. My "bad" students are burning my bank-note, fortunately they are not able to

POSITIVE OUTCOMES

In our school only a few students want to take a final exam in physics. As a consequence, they show little interest towards the theoretical and calculation problems of the subject. These events arouse the students' interest towards the phenomena and the experiments. During work they appear to be patient and try to be precise.

They are open to recognise interesting experiments found on the Internet. If necessary, they gear the given experiment to our facilities, to our appliances at hand. Their self-confidence grows when the experiment compiled and revised by themselves works. Even if it does not work, their endurance and creativity improve while correcting. Their communication also improves. They are proud to show and explain the experiment to the visitors, especially to their fellow students and teachers and do it in a very concentrated way.

They get better at experimenting and at manual skills. They become more patient, they get to the core more easily, sometimes even their aesthetic skills improve during the preparations and the presentation. They get more involved, certain rules and concepts get meaningful for them. Their skills in dealing with problems improve especially in solving practical difficulties. Their efficiency in learning academic curriculum gets better after they have relived the joy of understanding and carrying out an experiment. They enjoy showing and explaining experiments to visitors, their attitude towards the subject improves. Most of the visitors are students from our school who take in the explanations coming from their fellow students better than the usual teachers' ones.

On the whole, the episodes of the physics "show" mean twice as much for the presenting and the visitor students as even a double-time longer physics lesson. During the consecutive weeks several of them would like to take part in the presentation, in the work of the study group and ask about the date of the next show.

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FIRE TORNADO

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ABSTRACT

The fire tornado is a special natural phenomenon that can be produced artificially, too. It is significant in the science centres because it is really spectacular and easy to show. Moreover, it models a large range of phenomena in physics, technology and chemistry. Therefore, it can be applied in experiments as well as in study groups. A popular device modelling the fire tornado has been developed by the Mobilis Science Center. The phenomenon can be presented in several ways. We can demonstrate the turbocharger, the gas turbine, the conditions of burning, and the chemistry of flame testing with it. A simplified explanation of the complex hydrodynamic processes taking place in a fire tornado will be also presented.

1. NATURAL PHENOMENON

Fire tornadoes are vertical fire whirls which can be observed in wildland, urban, and oil spill fires and volcanic eruptions. Fire whirls have also been called fire devils, fire tornadoes, and even firenadoes. Their size extends from 1 meter to 3 km in diameter. They can be observed easily due to the burning gases, ash and smoke. Fire whirls are rare but often devastating forms of fire which may occur for example when a stronger convection blows into a forest fire [1]. Due to the convection the fire is often transformed into a several meter high, rotating fire column. Fire whirls accelerate combustion, produce significant suction pressures and lifting forces, and can carry burning debris. Studying them is very important because of their great potential for damage when occurring in nature [2, 3]. The dynamics of the fire tornado is similar to other swirling atmospheric phenomena such as dust devils, waterspouts, and tornadoes [4]. Although fire tornadoes are rare and special natural phenomena, they can also be easily produced artificially. Fire whirls produced in laboratories are widely used for the investigation of the properties of the fire tornadoes [4-6]. Besides their scientific values, these whirls are very spectacular and therefore might be tools for motivating students for learning physics. In the following we are dealing mainly with these latter aspects of the phenomenon.

2. ARTIFICIAL FIRE TORNADO

Artificial fire tornadoes are very spectacular and therefore they are very popular experiments at physics demonstrations of Science Centres. Lots of films about them are available at Youtube [7] too. The phenomenon can be produced in several ways, it can demonstrate a lot of phenomena in physics and chemistry. The fire tornado can be easily demonstrated with the use of simple devices in the laboratory. We need a rotating disk, a small non-flammable bowl and acetone. (Any other easily flammable liquid is proper e.g. 96 % alcohol.)

Put a small bowl into the middle of a rotating disk. Fill it up with acetone (about 50 ml) then set it on fire. A slightly flickering flame of about 15-20 cm height appears. Starting to rotate the disk, nothing special happens. The height of the flame remains about only 15-20 cm. However, if the small fire column on the rotating disk is covered by a cylindrical wire mesh the flame will grow up and twist. Reversing the direction of the rotation the flame twists in opposite direction.

3. THE PHYSICS BEHIND

In spite of the popularity of the artificial fire tornadoes, their physical explanations available on the Internet are often insufficient and incorrect. The reason for this maybe is that the underlying physics is complex, the mathematical description of the phenomenon is not simple and the various approaches presented in the scientific literature are too sophisticated [5, 6]. However, in our opinion, taking into account the experienced properties of the artificially produced fire tornadoes a relatively simple approximate explanation can be given for them.

Our experiments - in accordance with the literature - have clearly shown that the development of a fire tornado needs a flame in which burning gases are ascending in a buoyant plume and the length of the flame can be increased by imposing rotation on this plume[1]. Keeping constant the rotation velocity and the burning rate a steady fire column is created. According to detailed investigations [3, 5] this hot column is rotating as a rigid body, therefore its azimuthal velocity increases proportionally with the radial distance measured from the centre of the whirl.

The phenomenon is analogous with the whirl coming to existence in rotating a water column (Fig.1.). Pour some water into a magnetic mixing bowl, scatter some tiny buoyant plastic granules onto the surface of the water and start to rotate the water. A conical whirl is appearing and is getting deeper and deeper, the tiny pieces are gathering on the side of the cone, some detach from the surface and move downward. Throwing more granules into the water, it can be seen that the pieces go closer to the axis of the whirl [8]. The water whirl corresponds to an upside-down fire tornado, where the tiny plastic pieces with low density correspond to the hot gases [9].

Fig.1. Water whirl Left panel: with plastic granules [photograph taken by the author in the von Karman Lab of ELTE]. Right panel: with coloured oil [10]

The two phenomena differ in the boundary conditions. While in the fire tornado the less dense warm air is flowing inward along a rigid ground, the whirl of the water column is generated in a cylindrical vessel of rigid wall. In the latter case the centrifugal force presses the water outward, which climbs on the wall of the cylinder and produces a conical surface. Therefore the height of the water is increasing with the increase of the radial distance and due to this a pressure gradient force rises, which balances the centrifugal force. The tiny plastic pieces are floating on the conical interface of the water and air. The tiny buoyant particles move in the water and in the air upward and downward, respectively.

The existence of the stable and steady rigid body-like rotation of the fire tornado can be supported by simple arguments. The reasoning can be accomplished either in inertial or in accelerating frames. The comparison of the two ways might be very instructive for secondary school students. In the frame rotating together with the flame

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[1] According to our experiences at the beginning of the rotation the length of the flame increases with the increase of the angular velocity. However, reaching the angular velocity of 9 1/s, the fire column has not increased anymore; moreover it decreased a little, to the half of the height of the mesh. It means that a fire tornado has an optimal angular velocity to make the fire column be the highest.

column, the air particles are at rest due to the balance of the centrifugal and pressure gradient forces. With the notation of Fig.2. the forces acting on a cubic particle are:

$$F_{hidr.} - F_{cf} = 0$$

$$F_{hidr.} = p(r + \Delta r)\Delta r^2 - p(r)\Delta r^2 = \Delta p\, \Delta r^2$$

$$F_{cf} = \rho_{fluid} r \omega^2 \Delta r^3$$

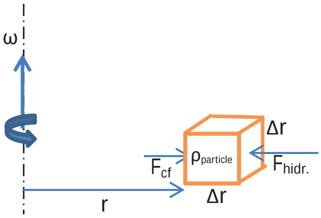

Fig.2. Air particle in the rotating flame column

It means that in the rotating fluid the pressure gradient is:

$$\frac{\Delta p}{\Delta r} = \rho_{fluid} r \omega^2$$

If there are density fluctuations in the flame and the density $\rho_{particle}$ of an air particle differs from that of its environment then a buoyant force acts on it. Due to this force the particle moves inwards (toward the centre of the rotation) if $\rho_{particle} < \rho_{fluid}$, otherwise if $\rho_{particle} > \rho_{fluid}$, it moves outwards. In the flame columns generally temperature fluctuations lead to the density fluctuations. Therefore as a consequence of the temperature fluctuations a secondary flow is generated in the flame column, hotter gas particles flow toward the rotation centre. This secondary flow strengthens the convection of the hot gas and lengthens the flame column. Due to the lengthening of the flame column its rotation is also accelerating. The effect is similar to the acceleration of rotation speed of figure skaters when they pull in their originally outstretched arms and decrease their rotational inertia.

A common misinterpretation of the phenomenon is based on Bernoulli's law. According to this explanation the pressure at the two sides of the mesh is different due to Bernoulli's law, therefore the air is flowing outwards at the mesh. This outflow is compensated by a descending flow along the mesh. This descending flow strengthens the upward motion of the air in the flame which - as a consequence of this - is lengthening and tightening. However, the Bernoulli-effect in this case is not strong enough to influence the flow largely. Because of the 1-mm thickness of the mesh and its relatively low azimuthal velocity air pressure difference is negligibly small between the two sides of the mesh.

A more correct interpretation may be the following: The inner surface of the cylindrical mesh drags the air so the flame starts to twist. The hot gases with small density flow up, as in a chimney, and they pull the flame up. The entrainment of the fresh air can occur only through the holes of the mesh.

4. THE APPLICATION OF THE FIRE TORNADO IN SCIENCE CENTERS

4.1. THE SOURCE OF THE IDEA

We have seen an artificial fire tornado for the first time at a demonstration performed by László Róbert Zsiros [11]. His construction, the idea of which originated from Heureka Science Center in Finland differed from everybody's one.

Zsiros used a boxy shape trash can instead of the cylindrical wire mesh for covering the flame. This setup was also suitable to create a fire tornado.

2. SELF-DEVELOPED VERSION

In Hungary the Mobilis is the only Science Center which presents the fire tornado as an experiment in science-shows and roadshows as well. We have remade the model and it became safer, more spectacular and still portable.

The data of our self-constructed device are the following: the thickness of the wire of the cylindrical mesh is 1 mm, the diameter of the holes of the mesh is also 1 mm, and the centres of the holes are 3 mm far from each other. The diameter of the cylinder is 40 cm, its height is 1.1 m. The flame obviously grows up to the top of the cylinder.

Preparing the cylinder (Fig.3.). A flat highly perforated plate of 1 mm thickness was bended into a cylinder of 42 cm in diameter. The bending of the plate was to be made cautiously because during it high forces are arising in the plate. The edges of the plate were fastened by five screws.

Fixing the cylinder and the fuel bowl Three L shaped steal plates were fastened to the rotating disk leaving narrow gaps between the rim of the disk and the vertical part of the plates. The cylinder should be slipped into these gaps to fix it. The fuel bowl was fastened by three nails.

Safety conditions: The safety implementation is very important because most people are afraid of the experiment. After lighting up the acetone, refilling is dangerous and it is forbidden. The removing of the cylinder is also forbidden until all the fuel has burned out.

This self-made form has won a prize at an experiment innovation competition which was hosted by the OFI (Institute for Educational Research and Development) and the EvoPro Kft together [12]. These Institutes made a promise to develop a standardized production from this equipment which can be easily used for demonstrations at schools.

Fig.3. The self-developed fire tornado and the equipment

4.3. SCIENCE CENTER MODELS ABROAD

The Science Centre Singapore has got a 5-mhigh device. For this equipment - as it can be seen in the video [13] the air flow is ensured with strong blow. This form is very spectacular but it is not interactive. The construction is very complicated and not portable.

The Phaeno Science Center in Wolfsburg, Germany has got a more than 6-m-high equipment. This construction is one of the most popular experiments in Wolfsburg. The air flow is ensured by ventilators which suck up the air from the space above the fire column. [14]

There are fire tornadoes which work with upper ventilators in Poland at the Copernikus Science Center (Warsaw) and in England at The Magna Science Adventure Center (Rotherham) too. Each of these pieces of equipment is several meters in height and is not portable.

5. METHODOLOGICAL AND DIFFERENT MODELING OPPORTUNITIES

5.1. WHY DOES THE MOBILIS SCIENCE CENTER USE IT?

The Mobilis Science Center has a unique subject in experiments, it focuses on car-vehicle-transport. The other Hungarian Science Centers are dealing universally with natural sciences and they append some concrete natural or technical applications. The philosophy of the Mobilis is reverse. We show technologies from the vehicle industry appending natural science analogies and explanations. Mobilis is located in a 1200 m^2 building. We have got 70 interactive exhibition devices and present physics-laden science shows, roadshows. We have also led study groups. In science shows, we present and analyze, for example, the fire tornado.

5.2. UTILIZATION

The experiment models a reverse-acting gas turbine, where we can increase the burning by rotating the cylinder. The real gas turbines work in the other way. The burning engenders the rotation, for example in the case of the jet planes. It is similar to the turbocharger because it flows more air into the combustion chamber. A Science Center which focuses on the vehicle industry has to present these analogies as well.

It holds the opportunity of interactivity. It is suitable for a teacher-led demonstration, but only works in small groups; over seventh or eighth grade students can do it independently. The kids can do the cap filling and setting the fire, but putting up the cylinder is two people’s job. Doing the experiment needs an adult observer or a teacher. Scientific birthday can be held with it. There is a big demand for scientific birthday parties in our center. There the kids do experiments, they play and they can watch a special science show as well. The celebrated kid can rotate the candle on the cake, the fire tornado. It can be applied in chemistry lessons. We can recommend this experiment for chemistry lessons because we can demonstrate flame-dyeing. We can explain the conditions of burning. It can be applied in physics lessons. Hydrodynamics, convection, density, buoyancy, rotating movements can be explained with this experiment.

5.3. VERSIONS

Double flame. We put two fuel sources into the serving disk. One of them should be filled with acetone and the other with methanol with dissolved copper sulfate. After igniting the fuels green and yellow flames are growing up and twisting around each other. Flame-dyeing. Before pouring methanol into the fuel bowl, put some copper sulfate into it since the methanol dissolves the copper sulfate well. The copper ions will dye the flame to green. Without moving device. Instead of the cylindrical mesh a transparent, tight plastic sheet can be also used as enclosure of the tornado. As shown in Fig.4., a tangential gap should be left on the cylindrical sheet. The flowing gases of small density only get fresh air from this gap. The tangentially entrained gas turns the air inside the enclosure and the flame is twisted.

Turn-way sensitive. We make a cylinder from an expanded disc. Due to the shape of the holes, the effect of turning the disk to right and to left is not same. If it turns left, the air flows inwards and the burning is stronger, so the flame is lengthening. Reversing the rotation, the air flows out from the cylinder, the flame decreases to the third of its former length. 12 big ventilators turn the air. It needs 5 liters of acetone and a heat resistant pot. This experiment can he made only outdoors. The flame is twisting up to 4-5 m height (Fig.5.).

Fig.4. Left: flame-dyeing.
Right: without moving device

Fig.5. Left panel: The turn-way sensitive expanded disc. Right panel: with 12 ventilators

CONCLUSIONS

Natural sciences should be popularized in all possible places. We should go into the streets among those people who do not come to the science center and should explain them that science, physics is all around us and science can be exciting. All Science Centers have the task to teach the people in informal ways. The spectacular and extraordinary experiments raise attention; provide the possibility to give explanations in different depth and from different points of view. The Science Centre can help the teachers: gives ideas how to make simple devices. Moreover, it provides additional knowledge and special experiments that cannot be shown in a school.

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III. ENVIRONMENTAL ISSUES

HARMFUL ALGAL BLOOMS IN THE OCEAN: AN EXAMPLE TO INTRODUCE HIGH SCHOOL STUDENTS TO ENVIRONMENTAL PROBLEMS

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ABSTRACT

Tackling problems in environmental science needs an interdisciplinary approach in which physics, chemistry and biology are coupled to address the impact of global change on processes in atmosphere, oceans and biosphere. Using simple conceptual models of populations we demonstrate (i) the complexity of the dynamics which can arise due to changes in the environment and (ii) how to analyze the problem of the formation of harmful algal blooms in the ocean. Furthermore, we show how methods from theoretical physics can be utilized to model ecological processes.

INTRODUCTION

School education is mostly devoted to the different science subjects like physics, chemistry and biology taught independently of each other. However, most major problems in climate and environmental science require the intimate interplay between different disciplines to understand e.g. the impact of changes in the physical environment like global warming on ecosystems. For this reason it would be most appreciated if already at the school level one would start demonstrating with simple models how important questions in environmental science can be tackled combining different disciplines of science. Here we will give a short introduction into some phenomena in ecosystem dynamics, particularly in marine science. We use methods borrowed from physics to set up the model and to analyse it. Furthermore we show how the physical environment influences the dynamics of the biological system.

Phytoplankton are organisms living in all oceans, rivers and lakes and can be considered as plants since they produce organic material from inorganic nutrients utilizing sunlight for photosynthesis. Moreover, phytoplankton constitutes the base of the aquatic food web [1] and produces more than half of the oxygen in the world [2]. Furthermore, it is an integral part of the global carbon cycle [3] and plays, hence, a major role in climate dynamics. Changes in phytoplankton dynamics would thus have major consequences for mankind. Due to seasonal changes in temperature and light conditions, i.e. the physical conditions in the environment, phytoplankton species develop large abundances called algal blooms mostly in spring and some also in the autumn. Such blooms, in turn, trigger the growth of species at higher trophic levels like zooplankton and fish, which feed upon phytoplankton. The phenomena, which we would like to address here specifically, are so-called harmful algal blooms that are caused by species, which are e.g. capable of producing harmful substances supressing the growth of competitors and predators or even leading to their death due to the toxicity of those substances. Besides the toxic substances can accumulate in predators and finally be transferred to organisms on higher trophic levels like fish and humans. Therefore, harmful algal blooms may cause large economic losses due to their threat to fish farming and the health of people. Moreover they have a severe impact on ecosystem dynamics.

To gain some insight into the formation of harmful algal blooms, we will firstly discuss briefly the main steps of modelling in science with particular emphasis on models in ecology. This methodology is based on the theory of nonlinear dynamical systems. Next, we will demonstrate that even in rather simple population models the dynamics can be rather complex and discuss the limits of predictability. Finally we analyse a particular model of harmful algal blooms to illustrate how changes in the environment influence the emergence of harmful algal blooms. Using these simple illustrations one can get school students interested in modelling environmental problems.

MODELLING ECOLOGICAL DYNAMICS

Dynamical systems are frequently used to study various phenomena from diverse disciplines of science such as laser physics, population ecology, socioeconomic studies, and many others. The corresponding mathematical models are often formulated in terms of balance equations, in which the time evolution of the state variables is determined by possibly several gain and loss terms. In the modeling process the modeler usually decides first which processes are important and need to be included in the model and second, which specific mathematical function describes best those processes and reflects either empirical evidence or some theoretical reasoning. In this way a specific model for the phenomenon under consideration is constructed.

When constructing models in physics one begins usually from the first principles like e.g. Newton’s laws in mechanics. However, in ecology such first principles are not available and the modeler has to formulate mathematical functions for processes like growth, competition, predator-prey interactions like grazing or death. In literature several such formulations are provided which fulfill some basic biological features. To illustrate the obtained dynamics we discuss here the formulation of growth as well as predator-prey dynamics.

In the simplest form the growth of a species X is modeled using a constant growth rate r of an individual which is multiplied by its abundance leading to an overall growth term $dX/dt=rX$. This formulation would lead to an exponential growth $X(t)=X(0)exp(rt)$, which is rather unrealistic since it does not take into account, that resources as a necessary input for growth are in general limited and individuals will compete for these resources. If one also considers this limitation, then one has to include a term for the competition, which can be expressed as a quadratic term in the abundances of the species X. This formulation results in a differential equation containing one gain term, the growth, and one loss term, the competition for the constant resource K, called carrying capacity:

$$\frac{\mathrm{dX}}{dt} = rX\left(1-\frac{\mathrm{X}}{K}\right) \tag{1}$$

The dynamics of this limited growth leads to a constant equilibrium in which the gain balances the losses resulting in an abundance of the species, which equals the carrying capacity. A growth described in this form is called logistic growth [4].

This situation changes if the model does not describe a system in which the time is continuous, but discrete [5]. Such population models represent species, which have a yearly breeding cycle like insects and birds and in which the number of individuals is counted each year at approximately the same time. The corresponding dynamics can be expressed in terms of a map in which the index i denotes the year in which the population is considered:

$$X_{i+1} = rX_i\left(1-\frac{\mathrm{X_i}}{K}\right) \quad . \tag{2}$$

The complexity of the dynamics in this model depends strongly on the value of the growth rate *r* (cf. Fig.1, upper panel). For a small growth rate, we obtain either a fixed point, in which the population does not change over the years or periodic behavior with different periods. For larger growth rate we obtain chaotic behavior in which it is impossible to predict the abundance of the population of species *X* in the next year. Though this model is rather simple, it possesses for certain growth rates a very complex irregular dynamics as depicted in Fig.1. (lower panel). This chaotic behavior limits the predictability of the system, since initially nearby trajectories diverge exponentially.

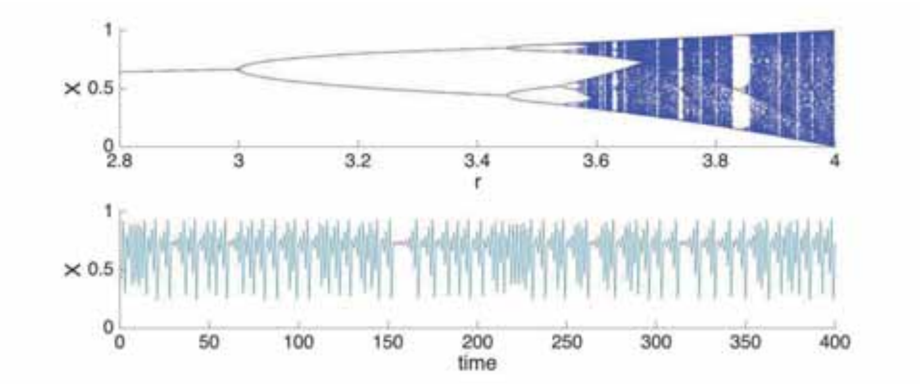

Fig.1. Discrete dynamics of a population restricted by limited resources described by the logistic map with carrying capacity K=1. Upper panel: Dynamics depending on the growth rate r. Lower panel: Time evolution of the population abundance in the chaotic parameter region, here computed at r=3.7.

As another example for modeling ecological processes, we mention predator-prey interactions, where the growth rate of the predator depends on the abundance of a prey called *X*. The formulation of the uptake or grazing rate has to fulfill certain biological empirical evidence. The grazing rate *f(X)* has to be zero if no prey is available, i.e. *f(0)=0*. Then it should grow with increasing prey availability, but finally saturate since the predator can eat only a certain amount of prey regardless of the number of prey species in case they are highly abundant. This would be well described by a function which is monotonously increasing for small values of *X* but finally go to a constant for large *X*. As an illustration we show in Fig.2 the mostly used mathematical formulations of the grazing rates of a predator depending on the prey [6].

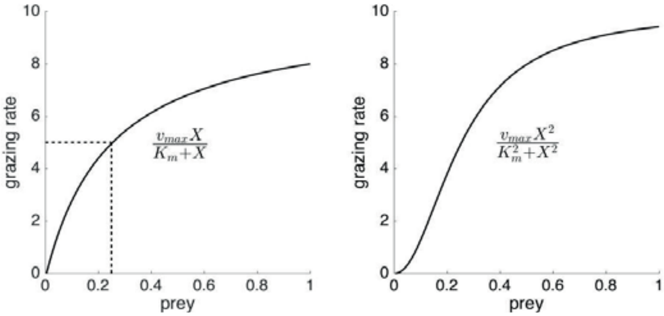

Fig.2. Different types of predator-prey interactions: Left panel: Holling type II, the dashed line indicates the line at which the prey abundance is equal to K_m and the grazing rate equals the maximum grazing rate v_{max}. Right panel: Holling type III

Depending on the complexity of the processes taken into account, these functions can be rather simple as described above or more complicated if e.g. the behavior of organisms like different hunting strategies depending on prey availability is additionally taken into account.

MODELLING HARMFUL ALGAL BLOOMS (HABS)

As already mentioned in the introduction harmful algal blooms constitute a major problem in many regions of the world's oceans. While there is an annual bloom of non-harmful species in spring, HABs occur either sporadically or if they appear on a regular annual basis, their magnitude, the exact timing of their onset, their specific location and geographical extent, their composition (i.e. which species dominates) as well as their duration and termination vary significantly from year to year. Therefore it is necessary to understand the mechanisms leading to triggering such harmful blooms in order to predict them. Several physical, chemical and biological factors are believed to contribute to the specific conditions under which HABs develop [7]. Moreover, climate change has led to a substantial increase in the number of HABs around the globe [8]. Possible causes for this increase are increasing input of nutrients into the oceans due to fertilizers used in agriculture and their subsequent transport into the ocean by river run-off, the warming of the ocean, changes in hydrodynamic flows due to climate change as well as the invasion of new species.

Several conceptual, empirical and numerical models have been developed to understand the main trigger mechanisms of harmful algal blooms [9, 10]. The complexity of those models depends on the number of processes and influencing physical and biological factors taken into account. We will focus here only on one model, which is particularly simple and can therefore be studied by high school students. Truscott and Brindley [11] formulated a model, which considers only the interaction between the harmful phytoplankton species as a prey and zooplankton as its predator. The mathematical functions taken into account for predator-prey interactions allow to explain dynamics as a nonlinear "excitable system". This model has been used to study red tides, i.e. HABs that are caused by a particular species, which changes the ocean color into red if they are very abundant. Excitability means here that a system which is usually in equilibrium is capable of developing a huge response in the form of a pulse when it is perturbed with a certain perturbation. A typical example for an excitable system is the excitation of a neuron, when it gets some input signal. The resulting dynamics consists of a fast growth of the so-called excitatory variable followed by a slower growth of the inhibitory variable. When the inhibitory variable is large enough, it starts suppressing the excitatory variable resulting in the end of the excitation and a return to the equilibrium.

The underlying model for a harmful algal bloom consists of two differential equations for phytoplankton P as prey and zooplankton Z as predator respectively:

$$\begin{aligned} \frac{dP}{dt} &= r \cdot P \cdot \left(1 - \frac{P}{K}\right) - \alpha \cdot \frac{P^2}{\mu^2 + P^2} \cdot Z \\ \frac{dZ}{dt} &= \gamma \cdot \alpha \cdot \frac{P^2}{\mu^2 + P^2} \cdot Z - d \cdot Z \end{aligned} \tag{3}$$

The first term in the phytoplankton equation describes the logistic growth of the phytoplankton with a rate r taking into the competition of phytoplankton cells for the limited resource K. The second term denotes the grazing of zooplankton cells upon phytoplankton. The grazing rate is modeled as an S-shaped Holling-type III function (cf. Fig. 2), i.e. it is very slowly increasing when prey is scarce, but then it is increasing quadratic with prey abundance until it saturates for large prey abundance. The time evolution of the zooplankton abundance is also formulated in terms of a balance equation in which the gain in zooplankton abundance is almost equal to the grazing term except for a prefactor γ which measures how much of the prey taken up is converted into predator biomass. The natural mortality of zooplankton – the last term in the zooplankton equation – is modeled with a rate d.

To illustrate the excitable dynamics we show in Fig.3. the time evolution of the response of phytoplankton and zooplankton after applying a perturbation in the zooplankton concentration. Truscott and Brindley [11] found that a zooplankton concentration below some critical level helps to bring the system into an “excited” state thereby initiating a bloom of phytoplankton. In the terminology of excitable systems, phytoplankton is the excitatory variable while zooplankton feeding upon it is the inhibitory variable.

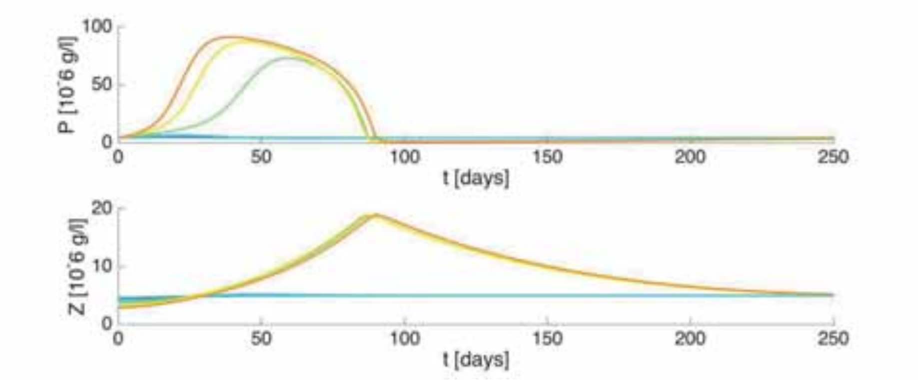

Fig.3: Time evolution of the Truscott-Brindley model, Eqs.(3), for different initial concentrations of zooplankton Z. Only low initial concentrations of zooplankton (orange, yellow and green curves) lead to a large response of phytoplankton P. The parameters for this simulation are: r = 0.3 day^{-1}, K = 108 g/l, α = 0.7 day^{-1}, μ = 5.7 g/l, d = 0.012 day^{-1}, γ = 0.05.

Let us now discuss the impact of the physical environment on the emergence of such harmful algal blooms. Two different important physical factors are considered in the following: temperature and hydrodynamic flows. While temperature influences the growth rates of plankton, hydrodynamic flows are responsible for the redistribution of nutrients and plankton in the water.

The growth of plankton depends crucially on the seasonal cycle. While in winter plankton abundance is low, it starts growing in spring when temperature and light availability are increasing. To take this factor into account, we introduce the temperature dependence of the growth rate via a factor, which scales the growth rate *r* based on the Arrhenius law as

$$r(T) = r \cdot Q_{10}^{(T-\bar{T})/10} \tag{4}$$

where Q_{10} is a species-dependent constant factor. This scaling means that a change in temperature by 10^o multiplies the growth rate by the factor Q_{10}. The temperature T varies with the seasonal cycle having a period of 365 days.

$$T(t) = \bar{T} + \Delta T \cos(\Omega t + \varphi) \tag{5}$$

Simulating the dynamics of the plankton model yields now a periodic behavior instead of the equilibrium we obtained before. When different initial abundances for the two species are selected we note that two different behaviors are possible: either we find a year in which no harmful bloom occurs or a strong harmful bloom develops (Fig. 4). This result reveals that we have two coexisting alternative states, years with and without blooms. Based on this finding we can explain the irregular bloom behavior observed in nature: When we consider a periodic temperature influence, that is equal each year, both, bloom and non-bloom dynamics are possible depending on the initial conditions. However, the temperature is only on average the same every year. In reality, small variations in temperature occur each year, so that the temperature on, say June 1, is not each year the same but possesses small fluctuations, which are caused by the weather patterns, which vary from year to year. Taking these fluctuations into account, the system is able to switch from non-bloom to bloom years and vice versa. This irregular switching resembles the dynamics of harmful blooms in nature [12].

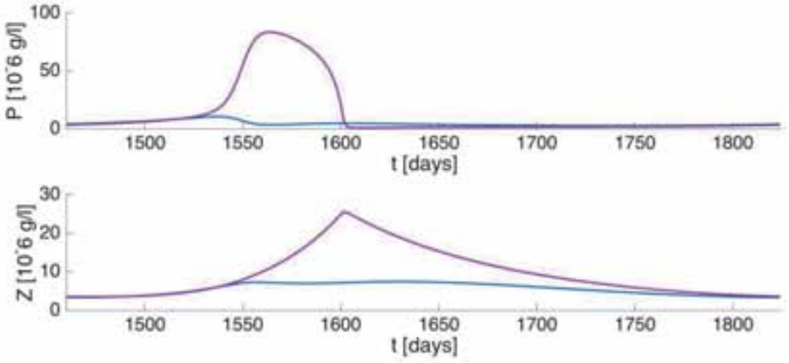

Fig.4. Abundances for phytoplankton (upper panel) and zooplankton (lower panel) for two different initial abundances: non-bloom year (blue), bloom year (magenta). Parameters are the same as in Fig. 3, $\Omega = 2\pi/365$ day^{-1}, T = 10^o, $\Delta T=6^o$, $\Phi = 0.59$.

Plankton blooms develop in the water column and are transported together with the inorganic nutrients – their food – by hydrodynamic flows. It is important to note, that hydrodynamic flows have in general very different time scales than biological processes. While the growth of plankton is on a time scale of days to weeks, ocean flow pattern travel in this time interval several hundreds of kilometers. To obtain an impact of flow patterns on plankton blooms one has to look for coherent structures in the flow which have a lifetime comparable to the biological time scales. Such structures are vortices in the flow, i.e. rotating flow patterns, which are present in all ocean flows and which possess different sizes and life times. Since the average lifetime of vortices is of the order of days up to several weeks [13], such structures can be essential for the emergence of plankton blooms. The role of vortices as incubators of plankton blooms has been shown using different food web models in simple kinematic flows [14] as well as in turbulent flows [15]. The rationale behind this behavior is the fact that the water is mostly confined within the vortex due to the very low exchange with the surrounding waters. Therefore, plankton can grow without much disturbance within the eddy. Moreover, such coherent structures in flows may lead to a separation of different species having different needs of nutrients. This separation opens up ecological niches for different species to coexist and hence to a sustained biodiversity in the ocean [16].

To demonstrate this dynamics, we address now the question of coupling the biological model to a simplified hydrodynamic model, which mimics basic properties of ocean flows. More specifically we show the emergence of a harmful bloom in a von Karman vortex street which develops in the wake of an island. Though the underlying velocity field in a two-dimensional spatial region is given analytically [17, 18], the numerical procedure to obtain these patterns is slightly more complicated and therefore omitted here. We only present the result for a plankton model, which contains two different species, harmful and a non-harmful one competing for the same resource. This model is a bit more complex but relies on the same assumptions than the previous one (for details cf. [19]). The emergence of a harmful algal bloom in a vortex is illustrated in Fig.5. showing the abundances of the harmful species blooming mainly within the vortex. Such localized blooms can also be observed in satellite pictures of plankton blooms around the world (cf. http://oceancolor.gsfc.nasa.gov/cms/).

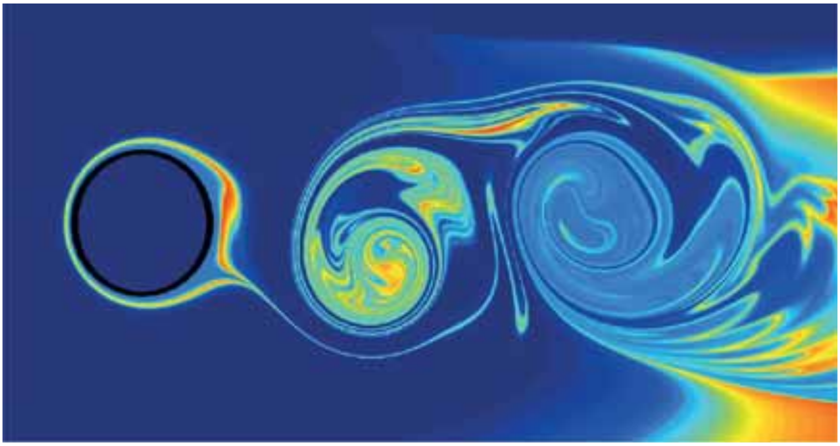

Fig.5. Phytoplankton bloom in a van Karman vortex street in the wake of an island: abundance is color-coded from blue for low abundance via green to orange for high abundance.

CONCLUSIONS

Interdisciplinary research on environmental problems requires an intimate interplay between different directions of science. To prepare high school students to those tasks and to get them acquainted to this much broader view on science it would be desirable if students would be exposed to questions, which are related to e.g. climate change. Utilization of such simple approaches to ecological systems as demonstrated here could be one way to start educating students in a comprehensive view on the earth system.

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MODELING CLIMATE CHANGE IN THE LABORATORY

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ABSTRACT

In a simple tabletop-size rotating wave tank experiment at the von Kármán Laboratory of ELTE, atmospheric climate change scenarios can be modeled by continuously decreasing the temperature difference between the two sidewalls of the tank, imitating the effect of global warming. As these boundary conditions slowly change, we can observe how the "weather" in the tank reacts to this non-stationary forcing. Such laboratory investigations may support the better understanding of the causal connections between global warming and the increasing number of unusually warm or cold seasons observed coincidentally in the past 30 years at the mid-latitudes of Earth.

INTRODUCTION

Understanding the underlying statistical properties of extreme weather conditions is crucially important to our society. Analogously to the engineering problem of sizing a dam to withstand extreme water levels, decision makers involved in long-term economic or political planning must consider and, if reasonably achievable, mitigate the risks of unlikely but highly hazardous events (e.g. to keep a certain amount of agricultural goods in reserve as preparation for extremely warm and dry Summers, as in the 3,500 year-old Biblical story of Joseph in Egypt). For such strategic purposes assigning odds to extreme events would be essential.

Unfortunately, quantifying such risks is far not trivial, firstly, because – by definition – extreme events are rare, thus reliable measurements are needed over as long time as possible. Even if this was granted, one must keep in mind that climate exhibits significant fluctuations on every imaginable timescale, yielding a power law-type long-range correlated behavior, as demonstrated by merging observational and paleoclimate data sets in, e.g. [1]. This feature implies that, strictly speaking, no data record can be long enough to define a stationary base period to which extremes can be properly compared. Yet, given the fact that only one realization of global temperature time series exists (we have one Earth, and we have no access to climate data from "parallel universes" with the same laws of physics but slightly different initial conditions), finding such "quasi-stationary" periods and taking them as the "golden standards" of climate variability is still the best thing climate scientists can do. It has some serious drawbacks, however, as we will point out.

Fig. 1 shows the monthly global average temperature anomalies of the Earth. By definition, anomalies are compared to the – relatively stagnant – three-decade base period of 1951-1980, whose temporal average is subtracted from the whole time series. As it is apparent from the graph, longer periods without any trend are more like the exceptions then the rule, as far as the past 150 years are considered.

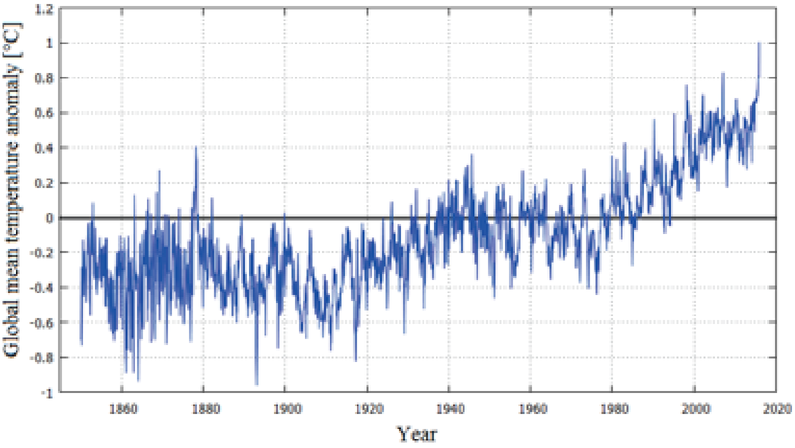

Fig.1. Fluctuations of monthly global mean temperature anomaly, as compared to the average of the 1951-1980 'base period'. Source: https://climexp.knmi.nl

Widely cited studies, such as [2] have come to the conclusion that coincidentally with the rapid global warming of the past 40 years, the so-called "climate dice", that describes the chance of unusually warm or cool seasons, has become more and more "loaded", or in other words, "the distribution of seasonal mean temperature anomalies has shifted toward higher temperatures and the range of anomalies has increased" (compared to their base period).

On the one hand, this is definitely a very interesting and important observation from the practical point of view; extremely hot summers can have disastrous effects on agriculture and our society in general. So this is clearly something important to know about, and prepare for. On the other hand, the finding, at least qualitatively, is exactly what one would expect from the simple fact that the time series of Fig. 1 in the considered period (i.e. the past 40 years) exhibits a marked increasing trend: if the mean is shifting upwards, previously rare high values more and more become the norm. The real question is therefore, whether the observed changes in the number of days in the year with "extreme temperatures" is merely a consequence of the shifting mean, while the statistical properties of the fluctuations (i.e. the physical nature of "weather") remain the same throughout the process, or there is also an inherent amplification within the dynamics of the fluctuations themselves, besides the shifting mean. Looking back to Fig. 1 the change in the past decades seems to be so rapid that even on the typical timescale of a larger fluctuation the trend line increases significantly: the observed process is nowhere near quasi-stationary. So the classic approaches of decomposing the signal to short term and long term components and identifying the former with "weather" and the latter with "climate forcing" can be very misleading.

The schematic drawings in the three panels of Fig. 2 are excerpts from the special report of the UN's Intergovernmental Panel on Climate Change (IPCC), titled "Managing the risks of extreme events and disasters to advance climate change adaptation" from 2012 [3]. Panel a) drafts the scenario of "shifted mean" in terms of the sketched probability density functions (PDFs) of global average temperature values. The graph corresponding to the base period is marked by solid line and the "climate change" scenario is sketched with the dashed curve. In this case the mean changes, but the fluctuations behave essentially the same way as in the base period. Panel b) shows just the opposite case: even though the mean does not change at all here ("no global warming" on the long term), yet, apparently something happens to the weather system, because the “tails” of the PDF become thicker (i.e. frequencies of extremely hot or cold days in a year increase). Panel c) represents a similar scenario: the mean stays unchanged, and so does the “left tail” of the PDF, but the probability of hot weather increases, thus the symmetry of the distribution changes.

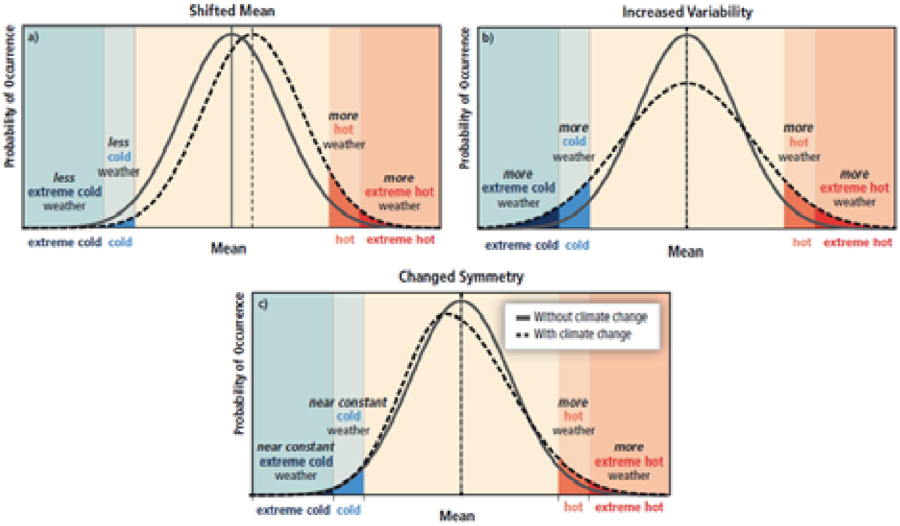

Fig.2. Sketches of probability density functions of the global mean temperatures subject to different “climate change” scenarios: a) shifting mean, b) increased variability, c) changed symmetry (source: [3])

The actual climate change probably cannot be described by any of these conceptual scenarios alone, but more likely as a combination of at least two of them. Yet, based on the available data, where – due to our incomplete understanding the climate system – separating the long-term deterministic components from stochastic fluctuations is practically impossible, therefore, it is hard to tell, which of the scenarios are actually contributing.

Since neither the true temporal behavior of the driving force (i.e. the climate system’s response to changes in Solar flux, carbon-dioxide emission, etc.) nor the statistical properties of the fluctuations can be determined independently, the only proper way to take them apart would be to observe many realizations (paths) of the same dynamical system, presumably with very similar initial conditions and with exactly the same time-dependent forcing scenarios. Then statistical analyses over such an ensemble can be carried out and thus the separation of deterministic and stochastic terms (and the true properties of fluctuations around the mean) could be, at least theoretically, achieved.

Obviously, since only one realization of the actual climate system exists, ensemble statistics cannot be used there. However, there is a way to imitate climate-like dynamics in a surprisingly simple laboratory experiment. This, being a physical experiment, can be repeated and therefore ensemble statistics can be constructed, as will be discussed in the next sections. It is to be noted that this approach has been successfully applied to numerical climate models of minimal and intermediate complexity in very recent works, e.g. [4]. Surely, the outcomes from simplified laboratory experiments will not solve the problem of separating processes and obtaining proper extreme statistics from the actual global temperature records, yet, they may help to drive attention to some serious methodological issues which inevitably arise when using single-realization statistics instead of an ensemble.

EXPERIMENTAL SETUP AND METHODS

The so-called "differentially heated rotating annulus" is a widely studied experimental minimal model of the mid-latitude weather system. It is "minimal" in the sense that it captures the two most important basic factors that contribute to the formations of cyclones and anticyclones in the atmosphere: lateral temperature difference (between the polar and equatorial regions) and rotation (around the Earth's axis). If either of these boundary conditions was absent, no weather-like flow patterns would emerge; so the model is "as simple as possible but no simpler". For more details on the history and the possible variants of rotating annuli, we would suggest the reader to consult our recently published textbook chapter [5].

A schematic drawing and an actual photo of our experimental tank (alongside with a cartoon demonstrating the aforementioned analogy with the terrestrial atmosphere) is shown in Figs.3 b), c) and a), respectively. The annular gap between the coaxial cylindrical sidewalls is filled up with water to height $d = 4.5$ cm (Fig. 3b). The inner cylinder, with a separate working fluid in it, serves to maintain the desired "polar" temperature. It has a radius $a = 4.5$ cm, whereas the outer rim (where the warming occurs) is at distance $b = 12$ cm from the axis of rotation. The radial temperature difference ΔT yields an overturning "sideways convective" background flow, similar to the large convection cells in the actual atmosphere. Due to the rotation of the tank, Coriolis force also acts on the fluid parcels (that otherwise would trace out an azimuthally symmetric, toroidal overturning cell) and drags them towards the respective right hand side of their direction of motion (since, due to our 'Northern-hemisphere-chauvinism' counterclockwise rotation is applied here; Australian laboratories typically do it the other way, then the Coriolis force has an opposite sign). For more information on the Coriolis force, and the way it can be taught in high schools, we refer to the paper of Andrea *Gróf* in the present volume [6].

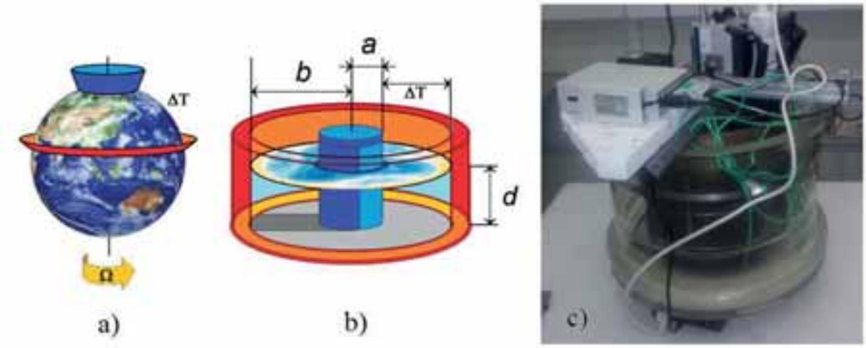

Fig.3. Schematic diagram of the mid-latitude atmosphere (a), illustrating that the basic boundary condition for it is a warm equator (red) and a polar region (blue) colder by temperature contrast ΔT. (b): Sketch of the differentially heated rotating annulus with its geometric parameters for which the boundary condition is similar to that of the real atmosphere: warm outer rim (red), cold inner rim (blue). (c): Photo of the actual experimental tank in the von Kármán lab

Coriolis force yields the formation of cyclonic and anticyclonic eddies, which can be seen by dye painting or via observing the water surface with a thermal (infrared) camera. A typical "atmosphere-like" flow pattern is visible in the left hand side of the composite image of Fig.4, alongside a satellite image of Earth as seen from poleward direction.

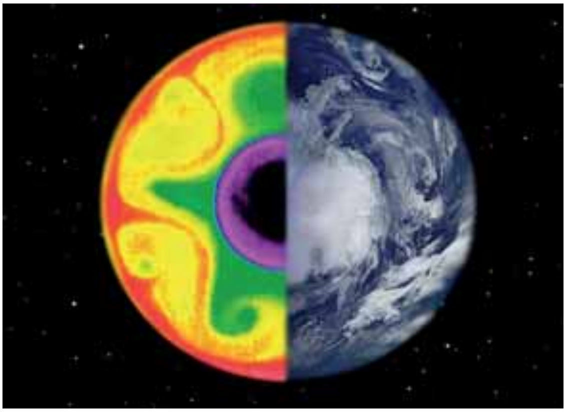

Fig.4. Infrared view of the flow in the laboratory setup (left) and cloud patterns of the Southern mid-latitudes as seen from space, looking down from the axial direction

The analogy between the atmosphere and the experimental configuration is of course far not qualitative only. Studying the equations of motion in both systems, one can derive two non-dimensional quantities that properly describe the possible flow regimes: these can be set in the experiment so that they match the same dimensionless ratios of the atmosphere. One of these parameter combination is known as thermal Rossby number *Ro*, and is defined as:

$$Ro = \frac{gd\alpha\Delta T}{\Omega^2(b-a)^2}, \tag{1}$$

where Ω is the angular velocity of the rotating tank, *a, b*, and *d* are the aforementioned geometric dimensions, α is the coefficient of volumetric thermal expansion of the fluid (water in the experiment and air in the atmosphere) and *ΔT* is the ("Equator-to-pole") temperature contrast imposed on the vertical boundaries of the rotating layer.

Besides *Ro* the kinematic viscosity *ν* of the medium also plays an important role in the dynamics. Its contribution is parametrized by Taylor number *Ta* that accounts for the ratio of rotational and viscous effects, and reads as

$$Ta = \frac{4\Omega^2(b-a)^5}{\nu^2 d}. \tag{2}$$

Ro and *Ta* are used together to characterize the different dynamical regimes in rotating, thermally driven systems, such as planetary atmospheres, oceanic basins and their minimal models in the laboratory. The parameter space with a few typical snapshots of the corresponding experiments is sketched in Fig.5: for smaller rotation rates, where the Coriolis force is of less importance (green shaded area) the flow stays axially symmetric. In an intermediate "anvil-shaped" domain of moderate *Ta* and smaller *Ro* values regular three- or four-fold symmetric wave structures emerge (orange domain), and towards higher rotation rates (larger *Ta* and small *Ro*) the flow becomes turbulent. The letter is the domain where Earth's mid-latitude atmosphere also belongs, once its actual physical parameters are plugged in the above formulae of *Ta* and *Ro*.

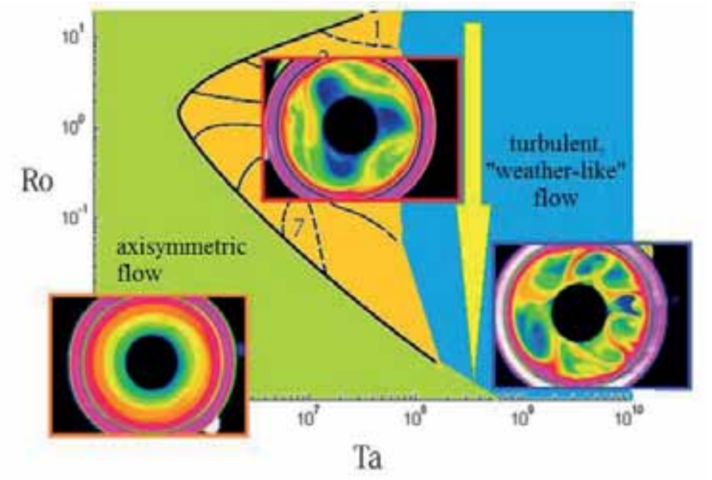

Fig.5. Regimes of the *Ta-Ro* parameter space with the observed flow patterns (insets). The yellow arrow shows the shift due to decreasing radial temperature contrast

The novelty of our experiments [7] carried out in the von Kármán lab and at the Brandenburg Technical University of Cottbus (Germany) is the following procedure: while keeping the rotation rate, thus, Taylor number *Ta*, constant – so that a "day" i.e. a full revolution of the tank lasted for 3 seconds – after a true "base period" of ca. 3000 revolutions of constant ΔT, we started to decrease the temperature contrast parameter, by turning off the computer-controlled cooling of the "polar" thermostat. After this change of the thermal boundary conditions we logged the data for another 3000 revolutions of time, corresponding to a "global warming" scenario with gradually increasing polar temperatures.

It is a well-established fact that the ongoing global warming of the Earth affects the polar regions the most in terms of mean temperature (melting sea ice and land ice), whereas in the local records from the equatorial regions the warming trend is not that apparent. Thus, climate change yields gradually *decreasing* mean equator-to-pole temperature contrast; this is what we imitated in the lab by lowering ΔT. Such a "global warming" in our experiment corresponds to a downward motion in the parameter space of the system, marked by a yellow arrow in Fig.5.

We repeated the very same forcing scenario 10 times with the same initial conditions, in order to create a statistical ensemble of virtually identical experimental runs, which only differed in the stochastic aspects of their evolution. We logged mean surface temperature $\langle T\rangle(t)$, defined as the spatial average of temperature signals obtained simultaneously from three digital thermometers placed on the water surface inside the annular gap of the tank. Their sampling rate was 1 Hz, and their temperature resolution was below 0.05 K.

PRELIMINARY RESULTS

Fig. 6 shows time series obtained for four typical experimental runs. In the top panel, the imposed temperature contrast forcing scenarios $\Delta T(t)$ are plotted, as obtained from the differences of measured temperatures at the heated and cooled lateral sidewalls. One can see that the reproduction of the experiments is very good. In each case, time $t = 0$ corresponds to the time instant when the cooling thermostat was switched off. The bottom panel shows the 'response' of the mean surface temperature $\langle T\rangle(t)$ in each run (colored curves) and their ensemble average (thick black curve). As expected, the latter is much smoother than any of the realizations: the stochastic fluctuations of the different runs average out fairly enough. Note also, that the response ensemble average does not exhibit a sharp turning point at $t = 0$; the transition towards "global warming" appears to be a continuous one, even in terms of its derivative, unlike the forcing itself.

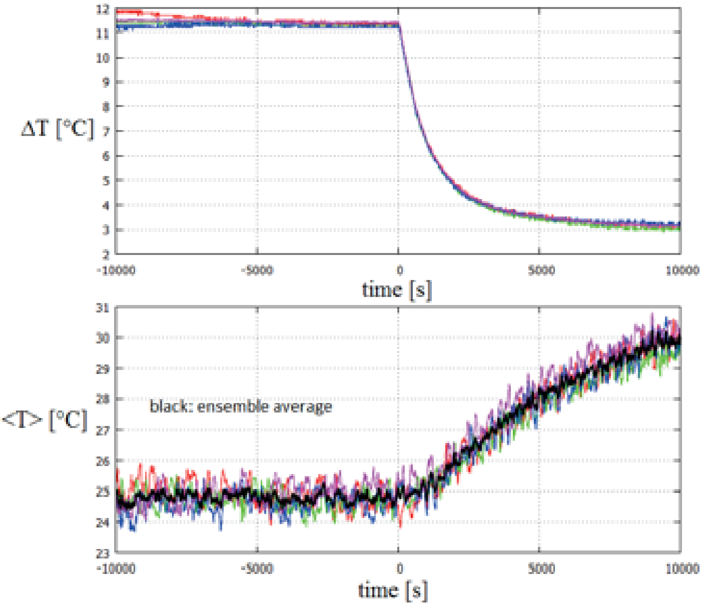

Fig.6. Time-dependence of temperature contrast $\Delta T(t)$ in four experimental runs (top) and the resulting records of "global warming" $\langle T\rangle(t)$ from the same experiments (bottom). The ensemble average is marked with black curve (data from our experiments at BTU-Cottbus)

To demonstrate our main point here, let us consider one of the realizations – namely, the red curve of Fig. 6, repeated in Fig. 7 – and treat it the same way as climate scientists analyse actual atmospheric data. Pretending that we do not have any *a priori* knowledge of the underlying forcing scenario, the best we can do to analyse fluctuations is to apply polynomial de-trending of the temperature record. This is achieved by fitting a polynomial function to the time series $\langle T\rangle(t)$ and subtract it from the original record afterwards. Two such polynomial fits are shown in the top panel of Fig. 7: a sixth-degree (green) and a tenth-degree one (blue). The ensemble average is repeatedly plotted here, too (black curve).

In the next step – as a measure of variance – we calculated the 1001-point, or 300 revolution-long (centered) moving standard deviations of $\langle T\rangle(t)$ defined as

$$\sigma_{1001}^{(i)} = \sqrt{\frac{1}{1001}\sum_{i-500}^{i+500}\left(\langle T\rangle^{(i)} - m_{1001}^{(i)}\right)^2}, \tag{3}$$

where index i is running from the 501th measured value of time series $\langle T\rangle(t)$, up to $i = N - 501$, N being the total number of data points in the record. $m_{1001}^{(i)}$ is the moving mean in the same window, obtained as

$$m_{1001}^{(i)} = \sum_{i-500}^{i+500}\frac{\langle T\rangle^{(i)}}{1001}. \tag{4}$$

The moving standard deviations of the original time series $\langle T\rangle(t)$ are shown with red in the bottom panel of Fig. 7. This can be understood as an estimated measure of "atmospheric variability": the larger its value, the more the time series fluctuates around the running mean. This is no surprise that here, without detrending, the variability increases instantly from around $t = 0$ on due to the increasing trend.

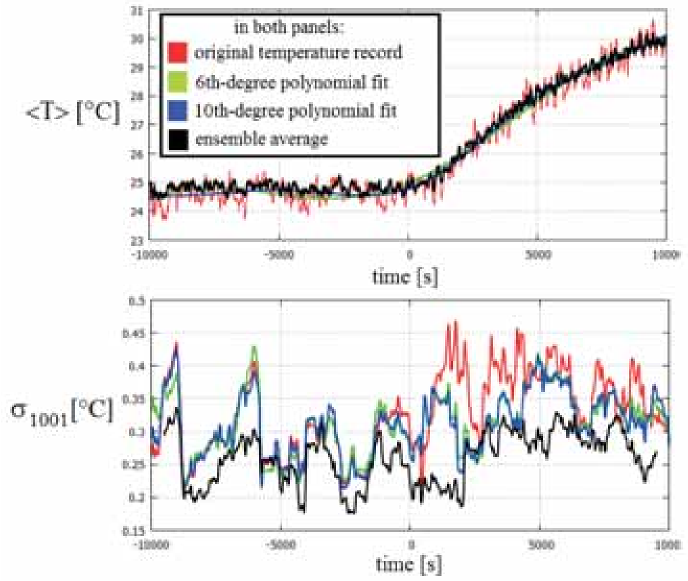

Fig.7. Top: A single realization of the mean surface temperature $\langle T\rangle$ (red), its polynomial fits (green and blue) and the ensemble average (black). Bottom: standard deviations of the original record (red), those of the detrended records (green and blue), and those obtained after subtracting the ensemble average from the temperature record (data from our experiments at BTU-Cottbus)

Afterwards, we carried out the same procedure with the *detrended* records as well: the moving standard deviations and moving averages were calculated in the same manner as written in formulae (3) and (4), but instead of the original $\langle T\rangle(t)$ now the detrended time series were evaluated. The results are plotted in the bottom panel of Fig. 7: the green and blue curves represent the moving standard deviations of the sixth and tenth-degree detrended records, respectively. We found in both cases that the average variabilities are significantly higher in the $t > 0$ range than before, although clearly, immediately after $t = 0$ these detrended records yield smaller fluctuations than the values of the red curve. Therefore, if these were real global temperature data and this would be the only known realization, a climate scientist would come to the conclusion that the internal variability of the system indeed increased coincidentally with the warming, as compared to the stationary base period ($t < 0$).

However, if we use the ensemble average (shown as black curve in the bottom panel of Fig. 6 and in the top panel of Fig. 7) for detrending, i.e. subtract its values from the original $\langle T\rangle(t)$ and calculate the moving standard deviations of the obtained detrended time series (black curve in the bottom panel of Fig. 7), we get a different result. Apparently, these variabilities appear to be systematically below and more uniform than, both polynomial residuals. In other words, fluctuations of the mean temperature around the ensemble average are *smaller* than even around the record's own polynomial trend. The other important observation is that unlike in the cases of polynomials, detrending with the ensemble average does not yield significant difference between the mean fluctuations in the base period ($t < 0$) and the "global warming" phase ($t > 0$), demonstrating that even high-degree detrending – based on the considered realization only – can produce "artificial" changes in the variability.

SUMMARY AND CONCLUSIONS

Experiments in the von Kármán Laboratory offer a unique insight into the large-scale dynamics of flows in the atmosphere and the ocean. In the present work the behavior of atmospheric variability in a changing climate has been studied in an experimental 'toy model' of mid-latitude atmosphere. Unlike in the case of real climate, in laboratory experiments it is possible to run the same scenario several times, thus creating a statistical ensemble. A large enough data pool enables the separation of the deterministic and stochastic aspects of temperature variations in the system. This was demonstrated by using standard tools of time series analysis on temperature records of several identical experiments. We concluded that if the fluctuations of an individual realization are compared to the proper (constantly shifting) ensemble average, no significant changes occur in their variability, as compared to a stationary base period.

These results have a certain methodological or demonstrational value and may help to increase awareness in the climate community of the fact that – as long as the underlying complex processes are not properly understood *a priori* – fluctuations and deterministic trends can hardly be separated, and therefore they may well yield statistical artifacts that can easily be misinterpreted.

ACKNOWLEDGMENTS

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APPENDIX: THE VON KÁRMÁN LAB

The von Kármán Laboratory for Environmental Flows of the Institute of Physics at the Eötvös University (ELTE) of Budapest is one of the very few of its kind in Europe. Based on the principles of hydrodynamic similarity, large-scale atmospheric and oceanic phenomena (shallow-water waves, tsunamis, weather fronts, atmospheric convection, cyclones, tornados, etc.) can be accurately modelled and demonstrated here in relatively simple, table-top-size experimental setups [1].

Our laboratory was founded in 1998, when a group of enthusiastic physicists, namely V. *Horváth,* I. M. *Jánosi*, G. K. *Szabó*, and T. *Tél* – by then already internationally recognized experts in their own fields, ranging from chaotic dynamics to materials science – developed an interest in the surprisingly nontrivial and modern field of geophysical fluid dynamics. ('Modern' is meant in the sense that the proper theoretical framework of atmospheric dynamics was mainly developed after the 1920s, and even later for oceanic flows. Thus, being a contemporary of quantum mechanics, it can indeed be rightfully regarded as 'modern classical physics'.)

The then-newly constructed campus and the relocation of the Institute of Physics to it from its previous historic building (where even Eötvös himself used to work around the turn of the last century), provided a very fortunate once-in-a-lifetime opportunity to obtain two rooms and financial support for creating such a laboratory in the new building. In the almost 18 years since then, von Kármán lab has matured indeed, and evolved into a superb educational and demonstrational hub, where – as a part of their standard curriculum – bachelor and master students in physics, meteorology or environmental science regularly attend classes, participate in laboratory practices, and some of them eventually end up doing their thesis work here.

Besides education, however, the lab, first and foremost, is a research institution. Even during a regular laboratory practice here, students often face problems for which the solution is simply not known yet. They help us collecting data points for active research projects and in turn, they get a glimpse into how science works, where pretty often even the teacher or laboratory assistant cannot predict the outcome of a given experiment either. Several research topics that started here as bachelor's or master's projects later have actually evolved into publications in peer-reviewed international scientific journals. Three PhD degrees have been earned in our lab (one by the author) so far, and currently our regular staff consists of two senior researchers, one post-doc, a PhD student, and a BSc student. As of today, we are running five different environmentally motivated research projects (three of which are collaborative efforts, involving international partners), see the collage of snapshots in Fig.8, one of which has been discussed in the present work.

It is fair to say that the results coming from the von Kármán lab are of comparable quality to those from any environmental fluid dynamics laboratory in the world; similar research facilities are located at the Universities of Oxford, Cambridge (UK), Aix-Marseille (France), the Brandenburg Technical University at Cottbus (Germany), and at MIT (USA).

The laboratory is open for high school groups to visit at any previously agreed-upon time (preferably Fridays): a typical 'lab tour' lasts for ca. 40 minutes and an ideal group consists of up to 12 students. As Fig.9. shows there is practically no lower limit for the age when a lab tour can be interesting for the children: here a group of kindergarten kids are apparently mesmerized by a demonstration of internal waves in a stratified fluid tank. We can say it with confidence that these experiments can be interesting for toddlers and university professors alike.

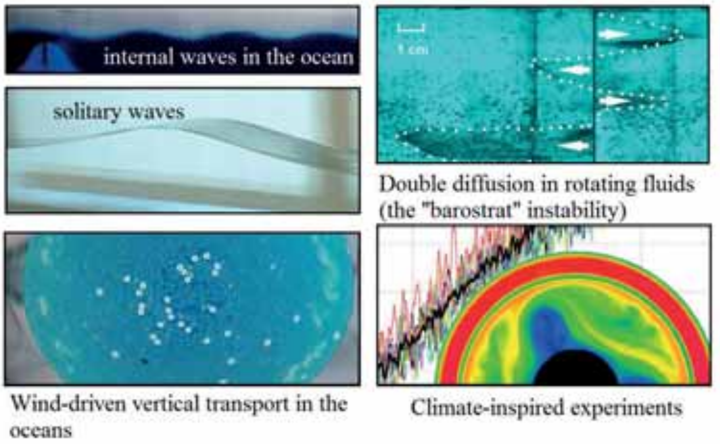

Fig.8. Snapshots from some of the currently active research areas in the von Kármán laboratory

Fig.9. "Visiting researchers" from a kindergarten (and the author) observe internal wave propagation in the von Kármán lab (2015)

Finally, it is appropriate to mention here that – to our great pleasure – the von Kármán lab is not any more the 'only place in its 800-kilometer radius where large-scale environmental flows can be demonstrated experimentally', as we used to claim. We refer to the paper of A. *Vörös* in the present volume [2], which describes somewhat similar experiments for educational purposes at the Babes-Bolyai University of Cluj-Napoca, Romania, and their usage to demonstrate tsunamis, weather fronts and cyclones for high school pupils.

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CAROUSELS TO CORIOLIS, OR HOW PHYSICS SUPPORTS UNDERSTANDING GEOGRAPHY

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ABSTRACT

There is a conflict between the ways motions are described in physics and geography classes. While non-inertial frames do not feature in official physics curricula, geography texts rely on inertial forces in explaining motions of the atmosphere and the seas. Prompted by a survey demonstrating that the physical principles behind geography are not understood, this paper presents a possible treatment within the limits of high-school mathematics. Through the classic example of a merry-go-round, inertial forces are introduced quantitatively, and the results are applied in problems related to motions in geography.

INTRODUCTION

The choice of reference frame is a central idea in the physics class, while in geography they just use their "natural" frame without addressing the issue of reference frame at all. Furthermore, that frame is a non-inertial one, whereas we at most switch from one inertial frame to another, and may even reproach our students if they dare to say "centrifugal force". When geography is taught in year 9, underlying physical concepts and principles are either lacking, or recently acquired knowledge is not yet supported by sufficient experience. Explanations given by geography texts are often superficial or even wrong, but the conflict exists even in the case of a correct approach. With more background knowledge and expertise in problem solving, it is worth revisiting geographic phenomena in physics lessons later on.

A SURVEY ON PHYSICS BEHIND GEOGRAPHY

A multiple choice survey with 215 students revealed a serious lack of understanding, with no significant difference regarding whether they had completed geography before physics, or they had studied both subjects in the same year. The survey encompassed a wide range of concepts related to timekeeping, the shape of the Earth, motions of air and the seas, etc. Two of the questions involving inertial forces are shown below.

One question tested the understanding of the nature of such forces: "The oblate shape of the rotating Earth is generally explained in terms of the centrifugal force. On the other hand, in physics problems dealing with circular motion and rotation, no centrifugal forces were considered. What is the difference?" The correct answer of different frames was only chosen by 17%. Distractor answers (based on classroom experience, and possible misinterpretations of geography texts) would deserve deeper analysis but that is beyond the scope of this paper.

Another question addressed the perennial myth of the kitchen sink: "Ivan in Moscow and Pedro in Buenos Aires each fill the kitchen sink with water and remove the stopper. The water drains with a whirl. What will they observe?" Only 10% gave the correct answer. The most popular distractor (56%) was the one stating that water whirls counter-clockwise for Ivan and clockwise for Pedro. This suggests that students learn their geography regarding cyclones, and apply it without criticism to anything that rotates. Just like Sylvester Stallone in Escape Plan, observing the toilet and concluding that the prison is on the southern hemisphere.

The myth is reinforced by “demonstrations” of the Coriolis force performed to tourists at the Equator, showing how draining water whirls one way or the other if the apparatus is moved a few metres to the north or to the south. They all cheat since the horizontal Coriolis force is zero at the Equator and varies as the sine of the angle of latitude. See [1] for an amateur video to observe angular momentum created by pouring water in a sink from the appropriate side. Tourists give credit to the presentation, although deception is quite apparent. It is instructive to reproduce the “demonstration” in class. (Just draw a random line on the floor and call it the Equator.)

INTRODUCING INERTIAL FORCES

The merry-go-round is a standard illustration of a rotating reference frame. However, high-school level resources normally offer conceptual treatment only. The approach demonstrated here is quantitative, without resorting to any vector calculus or even a vectorial product. Since it applies a lot of the dynamics taught in the regular curriculum, it can be used as a kind of synthesis, adding a little extra at the end of the year.

The programme features a rotating observer A whose reference frame is attached to the centre and rotates along with the roundabout, an inertial observer B, and two further characters: a lizard running along the rim, and a sparrow scared away and flying radially (Fig. 1). Numerical values are calculated in each case, to give an idea of how various forces or accelerations compare to each other.

Suppose the mass of A is 20 kg, the radius of the carousel is 1.5 m, and it completes a revolution in 3 s. As seen by B, the speed of A is then v = 3.14 m/s, and she is acted on by a net force of $m\omega^2 r$ = 132 N. It is important for students to understand that this is the inward push by the merry-go-round seat, and since it is a real force exerted by a real object, the same force must be present in A’s frame, too. Since A is in equilibrium in A’s frame, that raises the need for an extra outward force of magnitude $m\omega^2 r$, so the centrifugal force is introduced.

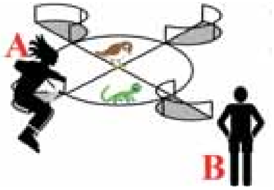


Fig.1. The four characters

Next, the motion of the lizard is considered in each frame. Assume its mass is 20 g and it runs at a speed of u = 0.50 m/s along the rim. Again, the observers must agree on the force exerted by the merry-go-round. That constitutes the net force for observer B (Fig. 2, top left):

$$F_{\text{net}} = F_{\text{merry}} = ma = m\frac{(v+u)^2}{r} = 0.0200\cdot\frac{3.64^2}{1.50} = 0.177\,\text{N}\,. \tag{1}$$

For rotating observer A, however, the speed of circular motion is only 0.50 m/s, and the net force is only 0.003N, so outward forces need to be added to the merry-go-round force of 0.177 N to produce a resultant of 0.003N. One such force is the centrifugal force of $m\omega^2 r$ that is calculated to be 0.132 N, but that alone will not produce the required resultant. Yet another outward force of $-0.003+0.177-0.132=0.042\,\text{N}$ is needed. What is the physical law behind that? Let us examine the forces and accelerations algebraically. Expand the square in (1):

$$F_{\text{merry}} = m\frac{(v+u)^2}{r} = \frac{mv^2}{r} + \frac{2mvu}{r} + \frac{mu^2}{r}\,. \tag{2}$$

The last term of (2) represents the net force for A, a resultant of real and inertial forces:

$$\frac{mu^2}{r} = F_{\text{merry}} - \frac{mv^2}{r} - \frac{2mvu}{r}\,. \tag{3}$$

The first term of (3) is the inward real force of the seat, the second term is the centrifugal force outwards, and the last term is the missing force, also outwards this time. Thus an object moving tangentially at speed u is acted on by a force $2mvu/r = mu \cdot 2\omega$. This is the Coriolis force, and substitution of numerical data yields the magnitude of 0.42 N.

Figure 2 below summarizes the forces in the two frames. The direction of the Coriolis force is the opposite when the lizard is running the other way. A special case of this situation occurs when A observes the motion of B, who stands on the ground, a distance R from the centre. According to A, he is moving in a circle at a tangential speed of $u = -\omega R$, that is, his (net) acceleration is $a = \omega^2 R$. Since there is no real horizontal force exerted by other objects on him, this acceleration is caused by the two kinds of inertial forces: the outward centrifugal acceleration $\omega^2 R$, and an inward Coriolis acceleration of $2\omega u = 2\omega^2 R$. So the resultant is $a = 2\omega^2 R - \omega^2 R = \omega^2 R$ inwards.

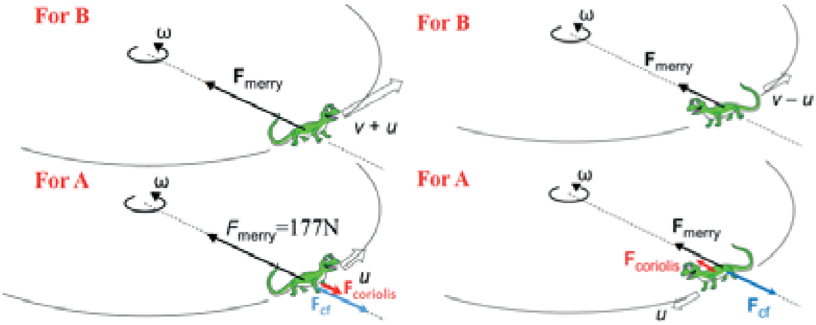


Fig.2. Forces on an object moving tangentially.
Left panel: in the direction of rotation, Right panel: opposite to the direction of rotation

So far, we have investigated objects in tangential motion and radial forces acting on them. The motion of the sparrow flying away from the centre is uniform and radial for B, but rather complex from the point of view of A. Radial acceleration is zero in A's frame, too, (like for the motion of B in the previous example,) but the tangential speed is increasing in proportion to the distance, so this time there is a tangential force, too. Figure 3 (right panel) shows the constant radial speed and increasing tangential speed of the sparrow at equal intervals of Δt.

If the distance from the centre increases by Δr in a time Δt, then $v = \Delta r/\Delta t$. In a short time Δt, acceleration can be considered uniform, angular displacement increases by $\omega\Delta t$, which means a distance of $\omega\Delta t \cdot \Delta r$ covered in a direction perpendicular to the radius. That is,

$$\frac{1}{2}a(\Delta t)^2 = \omega\Delta t \cdot \Delta r \,.$$

$$a = \frac{\Delta r}{\Delta t} \cdot 2\omega = v \cdot 2\omega \,.$$

The same formula is found to apply to the sideways force due to radial motion as to the sideways force due to tangential motion. Hence, it applies to every motion in a plane perpendicular to the rotation axis. The treatment of the Coriolis force is completed.

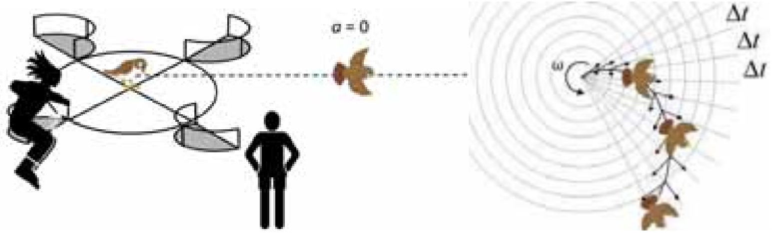


Fig.3. The motion of the sparrow as it appears to B (left panel) and A (right panel)

APPLICATIONS ON THE ROTATING EARTH

The selection below gives some outlined and some worked examples of quantitative exercises related to geography. Note that the angular speed of the Earth is $\Omega = 7.292 \cdot 10^{-5}$/s.

Exercise 1. Free fall acceleration is the resultant of gravitational acceleration towards the centre and centrifugal acceleration away from the axis. Thus, g is found to be 9.78 ms^{-2} at the Equator. The value of g influences sports results: for example, if an athlete can jump 8.00 metres at the poles then, assuming the same initial speed and angle, his jump is calculated to be 4.04 m at at the Equator.

Exercise 2. Budapest lies at a latitude of N47.5°. Find the magnitude and direction of the centrifugal acceleration and of the free fall acceleration at Budapest. Calculate with the average radius of the Earth, $R = 6370$ km.

Solution. $a_{cf} = \Omega^2 \cdot R\cos\varphi = (7.29 \cdot 10^{-5})^2 \cdot 6.37 \cdot 10^6 \cdot \cos 47.5° = 0.023 \frac{\text{m}}{\text{s}^2}$,

directed away from the axis of rotation. The magnitude of the vector sum (Fig. 4) with the gravitational acceleration towards the centre is obtained by using rectangular components:

$$a_g = \gamma \frac{M}{R^2} = 6.672 \cdot 10^{-11} \cdot \frac{5.974 \cdot 10^{24}}{(6.370 \cdot 10^6)^2} = 9.823 \frac{\text{m}}{\text{s}^2}.$$

$$g = \sqrt{(9.823 \cdot \cos 47.5° - 0.023)^2 + (9.823 \cdot \sin 47.5°)^2} = 9.81 \frac{\text{m}}{\text{s}^2}.$$

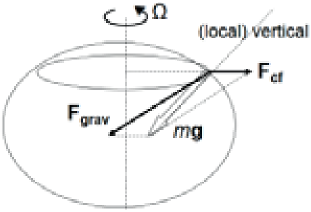


Fig.4. The direction of free fall acceleration

Its direction is somewhat to the south of towards the centre. This is what "down" means; the flattened shape of the Earth formed to make the surface perpendicular to this direction.

Exercise 3. To link with the merry-go-round example, the Coriolis force should first be investigated at the Equator. Suppose wind is blowing at a speed of $u = 20$ m/s towards the west at the Equator. The Coriolis acceleration is found to be $2\Omega u = 2.9 \cdot 10^{-3}\ \text{ms}^{-2}$, directed vertically downwards. Note that its direction is radial, that is why the whirling water "demonstrations" are hoaxes.

Exercise 4. At other latitudes the Coriolis force has a horizontal component, too. Since we consider motions in a plane perpendicular to the local vertical rather than to the axis, the situation is more complex than the carousel case. High-school texts normally refer qualitatively to Foucault's pendulum as demonstration, but they do not explain the value of the local angular speed. By a high-school level adaptation of the explanation (based on the transport of vectors on curved surfaces) offered by some advanced texts (e.g. [2]), the use of angular velocity vector and components may be avoided: Students know that the surface of a cone unfolds in a plane. Consider the cone touching the globe along the φ = N48.8° parallel of Paris (Figure 5). In one day, while the Earth turns through 2π, Paris (point P) only turns in the unfolded plane by an angle of $2\pi\cdot\sin\varphi$. Hence the local angular speed is $\sin\varphi$ times that of the Earth:

$$\omega = \Omega\cdot\sin\varphi = 7.29\cdot10^{-5}\cdot\sin 48.8° = 5.49\cdot10^{-5}\,/\,\mathrm{s}$$

which means 11.3° per hour. It would be 15° at the poles and zero at the Equator.

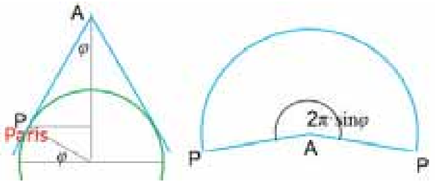


Fig.5. Demonstration of turning in a plane perpendicular to the local vertical

Exercise 5. (a) The mystery of the kitchen sink unravelled at last. Calculate the acceleration of a bread crumb in Budapest, circling at a radius of 2 cm, at a speed of 10 cm/s. What part of the acceleration is due to the Coriolis force? (b) Answer the same question for Jupiter's great red spot, a giant whirlwind at S22° latitude, angular size 25° by 12°. Wind speed is in the order of 100 m/s. The radius of Jupiter is about 72 000 km, and it rotates fast, completing a revolution in 9.8 hours. (Based on [3].)

Solution. (a)

$$a = \frac{v^2}{r} = \frac{0.1^2}{0.02} = 0.5\,\mathrm{m/s^2}.$$

$$a_C = 2v\Omega\sin\varphi = 2\cdot 0.1\cdot(7.3\cdot10^{-5})\sin 47.5° = 1\cdot10^{-5}\mathrm{m/s^2}.$$

The effect is very small compared to other effects responsible for the motion, such as the geometry of the sink or the initial angular momentum that the water happens to have.

(b) 1° on Jupiter corresponds to $2R\pi/360 = 1.2\cdot10^6$ m, so the roughly 9° radius of the spot means an acceleration of about $9\cdot10^{-4}\,\mathrm{ms^{-2}}$, while the Coriolis acceleration is found to be about $1\cdot10^{-4}\,\mathrm{ms^{-2}}$. It is comparable to the net acceleration, so the Coriolis force does play a role in the formation of this persisting storm.

Exercise 6. (a) A golfer in Scotland, N55° latitude, can hit the ball to 300 m at a 45° angle. (b) An artillery missile is launched at 700 m/s. Does the deviation owing to the Coriolis force need to be considered? (Calculate the sideways deflection owing to the Coriolis force.)

Solution. (a) Using the known formulae of projectile flight, a range of 300 m implies an initial speed of 54 m/s, and a flight time of 8.7 s. Hence

$$d = a_C\frac{t^2}{2} = (2\cdot\Omega\sin\varphi\cdot v_0\cos\alpha)\frac{t^2}{2} = 7.3\cdot10^{-5}\cdot\sin55°\cdot54\cos45°\cdot8.7^2 = 17\,\mathrm{cm}.$$

The deflection is probably negligible compared to other disturbing effects like wind.

(b) The range is now 50 km, and the sideways deflection is about 300 m. This time, the effect is significant, it has to be considered in aiming the missile.

Exercise 7. What happens if a hockey puck is hit in a perfectly frictionless ice rink? Not straight line motion! The net force on the puck is not zero in the rotating reference frame of the Earth. If the ice is perfectly horizontal, that is, perpendicular to the local vertical, all other forces will cancel, leaving the horizontal Coriolis force, a sideways force as resultant. That leads to circular motion.

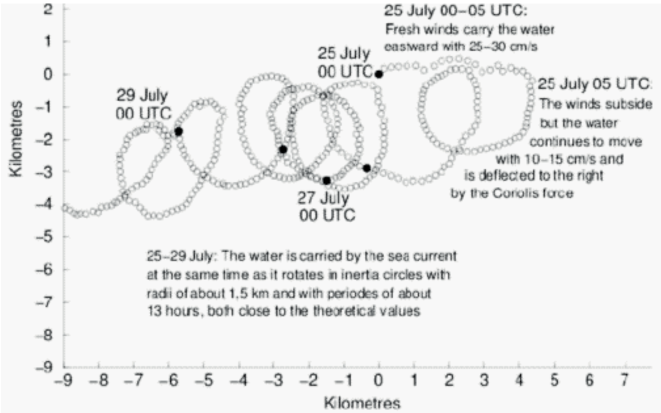
Exercise 8. How fast should we hit the puck in Budapest so that the circle fits in an ice rink 30 m wide? (Based on [3].)

Solution.

$$a_{\text{centripetal}} = \frac{v^2}{r} = 2\Omega\sin\varphi\cdot v \ .$$

$$v = 2\Omega\sin\varphi\cdot r = 2\cdot 7.3\cdot 10^{-5}\cdot\sin 47.5^\circ\cdot 15 = 0.61\frac{\text{mm}}{\text{s}} \ .$$

Quite slow. For speeds in the order of a metre per second, we need r = 9.3 km in Budapest (39 km at 10°, and 7.0 km at 80° latitude). Such large ice rinks we do not have, but nature realizes this kind of motion. Figure7 below shows the positions of a buoy in the Baltic sea, southeast of Stockholm at N57° latitude [4],[5].



25 July 00–05 UTC: Fresh winds carry the water eastward with 25–30 cm/s

25 July 05 UTC The winds subside but the water continues to move with 10–15 cm/s and is deflected to the right by the Coriolis force

25–29 July: The water is carried by the sea current at the same time as it rotates in inertia circles with radii of about 1,5 km and with periods of about 13 hours, both close to the theoretical values

Fig.7. A buoy at sea executing inertial motion [3], [4]

CONCLUSION

Quantitative treatment (algebraically as well as with numerical magnitudes) helped decide whether inertial forces should be considered or can be ignored in a particular situation. Application to geography-related problems supports a deeper understanding in both subjects. As indicated by the results of a short quiz, the investigation of the same motion from different points of view made students more conscious of different reference frames.

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CONSTRUCTION OF A LOW-BUDGET QUADROCOPTER AND DESIGN OF A SIMPLE MEASURING MODULE APPLICABLE FOR ATMOSPHERIC MEASUREMENTS

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ABSTRACT

During the past school-year a low-budget quadrocopter was constructed at the Bolyai High School. After successful test flights the quadrocopter was equipped with a simple onboard measuring module which contains air pressure, temperature, and humidity sensors, a GNSS module and a data logger. Vertical profile measurements were done in rural and urban areas with the aim of understanding land-atmosphere interactions during different stability conditions, as well as to extend our knowledge about the climate modification effects of cities, which is useful for urban planning strategies.

INTRODUCTION

UAVs (Unmanned Aerial Vehicles) are useful tools in a number of different engineering and scientific disciplines. Through their use, it is possible to test and evaluate new ideas in the fields of navigation, real-time systems, flight control, robotics, as well as environmental monitoring and measuring. A quadrocopter is a type of UAV that is lifted and propelled by four rotors. It uses two pairs of identical fixed pitch propellers, two clockwise and two counter-clockwise. By the independent variation of the speed of each rotor it is possible to control the flight of the UAV.

During the past (2014-2015) school-year the group of Bolyai High School (BHS) students constructed a low-budget quadrocopter and developed an onboard measuring module suitable for atmospheric measurements. The aim of this paper is to the describe characteristics of the BHS quadrocopter and to introduce the measuring module designed by our students. Results of the low altitude profile measurements done during the PABLS 15 (Pannonian Atmospheric Boundary Layer Studies) campaign [1], as well as Urban-Path project [2,3] are also presented.

THE QUADROCOPTER AND THE MEASURING MODULE

Due to limited budget, our aim was to build a multicopter suitable for atmospheric measurements that was as cheap as possible. The frame was made of an aluminium rod, the legs were superflat. The constructed quadrocopter operates using medium-priced hardware (ArduPilot flight controller, 30 A rotation speed controllers, 1000 kv brushless motors and GPS compass). An old radio controller designed for model airplanes was modified; the kHz band radio was replaced with a 2.4 GHz radio system. After tens of hours of practicing on a simulator, the first test flights were performed on the local football field (see Fig.1.). During the test flights we revealed that the quadrocopter can fly up to 20 minutes with a 5000 mAh battery.

Fig.1. Test flight, February 2015

After the successful test flights the students designed a simple measuring module. The module includes Sparkfun's air pressure (MPL3115A2), temperature (TMP102) and humidity (HTU21D) sensors, MicroElektronica's GNSS (Global Navigation Satellite System) click, as well as a simple data logger including a micro SD card. The measuring module was housed in a plastic box and attached to the copter's frame. The measuring module is shown in Fig.2.

Fig.2. The measuring module housed in a plastic box -
data logger with GNSS click (left) and the set of sensors (right)

THE PABLS 15 CAMPAIGN AND THE URBTA-PATH PROJECT

The PABLS 15 campaign [1] was organized at the Szeged Airport (Hungary) in July, 2015. During the campaign the group of students worked with the team for the direct sounding devices. Beside the multicopter soundings [4] the students got an insight into tethered (see Fig.3.) and free balloon soundings. Vertical profile measurements were done with the idea to understand land-atmosphere interactions during different stability conditions. Fig.4. shows characteristic daytime and nighttime temperature profiles obtained using the BHS quadrocopter close to the grassy runway.

Fig.3. Students are performing the tethered balloon measurements during the PABLS 15 campaign (Szeged Airport, July 2015)

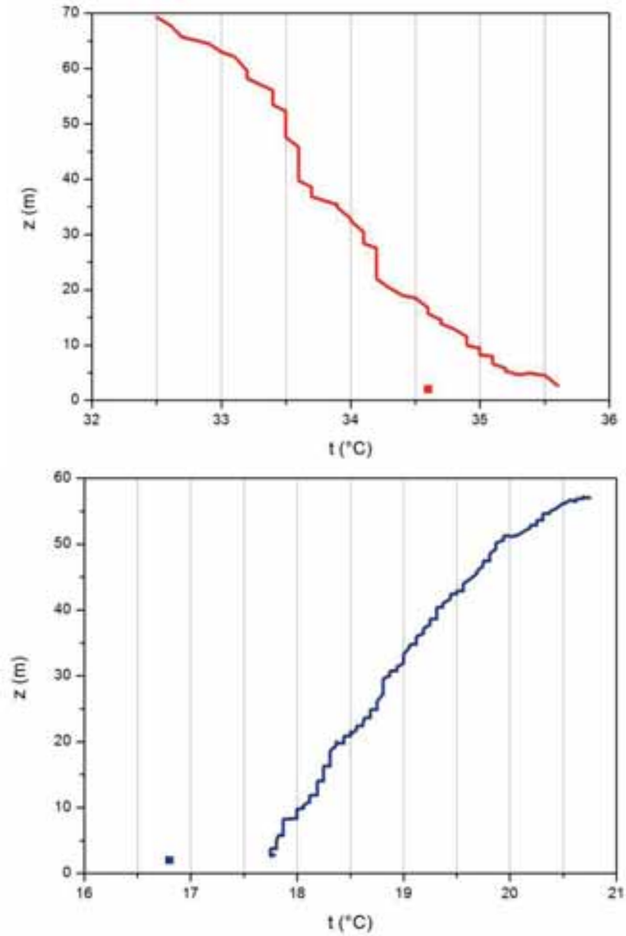

Fig.4. Daytime (red – 13.30 local time, 7th July) and night time (blue – 03.57 local time, 16th July) temperature profiles. Squares indicate temperatures measured at the ground station

Climate modification effects of the cities are very significant and affect many people. The aim of the Urban-Path project [3] was to monitor heat generated by the cities of Szeged (Hungary) and Novi Sad (Serbia) using measurement networks. In both cities more than 20 stations were installed. The spatial resolution of the stations provided high-resolution maps of the urban heat island [5]. Several high school students joined the Urban-Path project team. Vertical profile measurements were performed close to the urban meteorological stations. Differences between the day urban canyon and rural area temperature profiles are presented in Fig.5. Contrary to the rural data, the temperature increases slightly with height in the urban canyon.

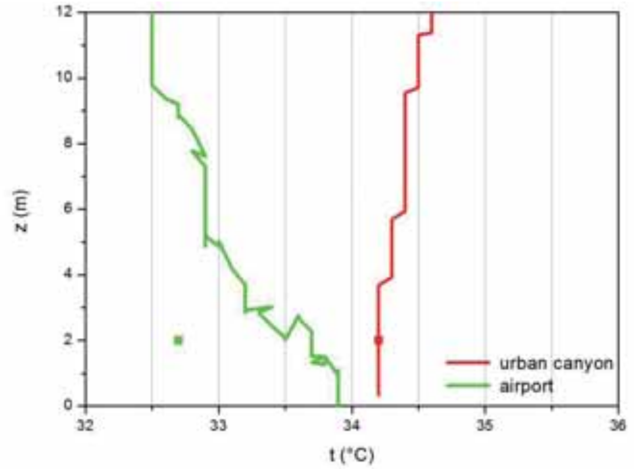

Fig.5. Raw temperature data obtained on July 6th in Szeged urban canyon (15.37 local time), and at the Szeged Airport (17.27 local time)

FURTHER PLANS

The next step in the development of the BHS multicopter is the installation and testing of the autopilot and improved safety pilot systems. The modified version of the measuring module attached to the DJI Phantom quadrocopter will be used for profile measurements during the Dry Andes Research Program [6].

ACKNOWLEDGMENTS

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OBSERVATION OF THE DRYING PROCESS IN SECONDARY SCHOOL

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ABSTRACT

Some years ago we built a solar dryer during an extracurricular class. Although we had no opportunity to analyse the drying procedure itself, with the help of students we did some experiments and measurements associated with the device. In latter works we used an electric dryer to physically capture the drying by eliminating the environmental effects. We made a series of experiments that are comprehensible in high school. We measured mass reduction of different fruits due to the loss of water over time and compared our results – which resembled the evaporation of a fluid consisting of two constituents – with the literature. A statistical model has been derived to demonstrate the drying.

INTRODUCTION

Some few years back in our school [Eötvös József Secondary School] extracurricular lectures ran on environmental physics, especially focused on environmental flows and solar energy. Related to the latter topic, former students built a solar dryer. They also monitored how it is functioning and made measurements with it. This work – besides raising the motivation of students – has succeeded in an educational point of view by showing it is capable of synthesising the notion of energy and it made possible for students to put abstract conceptions and quantities into use (e.g.: power, efficiency, luminosity).

In the last two years a new research subject adaptable in secondary schools has come into sight connected to the solar dryer. It is plausible to study the process of drying itself instead of the characteristics of a drying machine. The subject has an extended technical literature, but this ought to be made comprehensible for students. In the present article we are to show a train of thought on how the description and measurements are made comprehensible to students. We also show the resemblance of fruit drying and the evaporation of two-constituent compounds and introduce a toy model using dices to demonstrate evaporation.

INSTRUMENTS AND MEASUREMENTS

To describe drying quantitatively we had to work out a measurement procedure which is reproducible. A solar dryer is not suitable for this as it does not fulfil the criteria that the power density required for the loss of water should be constant in time. To exclude this and other environmental effects we obtained an electric dryer.

As a subtask we can compare the two devices by their evaporating efficiency. This quantity is defined arbitrarily and could be calculated from measurement data. A possible definition to this efficiency could be the following:

> *the ratio of the energy needed for a certain amount of water to evaporate from a standardized pot in an hour and the energy used during the process.*

In our case, we used a Petri dish (9.5 cm diameter) as the pot and we filled it with 50 g of water. The energy used by the electric dryer could be calculated from its power, while in the case of the solar dryer it is to be calculated from solar radiation and the effective size of the solar panel. Our measurements showed that the evaporating efficiency of the electric dryer is $\eta_{\mathrm{electric}} = 2.5\%$ and the same for the solar one is $\eta_{\mathrm{solar}} = 0.3\%$.

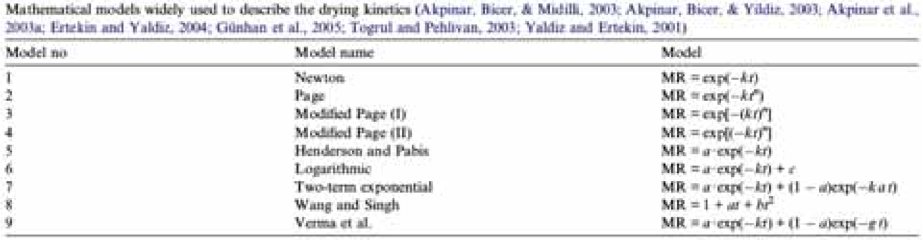
During our measurements with the electric dryer we registered the mass of the fruits (apple and banana slices) in the dryer over time. For this, we used a kitchen scale due to the dimensions of the dryer.

Measurements were also made on evaporation. In these cases - again - the mass of a compound of two constituents was registered over time. With a sugar-water compound being the subject of such experiment we used the above set-up due to time it requires to evaporate (we had to speed up the process to fit a double-length class), but when we investigated the evaporation of a paraffin-oil and pentane as a compound we used an analytic balance instead, because the time required was much shorter than in the case of sugar-water.

ANALYSIS OF DATA

There are several mathematical models that describe the drying of sliced vegetables and fruits. It is usual in food engineering articles covering the subject to compare these models to their measurements and use the model that fits the data better. For an example Akpinar et al., 2006 in [1], Akpinar, 2006 in [2] or Diamante and Munro, 1993 in [3] have gathered some of the models to choose the best one describing their measurement data. Table 1 shows the collection of models that are widely used.

Table 1. Mathematical models used to describe drying. This table is an excerpt from [1]



Mathematical models widely used to describe the drying kinetics (Akpinar, Bicer, & Midilli, 2003; Akpinar, Bicer, & Yildiz, 2003; Akpinar et al., 2003a; Ertekin and Yaldiz, 2004; Günhan et al., 2005; Togrul and Pehlivan, 2003; Yaldiz and Ertekin, 2001)

Model no	Model name	Model
1	Newton	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified Page (I)	$MR = \exp[-(kt)^n]$
4	Modified Page (II)	$MR = \exp[(-kt)^n]$
5	Henderson and Pabis	$MR = a \cdot \exp(-kt)$
6	Logarithmic	$MR = a \cdot \exp(-kt) + c$
7	Two-term exponential	$MR = a \cdot \exp(-kt) + (1-a)\exp(-kat)$
8	Wang and Singh	$MR = 1 + at + bt^2$
9	Verma et al.	$MR = a \cdot \exp(-kt) + (1-a)\exp(-gt)$

From this we will use the Modified Page (I) model because it gave the best fits – among the models mathematically comprehensible for an average high school student – with our experiments. For the description we will use quantities generally used in food engineering. These are: moisture content (on wet basis) and moisture ratio. M is used to denote the former one, while MR the latter. These quantities depend on time and are defined as:

$$M(t) = \frac{m_w(t)}{m(t)}, \tag{1}$$

$$MR(t) = \frac{M(t) - M_e}{M_i - M_e}. \tag{2}$$

In the formulas above m(t) denotes the mass of the sample, $m_w(t)$ the mass of water contained in the sample while M_i stands for the initial moisture content and M_e for the one in equilibrium, given the conditions (temperature and relative humidity in the dryer).

One could see that to determine the moisture ratio additional information is needed besides the moisture content, and this is the weight of dry matter in the sample. This will be marked with m_d. Equivalent to this is either the initial or the equilibrium moisture content. Unfortunately, neither of these could be measured with standard high school equipment, so a good guess on either of them is needed. In our case the guess is the data available in [4] to determine M_i for banana and apple – the fruits measured. Under the condition that m_d is constant, we see that $m_w(t)=m(t)-m_d$. Also, we can write the constants M_e and M_i with the masses:

$$M_e = \frac{m_w(\infty)}{m(\infty)} = \frac{m(\infty) - m_d}{m(\infty)}, \tag{3}$$

$$M_i = \frac{m_w(0)}{m(0)} = \frac{m(0) - m_d}{m(0)}. \tag{4}$$

The equation we will use (Modified Page model) to fit our data is the following:

$$MR(t) = \exp[-(kt)^n]. \tag{5}$$

This could be linearized easily in the following way:

$$\log(-\log(MR(t))) = n\log(k) + n\log(t). \tag{6}$$

This equation easily fits our data from experiments for given time intervals. We will discuss the results for both drying and evaporation in the upcoming sections.

DRYING PROCESS

The data from measurements with apple and banana and the result of the analysis described above are shown on Figs.1 to 3.

In Fig.3. deviations from linear could be seen at the high time values for both fruits. We suppose that the model we used lacks the correct description near the equilibrium. The fact that the concrete amount of dry matter is unknown also matters, especially at the equilibrium. Other than this, the linear fitting seems to be correct for most of the time with $R^2 = 0.997$ and the parameters are close to each other, n ~ 1.45 and k ~ 0.01.

Up to this point experiments and mathematical models were discussed, but as seen, we left out the actual physics of drying. This is because it is usually described by diffusion and other transport-equations. The different boundary and other conditions lead to the different mathematical constructions. This is a rather complex and difficult topic to discuss, even on extracurricular class, so we made a physical approximation and claimed that evaporation could be seen as a similar physical process to drying.

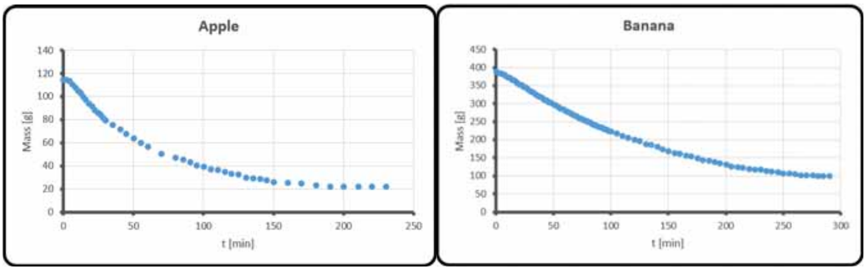


Fig.1. Mass of fruits over time: Left panel: apple. Right panel: banana

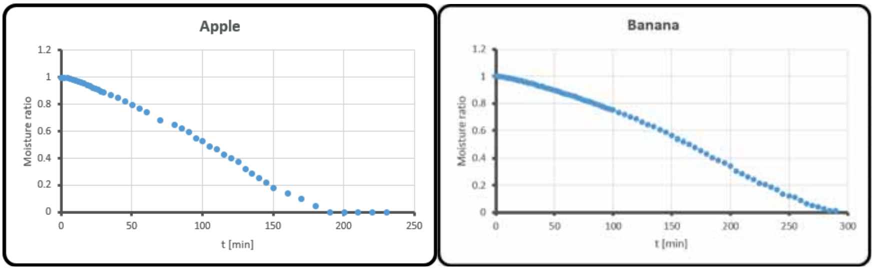


Fig.2. Moisture ratio of the fruits over time: Left panel: apple. Right panel: banana

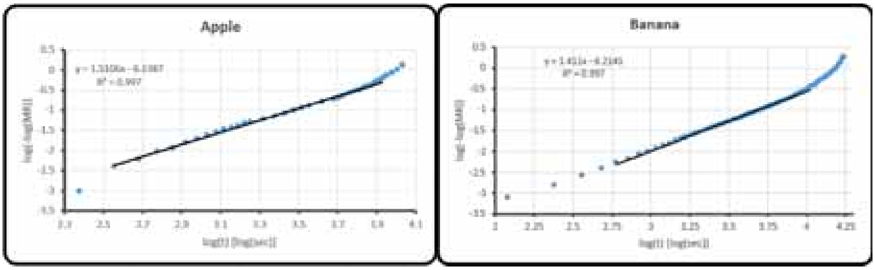


Fig.3. Values calculated using eq. (6), the line fitted with its parameters:
Left panel: apple, n = 1.5106, k = 0.0160. Right panel: banana, n = 1.4110, k = 0.0122

EVAPORATION

Experiments were made on the evaporation of two-constituent compounds – one of which is volatile (e.g. water) and the other is non-volatile – to physically model the drying process. The reason for this is that evaporation is a less complex phenomena taught on regular physics classes. The closest estimation of fruits (e.g. banana and apple) with two components is a sugar-water compound. In this physical model sugar represents the dry matter in fruits. The moisture content and moisture ratio was calculated for this compound from mass measured over time during the evaporation. The initial moisture content was 80%, which is a good generalisation for the fruits used previously. It is to be mentioned that the experiments with this compound were carried out with the same set-up as the one used in the case of fruit drying (an electric dryer on top of a kitchen scale), because the evaporation in open air took much more time than available for a double class (which is 120 minutes).

We investigated another compound, consisting of organic materials, paraffin-oil and pentane. Here, pentane was the non-volatile compound. This experiment is useful because in general, organic materials evaporate much faster, so in this case the set-up with the dryer was not needed to fit into the time of a class. An analytic balance and a petri dish was used instead to proceed with the measurements. The results, - extracted by the same analysis as in the case of drying before - can be seen in Fig.4.

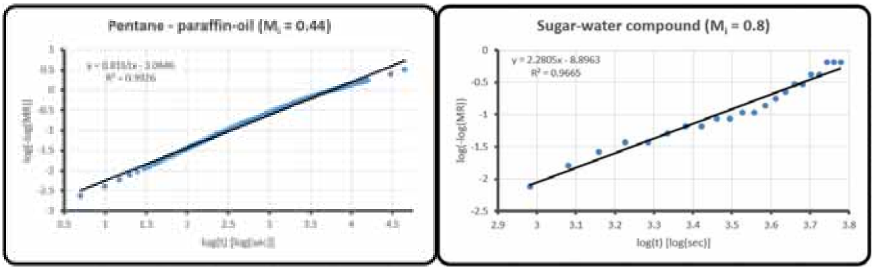


Fig.4. Values calculated using Eq. (6) for the description of evaporation, and the line fitted with its parameters: Left panel: pentane – paraffin-oil, n = 0.8161, k = 0.0233. Right panel: sugar-water, n = 2.2805, k = 0.0202

As seen in the figure, the mathematical model fits our data on evaporation well, in the case of the pentane – paraffin-oil even better than in the case of fruits. We think it is important that the dry matter content of the samples is known exactly this time, so this does not bring another uncertainty in the data.

To sum up: an approximation – a physical approximation – was made that the evaporation is similar to drying, and we described this with the same mathematical model successfully.

A TOY MODEL OF EVAPORATION WITH DICES

Investigating evaporation further, a toy model (or dice model, as it requires the use of dices) had been derived and was used successfully as a demonstration for this phenomena. To introduce this, we will need dices of two colours. Let us say that dices of one colour (these will be referred to as white dices from now on) represent the volatile component of a two-constituent compound (e.g. water), while the dices of the other (these will be referred as the red ones) represent a non-volatile component, or going further we could say that these stand for the dry matter in a given fruit. The ratio of the white dices to all of the dices represents a given initial moisture content, M_i. After this some dices are to be put on a table, which represents the surface of the compound or the fruit. After this initialisation we roll the white dices on the “surface” and if one of them is a six, we take that one out of the game – this is to be concerned as the loss of weight over time. This game or toy model supposes a constant surface area, so after taking dices out of the game one has to “refill” the table. This could happen in different ways, representing different physical conditions. Examples: one could refill from under the table with white and red dices in a way the ratio of whites and reds (taking into account both the dices on and under the table) remains constant, or this could be done with only white dices (see Fig.5.), this way the ratio will depend on time. After enough turns in the game, there will be no white dices left on the surface, so it ends.

This game could be introduced in high schools very easily as it demonstrates evaporation in a more engaging way than most books do. Also it is possible to analyse a game with the same method as used above for drying and evaporation. To exemplify this, Fig.6. shows data from a class where this model was introduced and tried with students.

Fig.5. Example for the toy model introduced. It shows a possible pattern for replacing white dices on the surfaces.

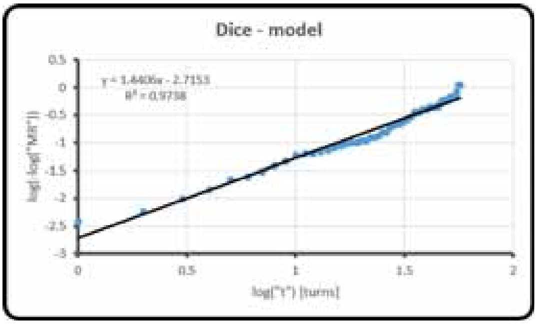


Fig.6. An example to show that the same data analysis could be done in the toy model.

CONCLUSIONS

We have shown a possible way of introducing supplementary material on fruit drying in high school physics (or other science) classes. This could prove a very rewarding area as it is possible to include device development (building a solar dryer), experiments and measurements (to explore the characteristics of a given device, or to investigate a physical process), data analysis with given mathematical models, linearization of equations, analogous thinking. It could also serve as an entry point for more advanced students into the topic of diffusion, or even model building with differential equations. We have also derived a new toy model of evaporation with dices. This proved to be a powerful demonstrational tool as it caught the attention of students besides those who were already interested.

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A FEW YEARS EXPERIENCE OF THE ENERGY CONSUMPTION OF A HIGH SCHOOL IN BUDAPEST

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ABSTRACT

I analyzed the consumption of electrical and heating energy based on the data of meters between April 2012 and March 2015 in Arpad Secondary Grammar School in Budapest. In my presentation I summarize the experiences which were obtained from the data. First I compare and explain the consumption of energy between the years and between the different periods of the years. I determine the amount of energy per person and per student groups too, and with a little calculation I interpret the results. After another short calculation I outline whether is it worth for our school to change heating mode. Finally I suggest potential solutions for reducing the consumption of energy which may lead to savings for the school.

INTRODUCTION

The Arpad Secondary Grammar School (Fig.1.), located in the northern part of Budapest, was founded in 1902. From 2012 it has 22 classes, the number of students is about 700.

The building of the school is 75 years old, it has central heating and it is provided with electrical energy by Budapest Electricity Works. We cannot say this building is an energy saving one because of the bad status of the doors and windows and the outdated heating and electrical system. There is no air-conditioning, and both the heating and electric providers are independent from the school.

Fig.1. Árpád Secondary Grammar School in Budapest

AIMS OF THE WORK

The aims of the investigation were to collect and to present those two types of energy data (electrical and thermal energy) which are most important in the field of education in the school. After analyzing them it will be shown through an example taken from everyday life how the data can be made understandable for high school students. Based on the interpretation some options for energy saving will be suggested, too.

DATA FOR ENERGY CONSUMPTION

All energy data – presented in GJ unit – were read in every month from the meter readings between April 2012 and March 2015. The annual (Fig.2.) and the quarterly data charts below (Figs. 3.-5.) show the consumption of energy.

EXPERIENCES

On the annual chart (Fig.2.) it is noticeable that in the first and in the third year the ratio of electrical and thermal energy is about one quarter, but in the second year it is only about one third. The reason is that the temperature of the winter in 2013-2014 was about 2.5 centigrade higher than the hundred-year average so though the consumption of electrical energy increased a little, but the consumption of the thermal energy decreased much more.

The other information is – as mentioned before – that the consumption of electrical energy increased. The value was higher not only in the second but in the third year too. One possible explanation for this was the creation of a new information technology room which operated throughout the whole school year.

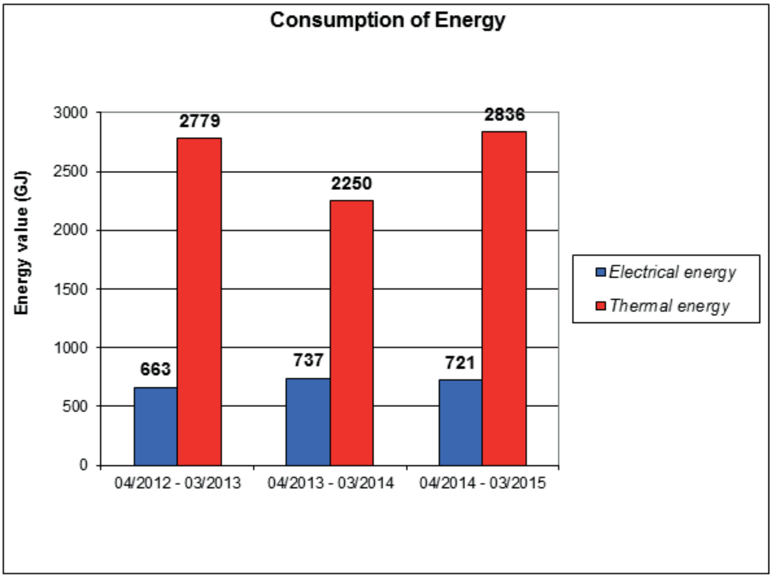

Fig.2. Annual data chart of energy consumption

The next three graphs (Figs.3.-5.) show the quarterly data charts. On all three graphs the periodicity can be seen and from left to the right we can separate the seasons, too. Probably it is not surprising that in the third and in the fourth quarters the thermal energy is 5-7 times more than the electrical energy.

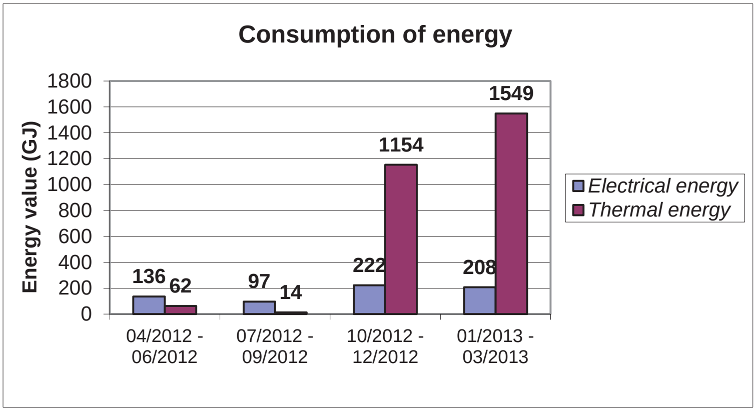

Fig.3. Quarterly data chart of energy consumption – 2012-2013

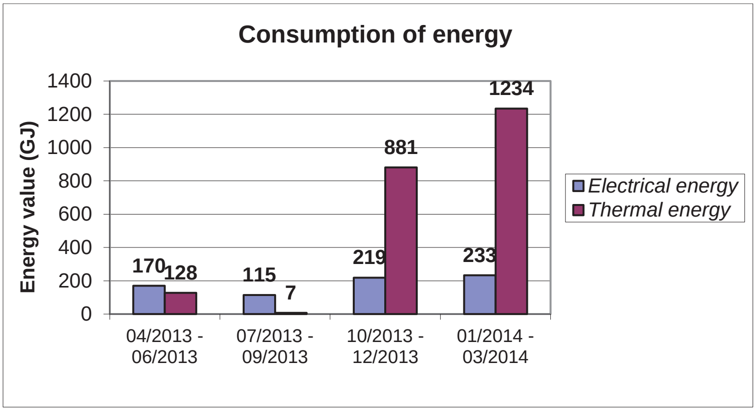

Fig.4. Quarterly data chart of energy consumption – 2013-2014

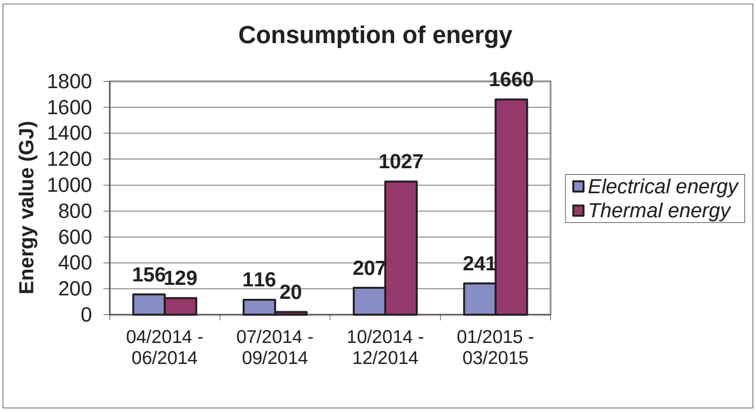

Fig.5. Quarterly data chart of energy consumption – 2014-2015

On the following diagram (Fig.6.) I show the cumulative annual energy values per capita. It is about 5 GJ on average per person.

I also calculated the price of this energy quantity, the value of it is about 100 Euros in Hungary in 2015.

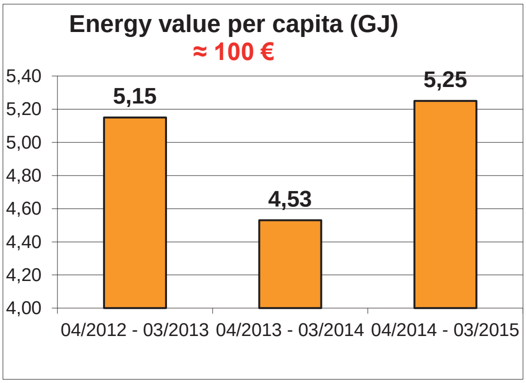

Fig.6. Annual energy consumption per capita

To make the data of the chart understandable for everyone I try to solve a calculation problem which is as follows:

The human body can burn 200 kilocalories in 10 minutes on an exercise bike in the case of a uniform load. The efficiency of the human body is 0.25 [1]. Calculate how much work can be done by a high school student and a class of 30 students in half an hour on it!

$$Q = 3 \cdot 200 \text{ kcal} = 600 \text{ kcal} = 2520 \text{ kJ} = 2.52 \text{ MJ}$$

$$\eta = 0.25$$

$$W = \eta \cdot Q = 0.25 \cdot 2.52 \text{ MJ} = 0.63 \text{ MJ}$$

$$\Sigma W = 30 \cdot 0.63 \text{ MJ} = 18{,}9 \text{ MJ}$$

The solution of the task is 0.63 MJ – assuming that the efficiency of the human body is about 0.25 [1] – and 18.9 MJ if we consider a class with 30 students. These values become clear if we assign such content to them which is in connection with the everyday life.

In our school the rooms are lit by fluorescent lamps, in each room the total power for lighting is 900 W. Let's assume that the whole work of the class produces electric energy.

$$\Sigma W = 18.9 \text{ MJ} = 18900 \text{ kJ} = 18900000 \text{ J}$$

$$P = 900 \text{ W}$$

$$t = \Sigma W / P = 18900000 \text{ J} / 900 \text{ W} = 21000 \text{ s} \approx 5.83 \text{ h}$$

In this case the energy produced by the whole class is sufficient for less than 6 hours. It means that 30 high school students with hard training cannot produce the amount of energy that a school needs for the lighting of a room in the daily teaching.

It is interesting to determine how much time a high school student needs to produce the annual energy consumption. I used the data of the chart "Annual energy data consumption per capita" (Fig.6.) and I calculate with the mentioned 5 GJ average value. I also used the result from the first calculation problem which showed how much work can be done by a high school student riding on an exercise bike in half an hour. It was 0.63 MJ.

$$\Sigma E = 5\ \text{GJ} = 5000\ \text{MJ}$$

$$W = 0.63\ \text{MJ}$$

$$t = \Sigma E/W \approx 7936 \text{ half an hour unit} \approx 165 \text{ day (without interruption)}$$

I think the solution of the problem is hard to believe, but it should be clear from this result as well that the energy that we can produce in a mechanical way is only a fraction of the quantity that a school needs for its operation. If we try to compare the energy produced by mechanical work with the annual energy consumption, the difference is about two orders of magnitude.

In the light of this striking result it is worth thinking about what the options of a high school for energy saving can be. Even students know that switching off the unnecessary lights will not cause significant saving so we have to look for more efficient solutions.

One possibility would be to change the heating system from central heating to gas heating. Knowing and using the different parameters of gas heating [2],[3] which are typical for traditional gas boilers, after a short calculation we can realize that the costs would be only about 70% of the current costs but the implementation would require serious investment.

$$\Sigma Q = 2800\ \text{GJ (Fig.2.)} = 2800000\ \text{MJ}$$

$$\eta = 0.85$$

$$L = 34\ \text{MJ/m}^3$$

$$V = \Sigma Q / (\eta \cdot L) = 2800000\ \text{MJ} / (0.85 \cdot 34\ \text{MJ/m}^3) \approx 97000\ \text{m}^3 \text{ (price of it is about 32000 Euros)}$$

The other and maybe more viable way for us would be to use alternative energy sources [4], the most feasible of these seems to be the photovoltaic system.

This photo (Fig.7.) was taken in another secondary school – Fasori Gimnázium in Budapest – where the system has been working since April 2015. According to the descriptions – that the school got from the manufacturer – it can produce about 30 MWh = 108 GJ, mainly electric energy. It covers the whole energy demand of the lighting and it is about a quarter of the total electric energy. The school won 85% of the investment costs in a tender opportunity. This solution can be reachable in the future for our school, too [4].

Fig.7. Photovoltaic system in Fasori Gimnázium in Budapest

CONCLUSIONS

In physics teaching the concept of energy is very important. Students meet both with conventional and renewable energy sources during their physics studies. In my teaching process I only mention the topic of this presentation and try to interpret the charts and the results of the calculation problems first in the eighth grade. The main focus of the whole theme of energy saving is in the tenth and eleventh grade where besides the correct interpretation students can complete their knowledge with more calculations and measurements which are in connection with concrete devices (e.g. solar cells).

In this presentation first I summarized and presented the thermal and electrical energy consumption of our school in the last three years. I have tried to interpret it with an example where a comparison was made to the human power. Although it had a surprising and thought-provoking result, it can provide an opportunity to our high school students to recognize that the energy saving will be vital in their future life. On the other hand as a physics teacher I tried to adumbrate some possible solutions for energy saving in my school, too, but all my activities were directed at the didactic task to raise students' awareness of the importance of the problem.

Finally anybody can ask what can be implemented from these? I think the main purpose that students' thinking can develop is achievable. The realization of energy saving ideas needs not only much money but the human will, too. I have 9 more years to retirement and I would like to see it as an active teacher. So I hope….

ACKNOWLEDGEMENTS

I want to express my special thanks to Professor Adam Kiss who supported me with his remarks, ideas and suggestions. I am grateful for the collected energy data to my working-place (Fig.1.), too.

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SIMPLE MODEL FOR THE ENERGY SUPPLY OF A STAND-ALONE HOUSE USING HYBRID WIND–SOLAR POWER SYSTEM

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ABSTRACT

A research project for secondary school students involving both physical measurements and modelling is presented. The problem to be solved is whether and how a typical house can be supplied with energy off-grid, based entirely on renewable energy sources, more specifically, on solar and wind energy, while using relatively simple devices, namely, photovoltaic modules, wind turbines and accumulators. Our students carried out a long term measurement series in order to assess typical energy consumption of houses. Further, the number of solar modules and wind turbines and the necessary accumulator capacity was estimated.

INTRODUCTION

Renewable energy sources are becoming increasingly important in energy supply. Their contribution covered an estimated 19% of the global energy consumption in 2011 [1]. The application of the renewable energy resources helps to reduce global greenhouse gas emission and mitigate global warming [1, 2, 3]. Due to their significance and perspective, it is desirable to give renewable energy sources an appropriate share in physics teaching. In this paper a related research project designed for and accomplished by secondary school students is described. Our students examined the role of the renewable energy sources and the behaviour of an off-grid hybrid wind-solar model system using elementary concepts of physics. In this model electricity was generated by means of photovoltaic (PV) modules and wind turbines, while the electrical energy was stored in accumulators. A quite similar model was discussed in [4].

We can make the traditional lessons more colourful with different project tasks. The well-planned project tasks augment students' knowledge in the particular topic and make students more motivated in learning that subject. According to my experience the most effective tasks were carried out in pairs or groups with the teacher's guidance, as well as in this project.

Our 'Renewable energy sources: stand-alone house with hybrid wind-solar power generator' project has been carried out in three stages. For the first stage the daily energy consumption of an average house was investigated. Energy consumption of electric home appliances and energy consumption of air conditioner and heating energy were monitored separately. During the project, which lasted for 2 years (from 2012-Oct-1 to 2014-Oct-1), the students measured the daily energy consumption of their households. The wind speed and the sunlight were also monitored. For the second stage we developed a mathematical model for an off-grid house with hybrid wind–solar power generator and accumulator system. For the third stage a computer simulation program was developed, based on the mathematical model and the data collected by students. This programme enabled the simulation of the energy system of an off-grid house. The feasibility of the model was also analyzed; in particular the necessary accumulator capacity was determined. The main purpose of the project was, however, educational.

MODELLING

The model setup is depicted schematically in Fig.1. The parts of the system are the power generating system (photovoltaic modules and wind turbines), the energy storage unit (accumulator system); and the appliances: electric home appliances, electric heating system and cooling system. The solar modules are mounted on the roof.

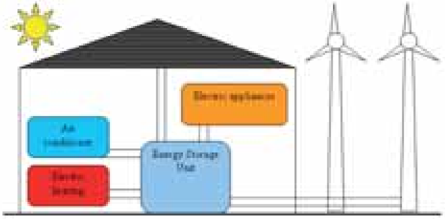

Fig.1. The stand-alone model house with hybrid wind–solar system and energy storage unit

Gathering data

Our 16 - 18 old year students took part in this project voluntarily. The number of students taking part in the project was N=31. Measurements were carried out partly at home and partly in extracurricular afternoon physics classes in team work. Students collected the data of the daily energy consumption of their own houses: the energy consumption of the electric appliances was monitored; the natural gas consumption was monitored by gas meter; the wood and coal burned in furnaces were measured in weighing-machines (scales). The electrical energy consumption of the air conditioner was monitored (estimated) separately from the electric home appliances. The data was gathered by students then we counted the averaged values on a daily basis:

$$E_{total,i} = \frac{A_{ave} \cdot N_{ave}}{N} \sum_{j=1}^{N} \frac{E_{total,i,j}}{A_j \cdot N_j}, \tag{1}$$

where $E_{\mathrm{total},i}$ is total averaged energy consumption of the model house on ith day, A_{ave} is average floor-space of houses, N_{ave} is the average number of inhabitants in the house, A_j is floor-space of the house of jth student, N_j is the number of inhabitants in the house of jth student, $E_{\mathrm{total},i,j}$ is total energy consumption of the house of jth student on ith day.

In the given 2-year period the average daily electricity consumption per household was 36.08 MJ; the lowest average daily electrical energy consumption was 27.44 MJ and the highest one was 41.89 MJ. (Before doing the project, most of the students could not even estimate the order of the energy consumption of their own home. During the project they learnt to collect, process and analyze data in the long run.)

We monitored the local outside temperature as well as the inside temperature during the project. The wind speed, the air pressure and the sunlight were monitored in every Δt=5 minutes automatically by the local weather station, so these data were available for us.

PV modules

A photovoltaic (PV or solar) cell converts the energy of light directly into electricity by the photovoltaic effect. A photovoltaic module is built from blocks of photovoltaic cells. The power of a photovoltaic module is proportional to the incoming light power [4]. The total energy production of the photovoltaic modules on ith day can be calculated as

$$E_{photov,i} = \sum \eta_{photov} \cdot A_{photov} \cdot I \cdot N_{photov} \cdot \Delta t, \tag{2}$$

where A_{photov} is the area of one PV module, I is the light intensity (incident solar flux in W/m^2), η_{photov} is the efficiency of the solar module on ith day and N_{photov} is the number of PV modules.

Wind turbines

Wind turbine generates electricity from the kinetic energy of the wind. In our model small (not commercially serialized) wind turbines are used to generate electricity. For simplicity the turbines are assumed to be self-orientating devices. The power output of the wind turbine is proportional to the cross sectional area swept by the rotor and to the cube of the wind velocity [5, 6]. The total energy production of the wind turbines on *i*th day can be calculated as

$$E_{windt,i} = \sum C_{po} \cdot \frac{\rho_{air}}{2} \cdot A_{rotor} \cdot v_{wind}^{3} \cdot N_{windt} \cdot \Delta t, \tag{3}$$

where ρ_{air} is the density of air, A_{rotor} is the cross sectional area of rotor, v_{wind} is wind velocity, C_{po} is the power coefficient, and N_{windt} is the number of wind turbines. The density of air is $\rho_{\mathrm{air}}=p\bullet M\bullet R^{-1}\bullet T^{-1}$; where p is the pressure (monitored), T is the absolute temperature of air (monitored), M=0.029 kg•mol^{-1} is the molar mass, and R is the universal (molar) gas constant.

Accumulators

The electricity demand of the model house can change significantly on a smaller timescale. When electrical energy is generated in solar modules and/or in wind turbines, it gets stored instantly in accumulators according to the model assumption. We discussed what size of accumulator capacity ($E_{\mathrm{acc\_max}}$) is suitable for the parameters given in our off-grid system. We must take a battery system large enough to prevent blackouts (total energy loss) in the whole period of the project.

ENERGY INPUT AND OUTPUT AND ENERGY STORAGE

In order to determine the necessary storage capacity of batteries, we studied the energy inputs (produced energy) and outputs (dissipated energy) of the system in detail.

Heat transmission

Temperature difference in any situation results in energy flow into the system or energy flow from the system to its surroundings. The former leads to the heating, the latter leads to the cooling of the system. The total energy flow of heat transmission process on *i*th day is

$$E_{heattr,i} = \sum U \cdot A_f \cdot \left(T_{out} - T_{in}\right) \cdot \Delta t, \tag{4}$$

where A_{f} is the free surface area of building, U is the overall heat transmission coefficient, T_{out} is the absolute temperature of ambient air, T_{in} is the absolute inner temperature of the building.

Thermal radiation

The accurate analysis of heat radiation of the system is a complex problem; so we try to construct only an approximate model accounting for thermal radiation. The total energy flow of heat radiation process on *i*th day:

$$E_{rad,i} = \sum \varepsilon \cdot \sigma \cdot A_f \cdot \left(T_{out}^{4} - T_{in}^{4}\right) \cdot \Delta t, \tag{5}$$

where σ is Stefan-Boltzmann constant (σ=5.67•10^{-8} W•m^{-2}•K^{-4}), ε is the overall (average) emissivity of the building.

Heating

Our building is an off-grid system and has electric heating; that is, electric current through a resistor releases heat. The total electrical energy consumption of resistance heating on *i*th day:

$$E_{heating,i} = \sum P_{heating} \cdot \Delta t, \tag{6}$$

where P_{heating} is the electric power of resistance heater.

In the model if the required inside temperature of the building is higher than the actual inner temperature, then we use the electric heating system. If the instantaneous outside temperature is higher than the required inside temperature of the building in the ‘heating season’ then it is not necessary to use the heaters, we can warm the interior of the house by opening the windows.

Cooling

If the temperature inside the house is too high (in summer) we can use an air conditioner; it is a device that lowers the air temperature. The cooling process is typically achieved through refrigeration cycles. The total electrical energy consumption of air conditioner on ith day:

$$E_{cooling,i} = \sum P_{aircond} \cdot \Delta t, \tag{7}$$

where P_{aircond} is the electric power of the air conditioner.

In the model if the required inside temperature of the building is lower than the actual inner temperature, then we use the air conditioner. If the instantaneous outside temperature is lower than the required inside temperature of the building in the ‘non heating season’, then it is not necessary to use the air conditioner, we can cool the house interior by opening the windows.

Internal energy

Our building can store energy as internal energy. The internal energy of a macroscopic system at a given temperature is proportional to its heat capacity [7]. The internal energy of model house on ith day is assumed to be

$$E_{internal,i} = C_{air} \cdot T_{in,i} + C_{wall} \cdot \frac{T_{in,i} + T_{out,i}}{2}, \tag{8}$$

where C_{wall} is the heat capacity of walls, and C_{air} is the heat capacity of air inside the building.

ENERGY BALANCE

Now the energy balance of the hybrid wind-solar power generating system is considered.

Heating season

It is supposed for the sake of simplicity that in the ‘heating season’ the internal energy of the model house on ith day ($E_{\mathrm{internal},i}$) depends on the internal energy on the previous day ($E_{\mathrm{internal},i\text{-}1}$), the net electric heating on ith day (if any), and the net energy flowing in or out of the system by heat transfer ($E_{\mathrm{heattr},,i}$) and heat radiation process ($E_{\mathrm{rad},i}$) on ith day:

$$E_{internal,i} = E_{internal,i-1} + \eta_{heating} \cdot E_{heating,i} + E_{heattr,i} + E_{rad,i}, \tag{9}$$

where η_{heating} is the efficiency of the electric heating device. In this model resistance heater is applied, thus η_{heating} is nearly 1 because an off-grid electric resistance heater converts (nearly) the full electric energy into heat. (Some energy is needed by ventilators, if any.)

According to the household’s need, the total daily electrical energy consumption on ith day is the energy of electric home appliances and electric heating. In the ‘heating season’ the energy stored in accumulators at the end of ith day ($E_{\mathrm{acc},i}$) depends on the energy stored in batteries at the end of the previous day ($E_{\mathrm{acc},i\text{-}1}$), the total electrical energy produced by PV modules ($E_{\mathrm{photov},i}$) and wind turbines ($E_{\mathrm{windt},i}$) on ith day, and the total energy dissipated in the electric resistance heater ($E_{\mathrm{heating},i}$) and electric home appliances ($E_{\mathrm{eapp},i}$) on ith day:

$$E_{acc,i} = E_{acc,i-1} + E_{photov,i} + E_{windt,i} - E_{heating,i} - E_{eapp,i}. \tag{10}$$

Non-heating season

In the ‘non-heating season’ the internal energy of model house on ith day ($E_{\mathrm{internal},i}$) depends on the internal energy of the house on the previous day ($E_{\mathrm{internal},i\text{-}1}$), the net cooling energy on ith day (if any), and the net energy flowing in or out the house by heat transfer ($E_{\mathrm{heattr},,i}$) and heat radiation process ($E_{\mathrm{rad},i}$) on ith day:

$$E_{internal,i} = E_{internal,i-1} - C_{cooling} \cdot E_{cooling,i} + E_{heattr,i} + E_{rad,i}, \tag{11}$$

where C_{cooling} is the coefficient of performance (COP) of the air conditioner.

According to the household's need the total daily electrical energy consumption on *i*th day is the energy of electric home appliances and air conditioning. In the 'non-heating season' the energy stored in accumulators at the end of *i*th day ($E_{\text{acc},i}$) depends on the energy stored in batteries at the end of the previous day ($E_{\text{acc},i\text{-}1}$), the total electrical energy produced by PV modules ($E_{\text{photov},i}$) and wind turbines ($E_{\text{windt},i}$) on *i*th day, and the total energy dissipated in air conditioner ($E_{\text{cooling},i}$) and electric home appliances ($E_{\text{eapp},i}$) on *i*th day:

$$E_{acc,i} = E_{acc,i-1} + E_{photov,i} + E_{windt,i} - E_{cooling,i} - E_{eapp,i}. \tag{12}$$

SIMULATIONS

We used spreadsheet software for the simulations. This method enables the solution of a complex physical (mathematical) problem in a relatively simple way. In the simulations we 'estimated' the energy consumption of a typical house with 4 inhabitants. We tried to choose realistic data for the simulations according to the data gathered by students. Our model house is a hollow rectangular building, with A_{ave}=100 m^2; the dimensions are a=10m, b=10m, h=3m (height), the thickness of walls is d=0.4 m. In Fig. 2. the electrical energy produced by photovoltaic modules and wind turbines can be seen in the 2-year period of project (from 2012-Oct-1 to 2014-Oct-1). The power coefficient of the not commercially serialized wind turbine is C_{po}=0.25, the cross sectional area of rotor is A_{rotor}=4 m^2, the number of wind turbines is N_{windt}=4. The area of one PV module is A_{photov}=1 m^2, the number of solar modules is N_{photov}=100, the efficiency of the solar module is η_{photov}=0.15.

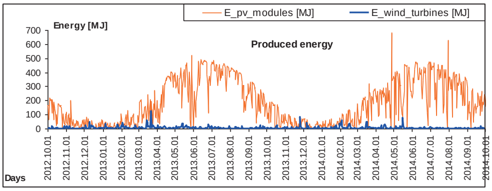

Fig.2. Electrical energy produced by PV modules and wind turbines during the whole period of the project

In Fig.3. the electrical energy consumption of the model house (electrical home appliances, electric heater and air conditioner) is shown in the 2-year period of the project (from 2012-Oct-1 to 2014-Oct-1). The efficiency of resistance heating device is η_{heating}=1, the coefficient of performance of the air conditioner is C_{cooling}=3. The overall heat transmission coefficient of insulated walls is U=0.18 W•m^{-2}•K^{-1}; the emissivity of the building's walls is ε=0.12.

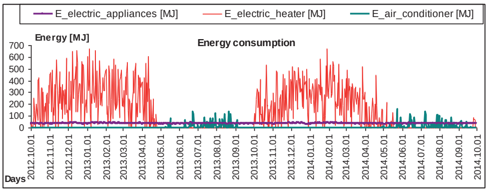

Fig.3. Electrical energy consumption of the house (electric home appliances, electric heater and air conditioner) during the whole period of the project

Computer simulations with spreadsheet software were performed in order to determine the necessary capacity of the storage unit [8]. In the simulation with the given data the necessary capacity of the energy storage unit that must be chosen is approx. 45097 MJ in order to prevent blackouts (in order to $E_{\mathrm{acc},i}$ take values only between 0 and $E_{\mathrm{acc\_max}}$) every day in the 2-year period of the project. We got that the capacity of the accumulator system derived from the simulations has a value too large for a real-world storage system. It cannot be realised in the real world in a house.

Without electric heating

Electric heating is the biggest form of energy consumption in the model house. If the electric heating is rejected and fossil fuel (e.g. wood) heating is applied, then the necessary capacity of storage unit is approx. 547.5 MJ according to our simulation. In this case all electric home appliances and even the air conditioner can be used in the model house in the whole period of the project [8]. This storage capacity might be realised (perhaps), but it would be very expensive.

CONCLUSIONS

Students had to consider some properties of a stand-alone house with a hybrid wind–solar power generator and accumulator system. The parameters of the model house and the dimensions of the hybrid wind-solar power generator system are fitted to data collected by students. Discrete energy balance equations were given to determine the necessary capacity of the energy storage unit. We think that this student project helps to strengthen connection between theory and practice, improving practice within the field of physics education. We hope that this simplified model can be profitable for interested students in grammar schools.

ACKNOWLEDGMENTS

I would like thank Gyula Bene and Tamás Tél (my supervisors) who helped me with useful information and data. I would like to thank my colleagues Orsolya Pap and Antal Fekete, and our students for their contribution to the project.

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RASPBERRY SOLAR CELL, A VERSATILE TOOL IN TEACHING PHYSICS

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ABSTRACT

The article describes the realization and teaching application of the raspberry solar cell. We present its components and the electron transports of the raspberry solar cell. The description uses the same four steps, the excitation, the charge separation, the diffusion and the regeneration, as the single n-p junction solar cell, and as the light-dependent reactions of photosynthesis. To strengthen the similarities between these solar energy converters, we underline analogies in energy levels and bands. These analogies offer an interdisciplinary approach in teaching applications. The real situation, the construction of the raspberry solar cell, allows the science teacher to place the notion of energy and the solar energy conversion into an interdisciplinary context. For this reason, we organized student activities around this versatile tool. Here we expose the results of a test, realized by homemade solar cells, sensitized by three organic dyes, exposed to different light sources.

RASPBERRY SOLAR CELL

A raspberry solar cell is a dye-sensitized solar cell composed of an anode, a cathode and an electrolyte. The construction of a raspberry solar cell is an interesting project work, but it requires special coated glass plates, laboratory materials, special equipment and preparations for the physics teacher. See needed materials and steps to follow with more references in [1].

The anode consists of a transparent glass plate covered by a semi-conductor layer (Fluorine doped Tin-Oxide or FTO). On this plate, we stabilized a porous, wide bandgap semiconductor (titanium-dioxide or TiO_2) layer. According to its wide bandgap, the semiconductor layers are insensitive to visible light. To prepare a light-sensitive anode, we fixed raspberry dyes (anthocyanin molecules) on the TiO_2 layer. On one hand, this combination of semiconductor layers and raspberry dye layer allows increasing the effective surface of solar cell. On the other hand, the difference between the conduction bands of FTO and of TiO_2 results electrons on the FTO glass plate. The energy of the captured photons excites the electrons (of anthocyanin molecules), which follow the energetically suitable way to the FTO layer.

As cathode, we used another transparent FTO coated glass plate, covered with a carbon layer. This layer acts as a photo-reflecting layer and a catalyst of the electrolyte regeneration. Between these two electrodes, a regenerative electrolyte (iodide/tri-iodide) solution closes the circuit. The solar cell is ready to convert the photon's energy [2].

The left panel of Fig.1. shows the simplified structure of a raspberry solar cell. The right panel presents a homemade raspberry solar cell. The anode side is beige, because TiO_2 is white, the raspberry juice is red, the electrolyte is brown and mixing these colours results in beige. The carbon on the cathode side is black.

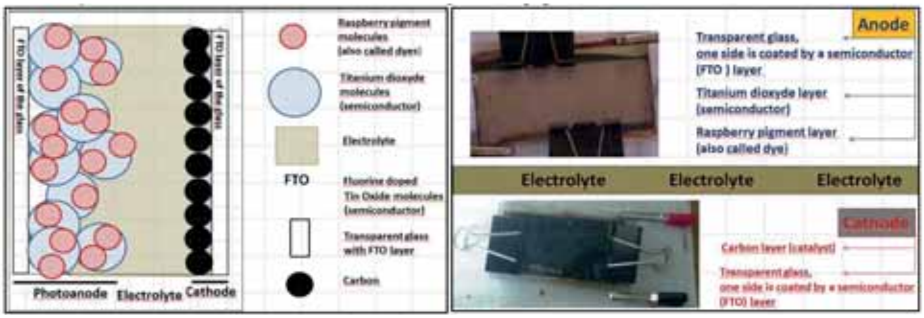


Fig.1. Structure of a raspberry solar cell. Components of a homemade raspberry solar cell

HOW IT WORKS

Due to the internal structure, the unit is a galvanic cell, and it works in dark as well. If we expose the anode side to light, first a ground state raspberry dye molecule absorbs a photon. The excited dye molecule injects an electron into the TiO_2 grain (crystal), at the point where the TiO_2 adsorbed the raspberry dye. This step is the charge separation. After that, the electrons diffuse to the FTO from the TiO_2 layer. Connecting a voltmeter between the electrodes, it measures a voltage. See the left panel of Fig.2.

If we connect the electrodes using an ammeter, it measures an electric current. The electron travels through the outer circle, reaches the cathode, and regenerates the electrolyte and the dye in two steps, as the right panel of Fig.2 shows [3].

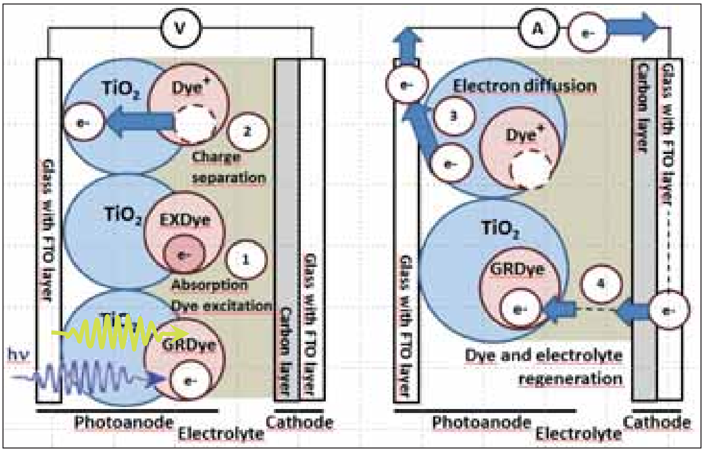


Fig.2. Photovoltaic effect   Electric current

One can follow the energy of an electron on the left panel of Fig.3, where we represent the relative energy levels and bands [4]. On the abscissa, there are the components of a cell in spatial order, starting with the place of the photon absorption (Dye). Here the excited state level (EX) is energetically the highest level. The four main steps of an electron-cycle are numbered on the figure. The right panel of Fig.3. represents the components as they are in space. The most absorbed photons, absorbed by the pair TiO_2 – raspberry dye, are the photons of 2.3 eV. See the main steps of an electron-cycle in Table 1 and [5].

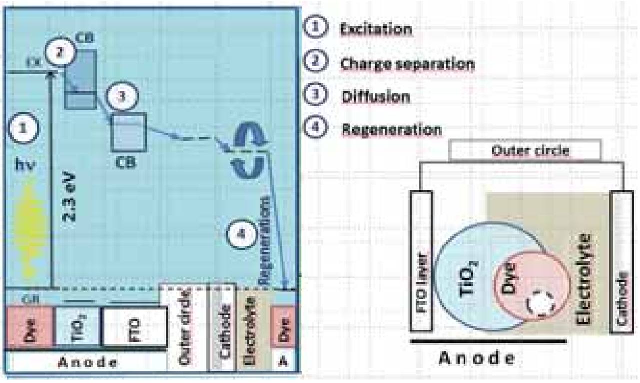


Fig.3. Raspberry solar cell: Relative energy levels and bands Actual order in space

Table 1. Main steps of an electron-cycle of the raspberry solar cell

Steps	Raspberry Solar Cell	GRDye = ground state dye
①	$GRDye + h \cdot \upsilon \rightarrow EXDye$	EXDye = excited state dye
②	$EXDye \rightarrow e^-_{TiO2.CB} + Dye^+$	I^- = iodide / I^-_3 = tri-iodide
③	$e^-_{TiO2.CB} \rightarrow e^-_{FTO.CB}$	$e^-_{TiO2.CB}$ = electron in the conduction band of TiO_2
④	Electrolyte: $I_3^- + 2e^- \rightarrow 3I^-$	$e^-_{FTO.CB}$ = electron in the conduction band of FTO
	Dye: $2\,Dye^+ + 3I^- \rightarrow 2GRDye + I_3$	

ANALOGIES AND SIMPLIFICATION I. – TEACHING SOLAR CELLS

In practice, most solar cells use semiconductors in the form of an n-p junction, which is formed by joining an n-type and a p-type semiconductor. Near the junction, in the depletion region, a photon's absorption results in an electron-hole pair. Both the electron and the hole can participate in conduction. After the diffusion to the n-type semiconductor, the electron travels through the outer circle and will recombine with a hole, which travels in the opposite direction and diffuse to the p-type semiconductor (see Fig.4.).

In a single n-p junction solar cell, an electron follows the same four main steps as in the raspberry solar cell. In the raspberry solar cell, the excitation and the charge separation steps are spatially divided, which simplifies the description. Here only the electron moves, because the positive dyes (Dye+) are adsorbed on the TiO_2 layer. These facts result in a simplified and localizable electron-cycle. Applying this analogy to the electron- and hole-cycle of a solar cell, the students can understand the basis of solar cells physics. See Fig.5. and Table 2.

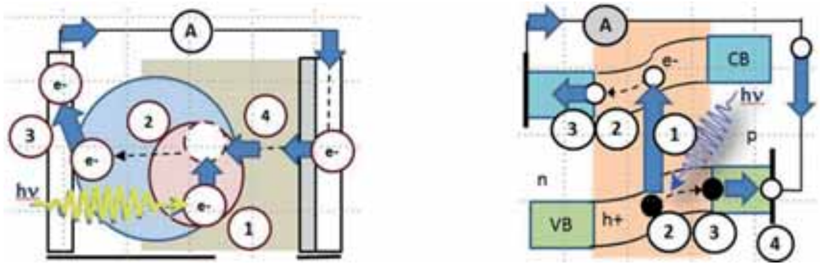
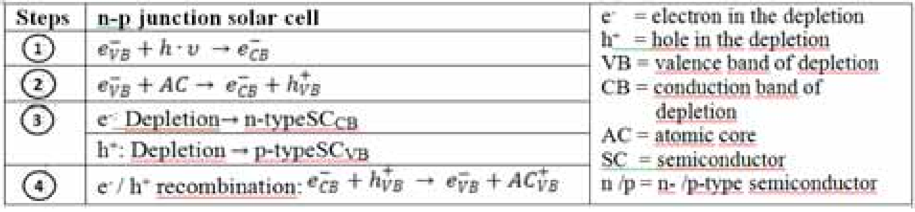


Fig.4. Raspberry solar cell: electron-cycle n-p junction solar cell: electron/ hole cycle

Table 2. Main steps of an electron-hole pair cycle of the n-p junction solar cell



Steps	n-p junction solar cell	
①	$e^-_{VB} + h\cdot\upsilon \rightarrow e^-_{CB}$	e^- = electron in the depletion h^+ = hole in the depletion VB = valence band of depletion CB = conduction band of depletion AC = atomic core SC = semiconductor n /p = n- /p-type semiconductor
②	$e^-_{VB} + AC \rightarrow e^-_{CB} + h^+_{VB}$	
③	e^-: Depletion→ n-typeSC$_{CB}$	
	h^+: Depletion → p-typeSC$_{VB}$	
④	e^- / h^+ recombination: $e^-_{CB} + h^+_{VB} \rightarrow e^-_{VB} + AC^+_{VB}$	

The comparison of the energy bands of the two types of solar cells shows that the raspberry solar cell has a simplified energy band structure because of the immobility of the dyes and of the localized steps of a cycle on the different components of the cell. On the n-p junction solar cell, the student has to follow the energy of the electron and of the hole, and has to understand the deformed energy structure of the depletion region, too.

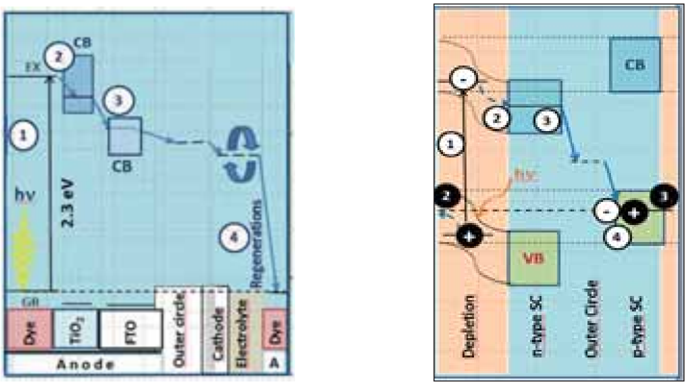


Fig.5 Raspberry solar cell: relative energy bands, n-p junction solar cell: relative energy bands

TEST OF A HOMEMADE RASPBERRY SOLAR CELL

After the realization, we used the raspberry solar cell as a galvanic cell, and we measured the voltage in dark. In use, the current supplied by the solar cells is important, and determines the electric power taken from them. We used different light sources (bulb, neon, halogen, LED, UV) and different dyes (raspberry-, blueberry- and mango dyes) to measure the generated current.

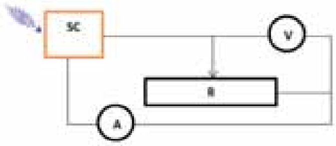
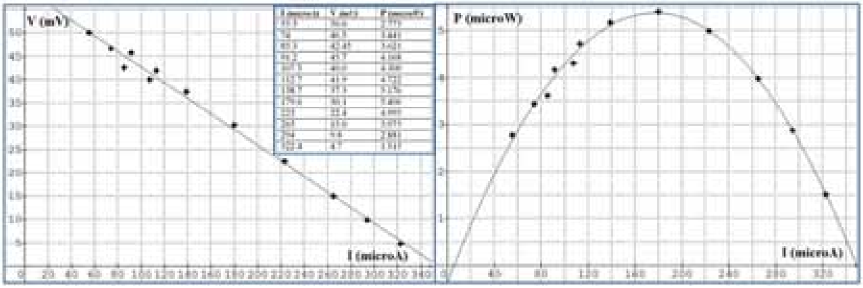


Fig.6. Solar cell as current source

For a comparative analysis of raspberry- and n-p junction solar cells, we used illuminated cells as current source in the electrical circuit of Fig.6, where we connected a variable resistor. We measured its voltage (V) and current (I) at same time. We found a linear dependence according to Ohm's law of the circuit ($V=V_0-R_{internal}\cdot I$), then we determined the internal resistances (R_i) and the electromotive forces (V_0) of the cells. For example, applying an UV light-source for raspberry cell, we measured a dependence V(mV)=60- 0.17·I(μA), by which

R_i=170 Ω, V_0=60 mV. For a commercial garden lamp, composed of n-p junction solar cells, we measured V(mV)=2471-307 I(mA), by which R_i=307 Ω, V_0=2471 mV.

We determined the maximal power output of the cells, on one hand using Ohm's law of the circuit ($P= (V_0-R_i\cdot I)\cdot I$), on the other hand analysing power-current functions. We defined the quotient $|P_{Ohm}-P_{function}| / P_{Ohm}$ as the relative power error. The test of the raspberry cell using an UV light-source, gives 7% optimal power relative errors. With the same light source, the relative power error for solar cell garden lamp was 12%. See Fig.7 and more test results in [6].



Voltage as function of current Power as function of current

Fig.7. Solar cells as current source, illuminated by UV light-source

ANALOGIES AND SIMPLIFICATION II. - TEACHING PHOTOSYNTHESIS

The raspberry cell uses the same basic principle as plant photosynthesis to generate electricity from sunlight. Both processes require the absorption of the energy of photons. In the cycle of light dependent reactions of the photosynthesis, the electron follows the four main steps twice: excitation, charge separation, diffusion and regeneration.

The right panel of Fig.8 presents the absorptions of two photons of different frequencies, and that the linear electron transport chain connects the two parts of light dependent reactions, the photosystems I and II. Photolysis, the regeneration process in this case, with the electron replacement results in a cyclic operation.

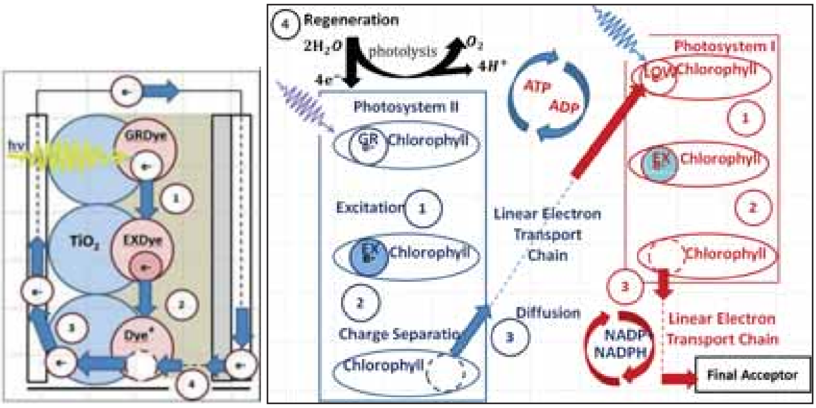


Fig.8. Electron-cycles: Raspberry cell Light dependent reactions of photosynthesis

From the point of view of physics teaching, a comparative analysis of relative energy bands and levels underline the similarities of the two processes, in spite of the electron-cycle repeating twice. On Fig.9, we compared how different parts of a raspberry cell and of light dependent reactions use the energies of the photons. (For more details see [4], [5] and [7].)

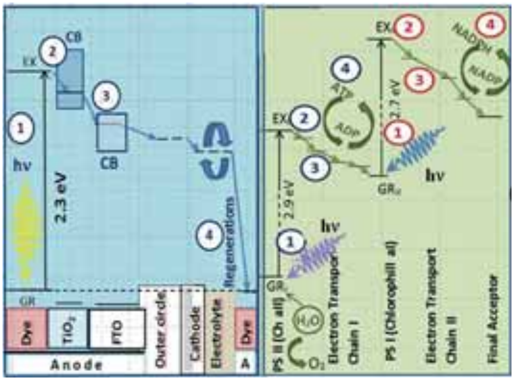


Fig.9. Raspberry cell: relative energy levels LDR of photosynthesis: relative energy levels

With the relatively simple energy cycle and energy band structure the raspberry cell can illustrate many different scientific subjects, like galvanic cells, semiconductors, n-p junction solar cells, light-dependent reactions of photosynthesis, current sources. Placing the energy concept into an interdisciplinary context can offer an understanding and integration of many different pre-existing concepts. It can help in the description of all types of solar energy converters, and in many issues of environmental sciences [8].

CONCLUSIONS

The raspberry solar cell works according to the same basic principle as other photovoltaic and galvanic systems. Based on this fact, physics curriculum and teaching objectives can utilize this analogy during physics teaching at several levels. We presented a short introduction of two possible analogies. We examined the electron cycles and the energy levels analogies, starting from the raspberry cell case and moving to the more complex photosynthesis and semiconductor solar cell cases.

We underlined that the teacher can organize physics, chemistry and biology class activities around the raspberry solar cell. We described here the steps to build a raspberry cell, even though we recommend the do-it-yourself method only to upper secondary classes, in the presence of a teacher, with prepared glass plates and electrolyte. To demonstrate its function and discover it in action, we tested the effects of light-sources and of different dyes on the cell. Finally, we used the cell as current source to compare to an n-p junction solar cell [1],[6].

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Refs. 1., 5., 6. are published by the authors.

IV. OUR COSMIC ENVIRONMENT

WITH SPACE RESEARCH FOR MORE LOVABLE PHYSICS CLASSES

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ABSTRACT

In this paper, I discuss how one can motivate students with the results of space research, and make them more interested in the subject of physics. In Hungary the MaSat-1, which is the first Hungarian satellite, presents an excellent opportunity for this. This spacecraft was designed and made by students of the Budapest University of Technology and Economics for educational purposes. Not only the MaSat-1, but the satellites in general provide opportunity for motivation in many topics in our teaching of physics. I attempt to prove in my presentation that not only in the traditional areas (for example laws of Kepler) can we refer to satellites, but also in other topics, such as thermodynamics or electrostatics.

INTRODUCTION

The fact that students do not like physics as a subject is a problem in teaching physics all over Europe. Although in the media we can learn about all the latest remarkable results of research done in physics, most of which are also available for anyone online, physics classes are not the students' most favoured classes. In my paper I intend to show how we could motivate students by integrating the results of space research into physics classes.

There has been a recent opportunity to make use of the results of space research in physics education in Hungary by means of MaSat-1, the first Hungarian satellite [1], see Fig.1.

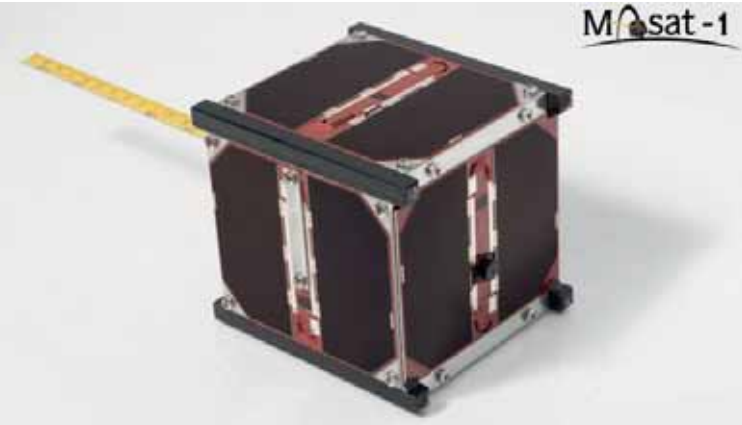

Fig.1. MaSat-1 (source: http://cubesat.bme.hu/en/hirek/page/10/)

This orbital vehicle was designed and constructed by the students of the Budapest University of Technology and Economics for educational purposes within the confines of the CubeSat programme of the European Space Agency (ESA). Some important data of MaSat-1: its mass was 1 kg, with an edge of 10 cm and there was no propulsion. This small satellite was functioning for almost three years, far exceeding its planned 3-month lifespan. Covering MaSat-1 in physics classes in secondary schools is an outstanding opportunity to motivate students as it is an exceptionally successful implementation of a student experiment. MaSat-1 itself as well as CubeSats in general can be used in an astonishing number of educational topics. In the present paper I will show their application not only in the traditional areas (e.g. Kepler's Laws), but also in branches of physics which may first sound astounding, e.g. in electrostatics and thermodynamics.

THE ORBIT OF MASAT-1

First of all, let us take a look at an otherwise common task, but this time using the real data of MaSat-1. Given the furthest and closest point of the elliptic orbit of MaSat-1 from the Earth, we can calculate its geometrical parameters, its orbital period and its lowest and highest speed of motion:

point closest to Earth (perigee): $r_{\min}$=300 km,

point furthest from Earth (apogee): $r_{\max}$=1450 km.

The geometrical parameters of the elliptical orbit are as follows ('*a*' being the semi-major axis of the ellipse, '*b*' its semi-minor axis, '*c*' half of the distance of its focal points and '*e*' its numerical eccentricity):

$$a = \frac{r_{\min} + r_{\max}}{2} = R + \frac{h_{\min} + h_{\max}}{2} = 6371 + \frac{300 + 1450}{2} = 7246\,(km)$$

$$c = \frac{r_{\max} - r_{\min}}{2} = \frac{h_{\max} - h_{\min}}{2} = \frac{1450 - 300}{2} = 575\,(km)$$

$$\mathrm{e} = \frac{c}{a} = \frac{575}{7246} = 0{,}079$$

$$b = \sqrt{a^2 - c^2} = \sqrt{7246^2 - 575^2} = 7223\,(km)$$

With the help of Kepler's Third Law we can calculate the orbital period. Since the mass of MaSat-1 is only 1 kg, we can simplify with it. It is fortunate if students have the opportunity to deal with more and more tasks in which they meet the notions of commensurability or incommensurability so that we can discuss when we can leave out a term. The gravitational constant is: $G = 6{,}67 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}$, the mass of the Earth is: $5{,}97 \cdot 10^{24} kg$.

The orbital period:

$$\frac{a^3}{T^2} = \frac{G \cdot (M + m)}{4\pi^2}$$

$$T = 2\pi \cdot \sqrt{\frac{a^3}{G \cdot (M + m)}} \approx 2\pi \cdot a \cdot \sqrt{\frac{a}{G \cdot M}} = 6{,}28 \cdot 7246 \cdot 10^3 \cdot \sqrt{\frac{7246 \cdot 10^3}{6{,}67 \cdot 10^{-11} \cdot 5{,}97 \cdot 10^{24}}} =$$

$$= 6{,}14 \cdot 10^3\,(s) \approx 102 \min$$

It reaches the highest and lowest speed in its perigee and apogee which can be calculated based on the following formula:

$$v^2 = G \cdot M \cdot \left(\frac{2}{r} - \frac{1}{a}\right)$$

$$v_{close} = \sqrt{6,67 \cdot 10^{-11} \cdot 5,97 \cdot 10^{24} \cdot \left(\frac{2}{6371+300} - \frac{1}{7246}\right) \cdot 10^{-3}} = 0,13 \cdot 10^5 = 13000 \left(\frac{m}{s}\right)$$

$$v_{far} = \sqrt{6,67 \cdot 10^{-11} \cdot 5,97 \cdot 10^{24} \cdot \left(\frac{2}{6371+1450} - \frac{1}{7246}\right) \cdot 10^{-3}} = 0,068 \cdot 10^5 = 6800 \left(\frac{m}{s}\right)$$

We have this formula from the energy integral and the fact that in the two-body problem we obtain the relation a=-m/2E where ‘a’ is the semi-major axis of the ellipse, ‘m’ is the reduced mass, and ‘E’ is the total energy [2].

MECHANICAL VIBRATIONS

When teaching vibrations, we may call the students’ attention to the fact that in reality mechanical vibrations are not predominantly harmonic vibrations. For instance, MaSat-1 in the rocket was mostly exposed to irregular vibrations when being launched and put into orbit. For this reason, it was tested on a vibrating platform (see Fig.2 and Fig.3) during qualification procedures in order to make sure that the parts would survive in the extreme conditions it was going to face in the rocket. The test was carried out after having the parameters of the launch vehicle called Vega set. We can say that statistical methods are used to describe random vibration loads because there is no inherent mathematical way to describe a random vibration time history. In Fig.2. we can see a CubeSat on the vibration platform, and in Fig.3. the vibration platform on which the Hungarian CubeSat was tested.

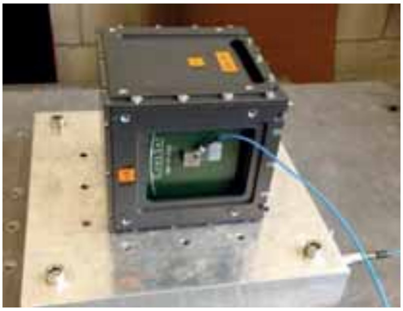

Fig.2. Vibration platform (Source: [3])

Fig.3. Vibration platform (Source: [1])

MASAT-1 AND OTHER CUBESATS IN THERMODYNAMICS

When introducing thermodynamics in class, first we discuss the notion of temperature and then we continue with the principles of thermal expansion. After doing experiments on thermal expansion in the classroom, we can look out to space. We can make the students calculate how much the earthbound geometrical data (edges, surface and volume at room-temperature, i.e. 20 °C) of the CubeSat were reduced when its internal temperature fell to 5 °C. At this point we can mention that the internal temperature of the CubeSat was not allowed to drop below 5 °C in order to protect the battery it contained and we can also tell the students that the metal plate of MaSat-1 was made of special aircraft aluminium. With the help of this exercise we can show our students one of the problems of spacecraft design, namely, that in the secondary school handbooks we find the value of the thermal expansion coefficient in normal atmospheric pressure. We may tell them there exists a separate space technology, where engineers take the special circumstances in space into account. It may be interesting for the students to find out that the discovery of Teflon coating for pans as well as hook and loop fasteners are both the results of the development of space technology.

In its simplest form, the First Law of Thermodynamics states that neither matter nor energy can be created or destroyed. The amount of energy in the universe is constant. This law will be better understood if we give a wider range of examples. Let us look at satellites to see how we can prove the validity of this law. Consider a satellite in its orbit. Why does this ‘perpetual motion’ not contradict this law? The students will probably give the right answer immediately that the satellite does not stay in its orbit forever; sooner or later it enters the Earth’s atmosphere due to friction, and it burns away afterwards.

See Fig.4 which shows that the apogee of MaSat-1 in its final months was continuously getting closer to the surface. The blue line shows the decrease of apogee, and the pink one shows the altitude of perigee. The satellite was destroyed at an altitude of about 130 km. It is interesting to note that the orbit had gradually become circular in shape.

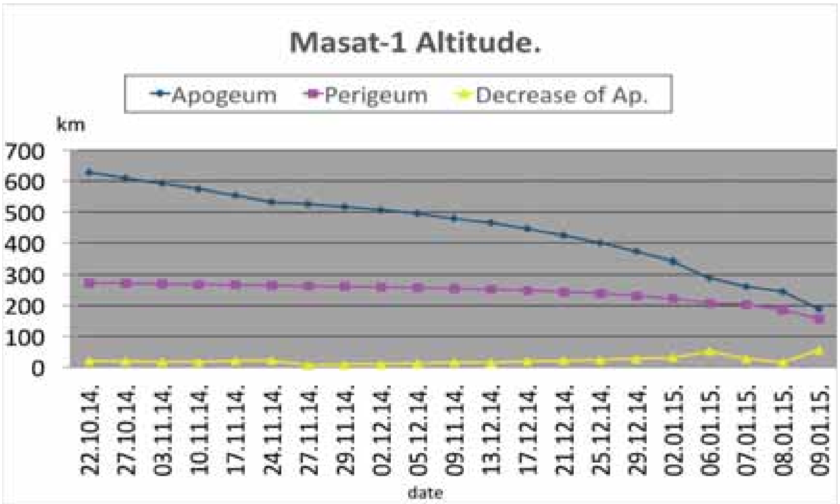

Fig.4. The last months of MaSat-1 (source: http://www.ha5mrc.hu/hamsat/sats.html)

The satellite’s return into the atmosphere and its annihilation, however, can be a very long process. Therefore, there may be satellites which no longer function but might stay in orbit for years, even decades. An interesting example of this is the ENVISAT, an Earth-monitoring satellite of ESA, which will be a ghost in space for 150 years. This problem is a new challenge for space research in the twenty-first century; it is necessary to deal with the increasing number of space debris.

ELECTROSTATICS

In the topic of electrostatics we can demonstrate a Faraday Cage in real-life practice. A Faraday Cage protected the central computer in the control room of MaSat -1 from lightning strikes. In the picture on the left we can see this room under construction, in the picture on the right we can see my students attending a lecture on MaSat-1 in the same room. (see Fig.5).

Fig.5. Control Centre of MaSat-1 - Faraday Cage (Source: [4])

ELECTRICITY AND PHENOMENA IN CONDUCTIVITY

In the topic of semiconductors we mention the solar cells since they carry significance not only on Earth but also in space. The energy from solar radiation transformed into electric energy with the help of solar cells is a determining factor for spacecrafts. Thus solar cells were placed on all six sides of MaSat-1 as well, for they served as its basic energy source. Once again using the original data of the device, we can make our students do calculations.

In the case of MaSat-1 a subsidiary power supply system was also needed in the form of a single-cell Lithium-Ion battery. One third of the cube contained the battery itself, and it took a great proportion of its mass as well. By means of the battery the CubeSat had sufficient energy supply even when it was orbiting the dark side of the Earth. Energy distribution was controlled by an on-board computer. With our students we can discuss that the Lithium-Ion battery is the most dynamically developing of all battery types. It has optimal figures regarding its mass and the proportion of its volume to the energy supplied. It is becoming more and more widespread in space industry; however, it is extremely sensitive to changes in temperature.

ELECTROMAGNETIC WAVES

Due to international frequency allocations, the CubeSat was operating on two different frequencies, i.e. on 437 and 145 MHz amateur radio frequencies. Therefore, its life could be tracked by radio amateurs and valuable information was forwarded to the control centre on the appointed website. We may also tell our students that three days after its launch, it was given the OSCAR number: MO-72, indicating that MaSat-1 is the 72nd radio amateur satellite. The first was launched in 1961 from private funds. OSCAR is a mosaic word meaning **O**rbiting **S**atellite **C**arrying **A**mateur **R**adio. In the reference given one can consult the conditions of giving out OSCAR numbers.

The antenna of MaSat-1 is also worth mentioning, it was not made of space-qualified material, yet it functioned impeccably. The antenna is a 17-cm-long part of a metallic tape-measure, available in all do-it-yourself stores (see Fig.5). Again we have a calculation exercise at hand: namely if the frequency of the wireless receiver is 437 MHz then what proportion of the wavelength is the 17 cm?

SPACE WEATHER

Space weather is an interesting new field of research which may attract our students' attention. Let us discuss with the students that by space weather we mean phenomena taking place in the ionosphere, magnetosphere and the interplanetary space near the Earth. The most important effects influencing space weather are solar wind, mass transfer from the Sun and magnetic phenomena in interplanetary space. Satellite damage may occur in the cases of intensive solar magnetic activity. In MaSat-1 each subsystem was monitored by a network of signal relays providing overcurrent protection against incidental particle radiation [4].

CONCLUSIONS

My in-class experience reveals that including a significant number of references related to space research makes physics classes more attractive for students. Since I started to use this method, several students of my classes have done research in the topic of space technology and have taken part successfully in the 'Physics in Science and Arts Competition', in spite of the fact that they study to be professional musicians. It is also important to note that as the list of references below shows, all the data referred to in this article are available online. This means that one way to make our physics classes more engaging for our students could be collecting this information from professional online material. At the same time we can also teach our students how to recognize which websites are reliable. Apparently they may come across inaccuracies this way as well, but the probability of mistakes is also there in the case of printed sources.

ACKNOWLEDGMENTS

I have had the opportunity to hold lectures on the present topic at:

- 1st International Conference on Research, Technology and Education of Space (13th February 2015, Budapest, Hungary) [5]
- Girep Conference (July 2015, Wroclaw, Poland)
- National Conference of Physics Teachers in Italy (October 2015, Trento, Italy).

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MEASURING ENVIRONMENTAL PHYSICS AND CHEMISTRY BY EDUCATIONAL HUNVEYOR AND HUSAR SPACE PROBE MODELS

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ABSTRACT

During the last decade various physical and chemical experiments were built on the Hunveyor lander and Husar rover educational space probe models. We report about several environmental monitoring experiments.

INTRODUCTION

The Hunveyor lander and Husar rover models were introduced to the education of technology- and environment-related courses since the 1997-1998 academic year. In the next years the program have been opened gradually and extended to several universities, colleges and high schools in Hungary. Two main blocks of principles governed the program. One was the scientific achievements in planetary geology [1] [2] [3] [4]. The other was a summary of planetary probe construction and operation [5], and also a summary of measurements and results of The Surveyor Investigator Teams. On the basis of the real operation of the Surveyor, and later the Mars Pathfinder Teams we extracted an educational program by constructing and operating the space probe models from the point of view of measurements carried out on various planetary surfaces and later in the analog terrestrial environment field works.

EDUCATIONAL PURPOSES OF SPACE PROBE CONSTRUCTION

The concept of **Hunveyor** is based on the space probe Surveyor of NASA. The Hunveyor name comes from the **H**ungarian **Un**iversity Sur**veyor**.

The main focus of teaching by construction is a relationship between the technological aspects of modern electronic and information technology machines connected with application in the science field of planetary geology. This focus means not only learning the associated principles (measurements, technologies, instrument systems and computer technology) but the testing of robots under real geographical conditions. In this educational process the student's knowledge gradually increases on physical, chemical, geological characteristics of the surroundings. By placing the space probe models in the terrains another objective rises: application triggers the need in students to develop measuring methods for environmental surface processes. In this educational process measuring technologies reveal interconnections between (interwoven) processes used both in measuring and in nature itself, so students get acquainted with the complexity of the environment. Simultaneously, they learn the benefits of using the complexity of a data processing system (Fig.1.). Working with the experimental space probe is always an interesting challenge because of its complexity.

MEASURING THE PLANETARY SURFACE AND PLANETARY ANALOG TERRESTRIAL ENVIRONMENTS

Stratigraphic works on lunar geology selected and emphasized those principles of terrestrial geology, which can be extended to the Solar System [3][4]. Characteristics of surface rocks were first investigated by their optical properties and morphologies, but later, the lander space probes showed details of the surface. Characteristics of a surface can be determined by mechanical (Fig.2.), optical, thermal, simple chemical property measurements of:

- mechanical properties: strength, rigidity, porosity, depth of regolith, depth of surface powder, roughness of the soil and the largest blocks scattered on the surface, [6] [7] [8] [9];
- optical properties to be studied by a television camera are: relative albedo, roughness, crater density, smoothness, height of the highest elevation in the vicinity of the lander, average inclination of the landscape [10] [11];
- thermal properties are: surface rock temperatures, thermal conductivity [12] [13].

Over these examples we intended to develop simple measuring instruments for soil properties. The planning of measurements on a specific soil property needs detailed understanding of the physics and chemistry behind these characteristics of the soil, and that is one crucial aspect of the space probe experiments as educational tools [14] [15] [16] [17].

Fig.1. The overview of the Hunveyor-4 system [15]

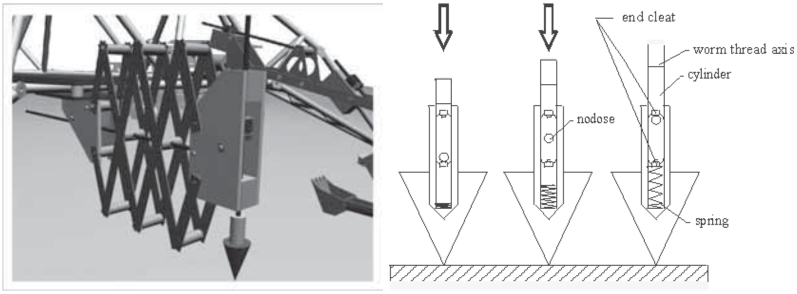

Fig.2. Soil hardness measuring effector on the end of the Hunveyor-2 arm [16] [17]

OUR HUSAR ROVER EXPERIMENTS

The basis for the extended works with Husar rover (**H**ungarian **U**niversity **S**urface **A**nalyser **R**over) is a car model based on the Sojourner of Pathfinder.

Experiment for pH measurements for the chemistry of the soil

First step in measuring the chemistry of the surface materials on a planetary soil is the pH. This measurement was constructed by using two arms and a pump on the rover (both from LEGO elements). On the first arm we placed a wireless camera, (being able to rotate around 360°-and could also bend down). The role of the second arm was to place the indicator ribbon to the surface, move it along a distance for contact with the wet soil. The role of the pump was to pour water on the soil surface. The basic technology was the following: (1) Husar-5 pours out water on the soil, (2) water dissolves important chemical components from the soil, (3) the indicator ribbon touches the soil surface and reports the main chemical characteristics of this chemistry by its color changes (Fig.3.) [18].

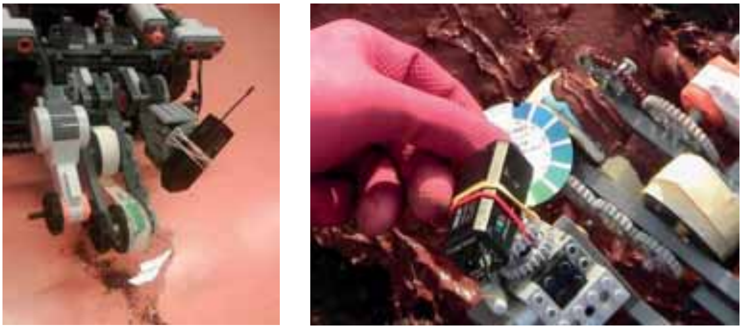

Fig.3. On the front of the rover there is an ultrasonic sensor of the obstacles before the rover. (Upper arm). There is also the camera (right up) and there is the arm moving the indicator ribbon. The ribbon is rolled from one wheel to the other wheel while the arm is contacting the surface and soil. The camera observes the changes on the indicator ribbon colour [18]

Measurement of the gas emission liberated by optical heating

The rover uses an optical lens as a classical heating experiment and uses several gas-sensors for measuring the chemical components liberated by the heating. This experiment demonstrates a classical-style heating combined with a gas sensor application. This way it measures the characteristics of the soil on the surface of a planet [19].

The steps of the measuring process: **Focusing**

1. Basic position: The lens is in resting position exactly a focus distance above the soil. The holding arm is horizontal, the plane of the lens is also horizontal, parallel with the soil.

2. The light sensor measures the intensity of the light and the program decides whether it is enough to begin the measurements.

3. As we shall see, we consider the soil surface as horizontal. The measuring place can be selected by the "terrestrial control". They observe the environment through the camera on the top of the tower on the Husar-5. (We also plan an instrument for making the soil flat and smooth in front of the rover. The ultrasonic sensor considers the larger humps as obstacles and turns back the rover.)

4. After selecting the location of the measurement, the computer program first moves the lens and finds the position (with the help of the light sensor) where the intensity of the light is the highest. This is an angle β with the horizontal plane.

5. The other motor moves the arm up and down and sets the position of the lens plane perpendicular to the solar light. The program takes the measured α angles into the memory.

6. Lifting up the arm is the next step. The height H where the lens collects the sunlight exactly at the focus of the lens reaching the soil surface: $H = h \cos\beta$, where $h = f \cos\alpha$ (see Fig.4. and Fig.5.). From the initial position the lifting motor sets the arm to the necessary position. After lifting the centre of the lens to the height of $y = f + k \sin\alpha$, the arm should be moved through a distance $y - h$. (Using the speed of the movement the program calculates the time of the motion.) This way the focusing was done. By the effect of the solar rays gases are liberated from the soil.

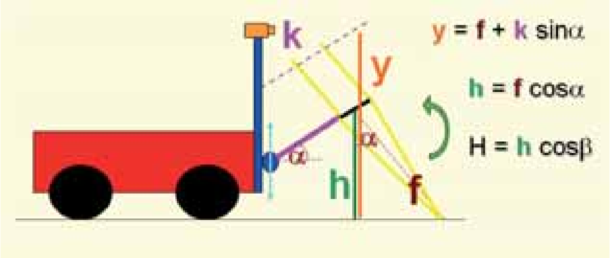

Fig.4. The lens at resting position on the front arm of the Husar-5 rover (right) and the steps in positioning the lens [19]. The height "H" and the angle "β" is not visible in this picture, because they are outside, in the perpendicular plane.

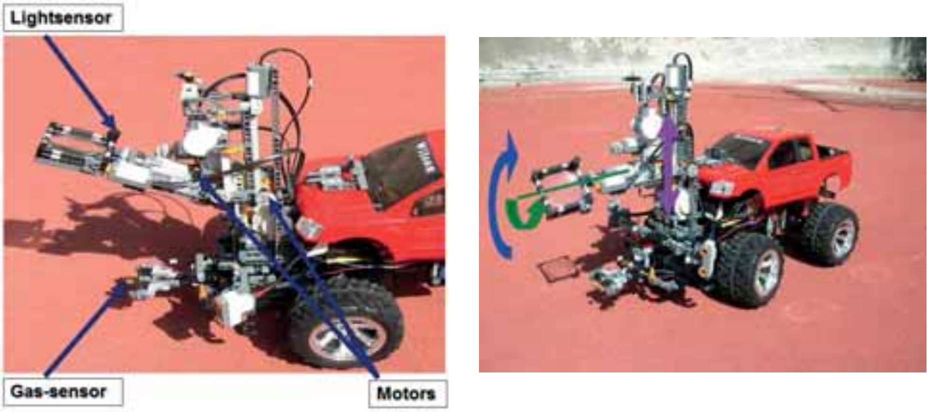

Fig.5. Movement possibilities: One motor makes the arm move up and down along an arc from the horizontal plane to about 40-45°. The lens can be rotated around its axis of symmetry. If that is the basic position shown on the figure (0°-angle), then the computer program moves it from -90° to +90° position. The whole system - consisting of two motors and the lens - can be moved together in a perpendicular direction, too. (This is called lifting.)

Identification of a carbonate rock specimen of a planetary surface

It is known that dropping acids produces rather quick reactions with carbonate rocks. This is the first robotic work to be realized by electronics. The CO_2 gas produced will be observed by gas sensors. This is the second act to be robotized. Of the carbonates some are paramagnetic, especially siderite (iron-carbonate). This results in a third step: magnetic contact and attraction of siderite by the magnet. So the main steps to get a robotic realization for finding carbonate specimens among the rocks on the field are the following: (1) identification of a carbonate by acid test, (2) measuring the gases liberated by acid, and (3) the magnetic test identifies the existence of an iron component (Fig.6.) [20].

Fig.6. The Husar-5 rover with the Carbonate experiment instruments [20]

Magnetic soil dispersing experiment onto an invisible magnetic patterned carpet

We imagined a Martian environment where the wind transports dust particles and the magnetic ones are trapped by small magnetic discs which were sewed into the carpet. In this experiment the adhesion of magnetic dust particles made the magnetic disc pattern fixed inside the carpet visible [21].

In preparing the experiment various composition of the sand + iron grains were mixed previously. Such dust mixtures were poured onto the unrolled magnetic carpet placed on Hunveyor. The magnetic discs between the two sheets caused magnetic adhesion of the magnetic component of the dust. Adhered grains made the pattern visible by coloring the surface of the sheet above the magnetic discs (Fig.7.). Similar experiment was carried out on Mars Pathfinder [22, 23].

Changing parameters in the dispersing experiment

There were two changing parameters in the previous stage of the experiment planning: the mixing ratio between iron and sand, and the slope of the carpet. In the experiments we used 4 sand+iron grain mixtures and 3 different positions of the carpet depending on the conditions how it is rolled out and sloped out from the Hunveyor frame: 1) on smooth flat carpet, 2) a small-angle (gentle) aslope carpet, 3) a high-angle aslope carpet (Fig.7.).

Fig.7. Experiment arrangement with various slope declinations of the magnetic carpet (a white sheet with invisible patterned magnet squares fixed inside). Left: the carpet is at a small angle, almost horizontal slope. Middle: dispersion and adhesion when the carpet is in position of a more elevated gentle slope position. Right: dispersion and adhesion onto a high-angle slope carpet [21]

Students enjoyed the experiment and gradually recognized the role of the two parameters in determining the real mixing ratio of a real distant dust. In carrying out experiments with an unknown (Martian) mixture, the mixing ratio was determined by interpolating the produced pattern between the previous experimental cases.

The students proposed the following questions:

– Almost perpendicular slope cannot show the magnetic content, only in the case of very strong magnetic particle content. Therefore somehow we must stabilize the rolling down in a gentle slope position.

– Magnetic particles adhere and form small clusters before they fall down from winds.

SUMMARY

Such robotic realization of basic experiments triggers enthusiasm in students for measurements both in physics and chemistry, and also helps physics and chemistry education to make learning the basic concepts and laws of these disciplines enjoyable.

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ROBOTICS, CANSAT, ARDUINO – PHYSICS AT SZÉKELY MIKÓ SCIENCE CLUB

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ABSTRACT

What can we do when our students are bored during the activities or they are not interested in the topic? The Arduino board based on ATMEGA chipset or similar devices with a few sensors or robotics can be the solution. I would like to present some devices based on Arduino applications used by me during physics lessons and Science Club. The students designed and built a space experiment with a CanSat, measuring pressure, temperature, air pollution, the atmospheric gases and some basic data during the flight. The data are collected and analysed by the ground station. LIFEBOT is a special rescue robot projected and built by students. This robot finds the victims after natural disasters, even in small and inaccessible places. It sends real images of them and basic information about their health condition.

INTRODUCTION

The students from the Science Club’s robotics group have been working with Arduino, Raspberry PI and Redboard for 4 years. These microcontrollers are suitable for both simple and very complex applications: from flash switches to line followers and rescue robots. The younger students (12-14 years old) started their work with the learning phase. I explained the basic information-details about electrical circuits, microcontrollers (without description of internal structure, semiconductors and microchip theory), sensors, communication between the sensors and the microcontroller, how the datasheets are used for each component to design a new measuring or dynamic device. The students from upper secondary school learned about the internal structure of Arduino board, communication protocol, how the sensors work and how to develop the software for our robots.

ARDUINO AND ROBOTICS

Arduino is an open-source electronics platform based on easy-to-use hardware and software, usable for interactive school projects. We mostly use Arduino Uno board (Fig.1.), which is a microcontroller based on the ATmega328 processor. Arduino boards are able to read inputs – from different sensors, messages – and turn them into an output, activating a motor, turning on an LED, send textual information about something. A set of instructions programmed through the Arduino Software (IDE) make the microcontroller work. The board has a few communicating facilities with a computer, a second Arduino or microcontroller. The software for the Arduino includes a serial monitor which helps us send data and simple texts from the sensor to the Arduino and computer [1, 2].

We built robots not only with Arduino-based microcontrollers but also using Lego NXT 2.0 and EV3 Mindstorm kit with programmable brick. Based on the creativity and knowledge of the students, the challenge is to create a unique but simple robot and develop the proper control software.

Fig.1. Arduino Uno and RedBoard

The main task is to build an autonomous robot which is able to carry out a pre-programmed mission without any human intervention (move and collect balls, avoid obstacles, follow a track or coloured line, move objects, etc.).

At the Science Club we built a couple of robots which participated in several contests: WRO (World Robot Olympiad – national phase) 2013, WRO2014, robochallenge, robotics-workshop where we won 3rd place and special awards. For the WRO2013 we made a service rover which operates on the imaginary "Commodore Island". This robot checks for dragon eggs and collects the good ones and leaves the bad ones on the ground**.** The second robot – for the WRO2014 – was a service rover which operates on the surface of an imaginary planet. There are 15 solar-panels, out of which only 7 work properly. This robot checks for broken solar panels and replaces them with operating ones. The broken panels are later transported to the storage.

We also designed self-made rovers using our own material from the physics lab. This type of robot follows a coloured track (Fig.2.), collects soil samples for analysis and detects the fire sources near the route [3, 4]. With these robots we organized interactive presentations and workshops for lower secondary students. During these events we presented the working principle of the robot, what kind of task it performs and the electrical and mechanical structure of the device.

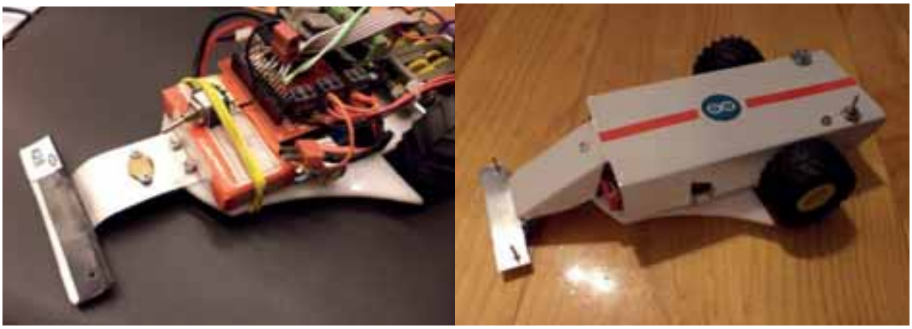

Fig.2. Line follower robots

LIFEBOT – THE RESCUE ROBOT

During the previous school year our most complex robot was the life rescue robot (Fig.3.) which was further developed from a firework-robot idea (built in 2012). This robot was designed and built for the 24th Youth Innovation Competition at the Science Club by student R. Krecht, where he won 2nd place.

Fig.3. LIFEBOT- the rescue robot

Characteristic of this robot:

- Helps the work of the rescue team, as it can get into hardly accessible and narrow places.
- It is an autonomous vehicle but it could also be radio-controlled. On the board there are 3 independent controlling and managing systems. The first is a 6-channel 35 MHz radio transceiver; 2 channels control the robot movements (forward and backward), 3 channels command the robot arm (open, close and rotate) and 1 channel commands the injections. The second unit is for sensors data, which are transmitted separately with a transmitter 434MHz unit to the microcontroller. The third system is for the IP camera, a 2.4-GHz wireless unit.
- It can be used on most types of terrain and 10 cm layer of water.
- The chassis is water- and shockproof, the full cover is fire resistant.
- Presents real-time parameters of the searched environment for the rescue team. The value of pressure, temperature, air pollution, flammable gases and presences of water are collected by the sensors and are transmitted to the microcontroller. With a proper program these data are decoded and displayed on the PC monitor.
- The flammable gases and the smoke are detected by a very sensitive sensor for butane, propane, hydrogen, CH_4 gases and air pollution.
- Measures the distance in front of it and avoids the obstacles. The distance between the robot and the obstacles is measured with a reflective infrared distance sensor. This sensor can measure the distance based on triangulation method. The light impulse is an infrared wave which is reflected from the obstacles located at 3 – 40cm under a certain angle. These angles help to determine the distance between the object and the robot.
- Identifies the vibrations occurring in the chassis with a gyro sensor, and prevents the rover from rollover.
- Can track victims by transmitting live video images about the searched area with an incorporated wireless IP camera. When the robot is turned on, the camera connects automatically to a router belonging to the robot control unit. The router transmits real time image about the victim to the PC where it is displayed using a C# Windows Form application. The sensors built into the robot arm measure body temperature and pulse. If it is necessary, it is capable of minor medical interventions: disinfects and injects medicine.

METEOROLOGICAL MEASUREMENTS WITH CANSAT15

Over the past few years (since 2012) we built a couple of cansat devices. The cansat is a semi-autonomous vehicle which is small enough to fit in a soda-can (115 mm – height and 66 mm – diameter). Our “mini-satellite” was designed and built in a way to withstand forces like a small rocket launch, explosion and being ejected from the rocket at an approximate height of 1km and landing. It landed within a 165-s timeframe counted from the moment of exiting the rocket. During its descent sensors sent data (pressure, temperature and humidity values, UV radiation intensity, solid pollution and flammable gases concentration, acceleration) to a ground station. The ground station’s parts are a 434-MHz radio receiver (which converts the received message), a 5-segment Yagi antenna and a laptop. Throughout the whole experiment GPS data were sent to localize our flying device. The gathered data were saved into a database and analysed after the mission had been completed [6].

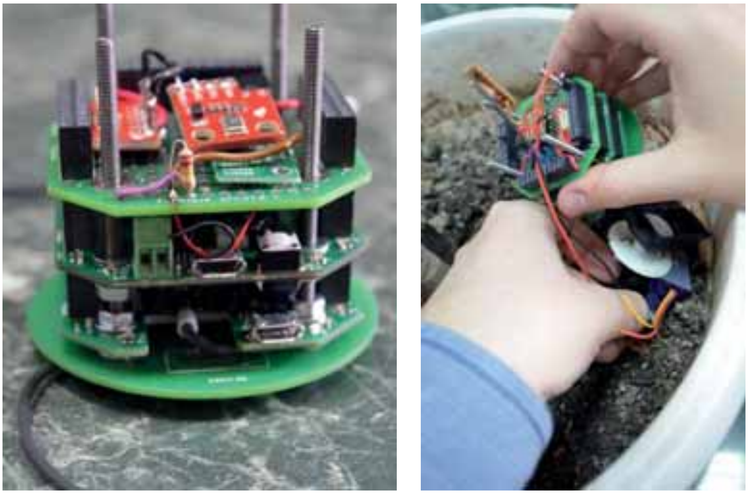

Fig.4. CanSat device for the 2015 European Cansat competition with soil sensor

For last year’s CanSat competition (Fig.4.) we designed a minirover for ground measurements. After the CanSat15’s landing the mini rover exits from it and reaches a certain distance from the main unit. There it introduces two small needles into the soil (at a depth of 35-45 mm) serving as measurement probes. We measured the resistance between the two electrodes and analysed the current variation. This measurement was repeated after every 1m distance travelled. From these values we were able to determine the humidity and possible other properties of the soil. Based on the acquired data we plotted a graph corresponding to the studied assumptions.

To protect the device, we managed to create some outer shells. The thickest is made from six layers of fibreglass and the heavier shell is from metal as well. This metal shell is made up from a cylindrical piece with a spring-loaded door for the rover. We tested our parachutes at the school yard throwing it out from the top of the buildings. The students filmed the weight’s fall to the ground from different heights. They made several films and analysed the videos. Knowing the heights of the buildings and captured pictures from the videos, we compared them and calculated the falling speed of the soda-can for different types of parachutes. The parachute tests showed us that we should use the metal shell if the ground is hard, or one of the fibreglass shells if the ground is soft or covered with grass.

For the CanSat device measurements we used the Arduino environment with wiring library, based on C/C++ language. The students wrote a proper program to run all the data collection process (Fig.5.).With this program we could activate the primary sensors and send the gathered data to the computer [3, 5].

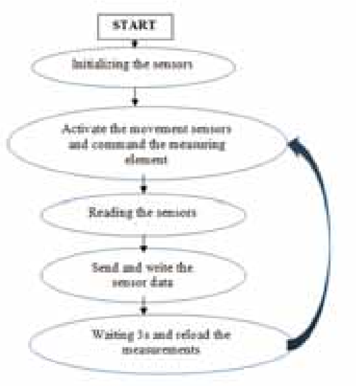

Fig.5. Diagram for appropriate control and command software

The sensors we used for this device and the connected meteorological station were: gyro, accelerometer, compass and altimeter**,** pressure and altitude; humidity and temperature, magnetometer, UV index, gas; GPS and Camera.

The UV sensor measures the intensity of UVA radiation from the solar spectrum and gives us a weighted value called UV index. Our sensor provides us with a mean value of the UV index measured on distances of 100 m each.

For school experiments we elevated the cansat with a quadcopter to a height of 400-600m. We established a wireless connection between the cansat, the meteorological station fixed on the top of the gym and the central PC located in the phyics lab. The cansat and mini meteo station (Fig.6.) sent humidity, pressure, temperature, solid pollution, UV index data from different altitudes, during several days. We compared these data, plotted graphs with them (pressure and temperature measured by the two devices at same time but different location) and analyzed the evolution of air parameters. These measurements helped the students understand the thermodinamic processes and atmosphere physics easier.

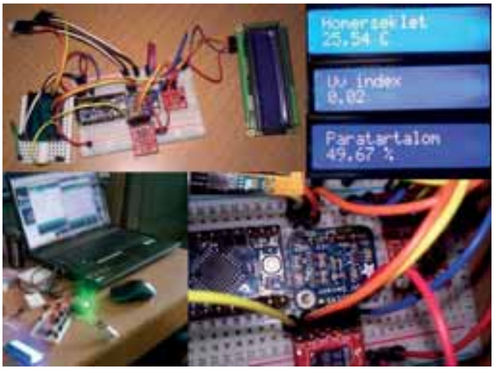

Fig.6. Meteorological station with Redboard and Arduino Mini pro

CONCLUSIONS

This creative process performed with my students helps them deepen their understanding of the internal connection between the theory taught at physics and IT classes and those practical, technical applications. The students enjoy these classes because they participate actively and innovatively in every phase of the activities. The brainstorming is the introductive moment of every class. They present their ideas on how they will solve the specific task: how they will move the device, what they will measure, what sort of elements we need, power supply problems, how we could command the device to perform the tasks, etc. After a detailed analysis of the proposals we summarise the theory necessary to solve the problem. This is a very good opportunity for them to review and complete with new data what they have learnt in class.

These activities are successful because we learn about:

- Teamwork – for every work phase they are divided into groups of 2-3 students with well-defined tasks. For the manual work (soldering, drawing circuit diagram, drilling, moulding, etc.) the group leaders are the students who are modelling airplanes or boats.
- Project management – how to carry out a scientific project from planning through design and to final product, results. For each project we prepare a complete documentation: design and building plan, scientific mission and objective description, task list with time schedule, software design and development, testing plan, mechanical and electrical structure design, group organisation, resource estimation, budget, etc.
- Problem solving skills, presentation (ppt, prezi) and workshop for younger students. The students prepare presentations and group activities to present their results and to awaken the younger students' interest and curiosity toward robot construction and technical tasks.
- A lot of physics: mechanics, atmospheric physics, electronics, electricity;
- Computer science, IT; programming (Arduino software, C++, icon-based software, object oriented programming C#, data analysis with data base)
- Robot planning and building, from the simple object lifting devices to complex machines which could make decisions using sensors' data based on a proper program.

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EARTH'S TWINS? SEARCHING FOR EXO-EARTHS

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ABSTRACT

High school students are very interested in astronomy, especially, in modern astronomical discoveries. The most exciting recent discoveries refer to exoplanets. Among the approximately 2000 known exoplanets there are several dozens which orbit in the habitable zone of their host stars. There are some Earth-like exoplanets, too. Finding a true Earth-like exoplanet, which hosts life, is one of the main goals of searching for exoplanets. We have to illustrate to our students the differences and similarities between our and other planetary systems. Let's explore with our pupils the wonderful new world of exoplanets.

ARE WE ALONE IN THE UNIVERSE?

For thousands of years people have wondered if there are other worlds like ours and other living beings, especially intelligent forms of life in the universe. The study of the scientific questions associated with the search for life in the universe gets more and more attention each year. Since Copernicus, we know that the Earth is not in the centre of the Solar System, nor is the Solar System in the centre of the Milky Way galaxy, and even our galaxy is not in the centre of the Universe.

Today, life is only known on the Earth, but there are many other planets outside the Solar System that can host life, suggesting we are not alone. Life is so common on the Earth that it can be found in any harsh environments. The question is how prevalent life is in the Solar System, in the Milky Way, and in the Universe.

There are many questions awaiting answers. What is our place in the universe? How did we get there? Are we alone? Where are the other beings? (Enrico Fermi) Shall we find intelligent life? (SETI) What is life? Is there life beyond Earth and how could we detect it? How did life evolve on the Earth? What makes a world habitable? Could we live elsewhere in the universe? What fractions of stars host planets? Are Earth-sized planets, in the habitable zone of stars, common or rare in our galaxy? Are there Earth-like planets around our neighbouring stars? And we could continue the list. Some decades ago we did not have any answers for these questions, but now we are able to answer some of them.

Are we alone in the universe? The answer is almost certainly "no" according to Ellen Stofan, chief scientist for the National Aeronautics and Space Administration (NASA). "I believe we are going to have strong indications of life beyond Earth in the next decade and definitive evidence in the next 10 to 20 years", "We know where to look, we know how to look, and in most cases we have the technology" she said at a NASA panel discussion [1].

In this paper we deal with habitable planets, especially the Earth-like planets that could harbour life.

SEARCHING FOR EARTH-LIKE PLANETS IN THE SOLAR SYSTEM

The Solar System consists of the Sun, the planets, dwarf planets, moons, asteroids, and comets. There are eight planets in the Solar System, each very different and peculiar in its own way. We know that at least one harbours life, the Earth. Although men have only been on the Earth and the Moon, we have detailed pictures of most of the planets, their moons and of some asteroids and comets. These have been taken and sent to us by spacecrafts, rovers and space telescopes.

Our two neighbouring planets, the Venus and the Mars are the most similar to the Earth in the Solar System (see Fig.1.). Although Venus is hardly different in size from our planet and formerly people imagined a rich wildlife on it, due to its hellish surface circumstances our interest is focused on Mars. While the Venus's surface is obscured by thick clouds, Mars has a thin atmosphere.

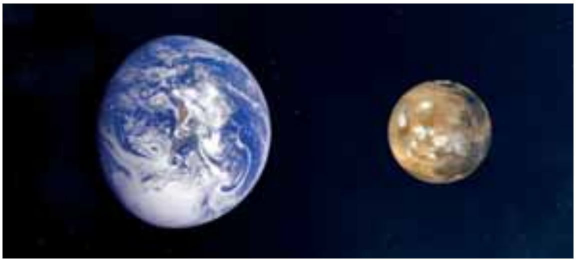

Fig.1. Comparison of Earth and Mars, NASA

Scientists have been curious for centuries whether life exists on Mars, yet we do not know if Mars has ever hosted life. In 1877 the Italian astronomer Giovanni Sciaparelli observed Mars 'channels' through his telescope. The American astronomer Percival Lowell thought that there was intelligent life on Mars, capable of constructing large canals which he saw as lines in his telescope. The public mind has spread this perception. Scientists expect that if we discover life on Mars, it will most likely be simple bacterial life and not humanoid aliens like most of the Martians one has seen in the movies. Many missions have orbited and landed on the surface of Mars, but so far no evidence of life has been discovered. Mars is a right target for searching life beyond the Earth, because it is easily reachable and could have been habitable in the past [2].

Though we might find life on other celestial bodies (for example on some moons) in the Solar System, we do not discuss them in this paper.

SEARCHING FOR EARTH-LIKE PLANETS BEYOND THE SOLAR SYSTEM

To search for life beyond our Solar System, one of the first steps is to find an exoplanet that might support life. An extrasolar planet, or exoplanet, is a planet that orbits a star different from the Sun. As astronomers discovered that the stars in the sky are other suns, and the galaxies consist of hundreds of billions of stars, they suggested that planets must orbit around them. However, there was not any proof until the early 1990s. Exoplanets are difficult to observe, because most of them are too small, too far away and too faint to be detected directly.

How are the discoveries made?

Astronomers have developed several methods for finding exoplanets. They use telescopes armed with photometers (a device that measures light), spectrographs and infrared cameras.

One way how astronomers look for exoplanets is the **radial velocity method**. If a star has a planet (or planets) around it, the planet and the star orbit their common centre of mass. Because the star is much more massive than its planets, the centre of mass is usually within the star and the star appears to wobble slightly as its planets revolve around it. These wobbles can be detected with a spectrograph. If a star is moving towards us, its light and all the dark (absorption) lines in the spectrum will appear blueshifted, while if it is moving away, the light will be redshifted (Doppler-effect). A big, Jupiter-like exoplanet might cause a star to wobble by several meters per second. But a small, Earth-like exoplanet might only wobble its star by ten centimetres per second. The first exoplanet discoveries were 'hot-Jupiters' (that are much larger than Jupiter and orbit very close to their stars) because it was easier to detect them than the smaller ones or others that orbit farther from their stars. We can determine the (minimum) mass of an exoplanet, as well as its orbital period and distance by using the radial velocity method [3].

Another effective exoplanet searching method is the **transit technique**. If an exoplanet's orbit crosses the line of sight between its parent star and Earth, it will block some of the light and cause the star to dim. Extremely sensitive instruments can measure the tiny drop in the star's brightness. By measuring its depth and knowing the size (radius) of the star, we can determine the size (radius) of the exoplanet. By measuring the elapsed time between consecutive transits we learn the orbital period of the exoplanet. Using Kepler's Third Law of Motion, we can calculate the average distance of the exoplanet from its star [3]. Although only a small fraction of exoplanets produce occultation, still it is the most successful exoplanet detecting method. CoRoT and Kepler are two space telescopes whose goals were to search for exoplanets by using the transit method. CoRoT discovered the first small rocky exoplanet (CoRoT-7b) [4]. Kepler detected the first Earth-sized exoplanet, which was in the 'habitable zone' of its star (Kepler186f) [5].

As I have mentioned before, the exoplanets are faint because they do not emit own light. It is very difficult to search for an exoplanet near its star in a photo. One way to see a dim planet near a bright star is to blot out the star using a device called coronagraph. The **direct imaging method** uses infrared lights to observe exoplanets because in these wavelengths the host star not as bright as its exoplanet compared to visual wavelengths. This method works for planets that are very far from their stars [3].

There are other exoplanet searching methods as well, for example astrometry, the gravitational microlensing method and pulsar timing [3].

The discovery and characterization of exoplanets (see Fig.2.) is one of the most exciting and fast-changing areas in modern astronomical research. Today we know that exoplanets are common around different types of stars. It is possible that every single star we can see at night has at least one planet. That would mean that there are at least a hundred billion exoplanets just in our galaxy. According to recent discoveries, it is possible that most stars have planets in their habitable zones, among them there are some Earth-like planets, too [6].

Astronomers are discovering new extrasolar planets incessantly. But the goal is to find habitable, Earth-like exoplanets, that are rocky, roughly have the same size as our planet, orbit a star similar to our own, and have a right surface temperature for liquid water.

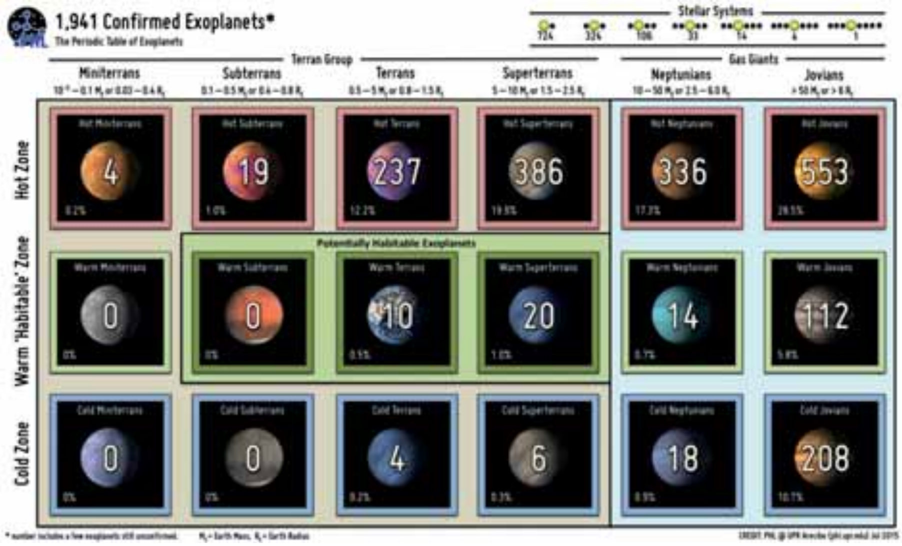

Fig.2. 'Periodic Table of Exoplanets' (The Earth is a warm planet.), PHL@UPR Arecibo

HABITABLE ZONE

The habitable zone or Goldilocks zone is the region around a star where the temperature is just right to have liquid water on the surface of a planet (see Fig.3.). If a planet is too close to its parent star, it will be too hot and the water would evaporate. If a planet is too far from a star, it is too cold and the water is frozen. Stars that are smaller, cooler and have a lower mass than the Sun (for example M-dwarfs) have their habitable zone much closer to the star than the Sun. Stars that are larger, hotter and more massive than the Sun have their habitable zone much farther out from the star. The habitable zone is not the only place in the planetary system that supports life, it is possible that an exomoon being outside the habitable zone gets enough energy from the tidal heating to be habitable. Tides are due to differences in the strength of gravitational force acting on an exomoon orbiting its host exoplanet. When an exomoon is moving around an exoplanet, the tidal attraction of the exoplanet distorts the shape of its satellite. The created bulges migrate around on the exomoon. Tidal dissipation can result in internal heating that could be enough for example to maintain liquid water beneath an icy surface.

The Kepler-452b and its star is the most similar to the Earth-Sun system found yet. Before its discovery, the Kepler-186f, Kepler-62f, and Kepler-22b were the "most similar" exoplanets to the Earth. Kepler-186f is 17 percent larger (in its radius) than the Earth, and makes a revolution around its star every 130 days in the habitable zone. The host star is a red-dwarf star that is much cooler than our Sun and only half of its size, so Kepler-186f gets about one-third of the energy from its star that Earth gets from the Sun. Kepler-62f is a "super Earth" about 40 percent larger than our home planet. Its star is cooler and smaller than the Sun, and Kepler-62f orbits in its habitable zone. Kepler-22b was the first of the Kepler planets found within the habitable zone, and its star is very similar to our Sun. Kepler-22b is about 2.4 times of the Earth's size [7].

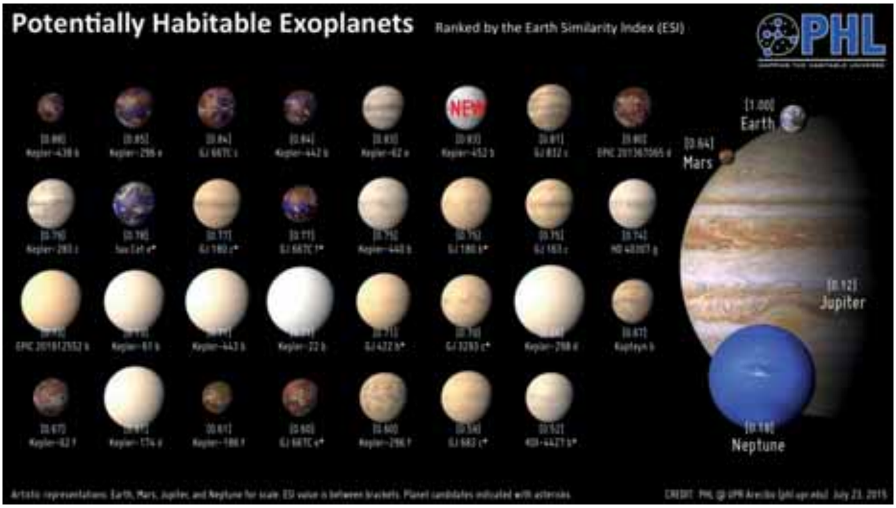

Fig.3. Artistic representation of the habitable exoplanets. Earth, Mars, Jupiter, and Neptune are shown for scale on the right. Source: http://phl.upr.edu

Not all the Earth-like exoplanets were discovered by the Kepler Space Telescope. For example Gliese 667Cc was detected by the European Southern Observatory's 3.6-meter telescope in Chile. The planet's mass is at least 4.5 times that of the Earth's mass. It orbits around a red dwarf in the habitable zone with a 28-day period. Gliese 667Cc receives around 90 percent of the flux we get from the Sun. This planetary system is 22 lightyears from the Solar System. There are five more exoplanets in this planetary system, among them two in the habitable zone [8].

Kepler-452b the most Earth-like exoplanet we know, circles a sunlike star at about the same distance as Earth orbits the Sun. This exoplanet is about 60 percent larger than our home planet, therefore it is not a true "Earth twin", rather an "Earth cousin". Kepler-452b's orbital period is 385 days, just 20 days longer than our own year. Its star is just 4 % larger, 1.5 billion years older and 20% brighter than the Sun. Kepler-452b is the first known possibly rocky habitable exoplanet orbiting around a Sunlike star [7].

Scientists have found a Jupiter's twin. They used the ESO 3.6-metre telescope to identify an exoplanet (HIP 11915b) orbiting at the same distance from a Sun-like star, HIP 11915, as the Jupiter orbits the Sun. The host star has the same age as the Sun and there may be rocky planets in this planetary system, too [8].

The search for Earth's twins is speeding up. In the years ahead even more improved methods will allow us to detect many exoplanets like Earth. Whether they harbour life is a harder question that we might answer in decades. Another difficult question is how we could travel or send a spacecraft to an exoplanet. We can use the Interstellar Trip Planner (http://planetquest.jpl.nasa.gov/system/interactable/5/) to get to know how long it would take to travel to an exoplanet by different space vehicles. I recommend another interesting, interactive website about the exoplanets: http://eyes.nasa.gov/eyes-on-exoplanets.html.

SPACE TELESCOPES AND FUTURE EXOPLANET MISSIONS

The NASA Kepler Space Telescope was designed to seek exoplanets and determine their size and orbital period. This most successful space telescope found the first Earth-sized planet in the habitable zone of a star (Kepler-186f).

The Transiting Exoplanet Survey Satellite (TESS, 2017 NASA) will measure light curves of stars in the whole sky. The main goal of the TESS mission is to detect Earth-sized exoplanets around bright stars near our Solar System.

The James Webb Space Telescope (JWST, 2018 NASA) will use the infrared light. It will study the atmospheres of exoplanets to find an Earth's twin among other scientific goals.

CHaracterizing ExOPlanet Satellite (CHEOPS, 2017 ESA) will detect exoplanetary transits of bright stars already known to have exoplanets. The CHEOPS mission will determine the bulk density of small exoplanets orbiting bright stars.

The PLAnetary Transits and Oscillations of stars (PLATO, 2024 ESA) mission will find and characterise Earth-sized exoplanets and super-Earths. It will help understand the planet formation, too.

WHY TO STUDY AND TEACH EXOPLANETS?

Teaching exoplanets in the school is usually a challenge for physics teachers, because it is a complex subject of physics and other fields of science. Astronomy, especially teaching exoplanets is a very efficient way to teach science including physics.

The more we learn about exoplanets, the more we know about how our Earth and the Solar System function, how planets form and interact with each other. Students would like to know more about exoplanets, and they take part enthusiastically in assigned projects related to habitable exoplanets.

We live in a special era, when we can determine some properties of planetary systems hundreds of light-years away and able to answer some questions about the universe that humans have asked for a long time. We efficiently explore our Solar System and beyond to understand our place in the Universe, and look for extraterrestrial life. The search for and the understanding of life in the Universe are fundamental questions in the natural sciences as well as in philosophy, psychology, sociology and theology.

ACKNOWLEDGMENTS

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HISTORICAL EXPERIMENT USING VIRTUAL OBSERVATION

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ABSTRACT

Effective and interesting physics education is conditioned by exploratory character of student's activity. One aspect of how to support pupils' curiosity and imagination, as well as observation is to integrate teaching with historical observations of the night sky. Within the informal education we can use virtual observations by means of astronomical computer programs EURO – VO (The European Virtual Observatory) that allow us to conduct simulations in space and time and help us explain individual phenomena in their historical context and discovery. The author presents a case study of including selected historical components of observations in physics education by means of interactive computer programs and also describes her experience with such work.

INTRODUCTION

The current period of astronomical development is accompanied by a huge increase in information data, which has prompted a new way of archiving them. The digitization of astronomical data marks a new era not only in the processing and use of these data by the professional community, but also in making it available for educational needs as well as to the general public. The rapid development of information technology in recent years has greatly expanded opportunities in education. It stimulated new forms of education and significantly reshaped the aims and methods of teaching. The inclusion of interactive computer programs in teaching can be seen as an essential element to promote a quality learning environment. At present, the implementation of innovative technologies in teaching has been discussed by various educational researches not only abroad but also in Slovakia [1, 2]. Virtualization and interactive programs have become a key method in many educational standards and encourage an active learning method at all levels of education.

It turns out that inclusion of the practical part of the learning process in different areas of astronomy, e.g. the virtual observatories, promotes pupils' active learning process. The biggest attraction for pupils of primary and secondary education level is, undoubtedly, the observation. A very practical astronomical observation in the context of teaching, however, is associated with a number of problems – ranging from schools being poorly equipped with observational techniques, light pollution of the site, the weather changes to time requirements. Additional restrictions stem from the fact that observations at night cannot be conducted during regular school hours and thus require special arrangements that are not easily made in most of the primary and secondary schools. Astronomical interactive virtual programs are thus an excellent substitute for the real observations. Their inclusion in the process of teaching is currently highly relevant.

We know a number of European projects which aim to streamline the teaching of astronomy through modern technology education. European Virtual Observatory project EURO – VO offers special products - computer programs that enable global electronic access, offer software tools for search, virtualization, and data analysis for research and educational purposes [3]. Computer programs Stellarium and Aladin can rightly be called virtual observatories. Their application introduces us into story lines of the night sky in real time, in the past or in the future. Using the displayed data the phenomenon in its historical continuity of the discovery process as well as the latest astronomical data can be explained. In this paper, we focus on the application of certain options listed in computer programs to physics lectures or to working with interest groups.

STELLARIUM

Stellarium [4] is a computer planetarium that displays a realistic sky as it can be seen with the naked eye or binoculars. However, it is not restricted to visualization of the celestial sphere. It also allows to view different parts of the universe both in space and in time. It is mainly based on the Hipparcos catalog. Stellaria Basic Catalog contains 600,000 stars with their basic identification data. The virtual observatory Stellarium with its software suite provides the user with a number of variations of creating the outputs. In our contribution we focus on those that can be used in teaching.

The student's ability to navigate in the night sky is one of the goals of teaching astronomy in our schools. Due to the fact that Stellarium can specify the location of the observation points, in this virtual world we can demonstrate the beauty of not only the northern but also the southern night sky. To determine the constellations we can use an "assistant" to determine the name of the constellation and its brightest stars, to determine the shape, but also its mythological representations (Fig.1). Attached circles allow us to visualize the constellations according to the basic distribution, to track astronomical phenomena, such as the position of planets, stars occultation by the Moon, and also, for example, meteor showers. For an explanation of real phenomena in the sky, Stellarium provides additional programs (scripts), which can be downloaded from the Internet. Furthermore, new customized programs can be created. Stellarium has been developed as an open source software project under the GNU GPL license and allows users to add their own plug-in modules (satellites, control of telescopes etc.). The scripting language ECMAScript offers the users possibility to create their own views, to find positions of various objects or to demonstrate different phenomena.

The existing scripts contain examples of eclipses of the Sun and the Moon, projection of the Earth from other planets, as well as surface maps of particular planets.

The program allows the users to monitor real orbits of planets and their moons. We can see, for example, Jupiter moons, as they were first seen by Galileo Galilei. Stellarium allows much more, their zoom and even their movement over time. For a few seconds we can see the whole circulation of the moons around the planet. In Stellarium, information can be found on parallax, spectral type and absolute magnitude of the brightest stars, which allow us its use in teaching. In this way it is possible to construct, for example, the HR diagram of the brightest stars of the night sky.

In the next section, we present an example how to compare the age of three open star clusters. We choose the best-known open star clusters: the Pleiades, Hyades and the Beehive (Praesepe). Stellarium program will allow us to locate the clusters and the necessary data for the stars, in particular – absolute magnitude and spectral class (Fig.2). These data were processed in the table editor. The displayed diagram represents a shift from individual stars on the main sequence of the HR diagram.

Fig.1. Exploring constellations asterisms Summer Triangle

The HR diagram basically shows the relationship between the stars´ brightness versus their spectral type. The stars of the Pleiades are listed on the main sequence, which documents their younger age compared to the stars in the Hyades, for which the offset from the main sequence on the HR diagram is larger [5].

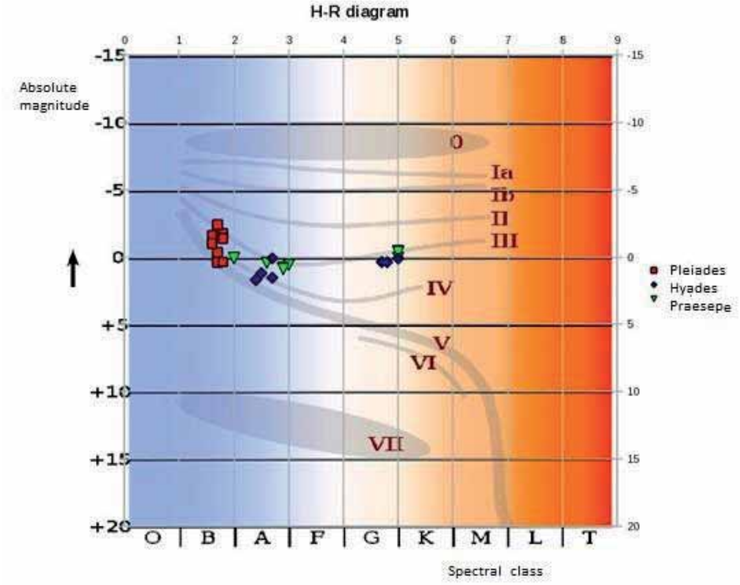

Fig.2. The HR Diagram for the open clusters Pleiades, Hyades and Praesepe

ALADIN

The interactive computer program Aladin [6] acts as a space atlas which allows the user to visualize digitized astronomical images, to search astronomical catalogs of data and databases (e.g. Simbad, VizieR) and to connect all the servers of virtual observatories. In teaching it allows students to reproduce astronomical discoveries by providing the necessary data. It includes a built-in spreadsheet for calculations which other programs lack. Having in mind the complexity of the program it is more suitable for students who have learned the basics of working with a computer as well as basic knowledge of astronomy. In settings, the control level can be selected, one of the possibilities is the student profile. ALADIN is a basic environment that can run specialized tools of virtual observatories available on the Internet in the form of modules, for example for data visualization and spectrum analysis. For the first orientation in available options for computations needed in astronomy, methodically worked examples on the web EURO-VO can be used.

For illustration, we can give an example of using the ALADIN program to help determine a distance of a galaxy. Firstly, a distance of the galaxy M31 in the constellation Andromeda was determined by Edwin Hubble. In determining a distance, he used characteristics of Cepheid variable stars (Ceph). Period changes in brightness of the variable star depend on the absolute magnitude according to the equation

$$M = -1{,}43 - 2{,}81 \log P, \tag{1}$$

where M is the absolute magnitude of a given star, P is the period of the star's brightness changes. The distance of the galaxy can be determined by the distance module, which is a function of the absolute magnitude. The module distance can be expressed as

$$m - M = 5 \log r - 5, \tag{2}$$

where M is the absolute magnitude, m the apparent magnitude of the star and r is the distance expressed in parsecs. In the following section we present a practical application of the procedure for determining the distance of the galaxy M81 in the constellation Ursa Major. In the ALADIN program we open the catalog VizieR M81 and find an object and choose the type of variable star Ceph. The program displays the stars and a data sheet. In the table of data we are interested in a column with a period. To calculate the absolute magnitude of stars found we can use a built-in calculator of the ALADIN program, or process the data by other means (Fig.3 a, b).

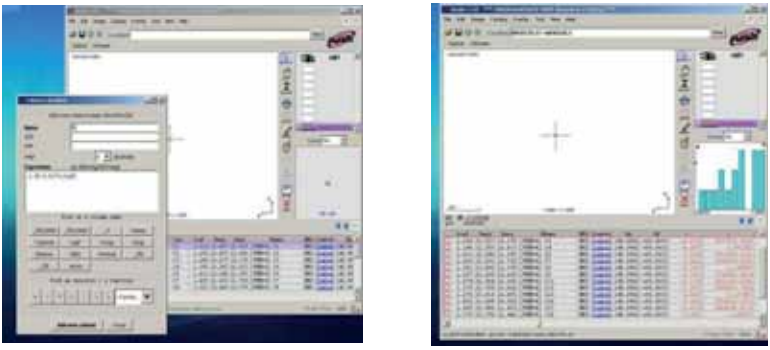

Fig.3 a) calculation of the absolute magnitude and
b) distance Ceph in M 81 in the program Aladin

PROJECT OF KNOWLEDGE ACTIVE CREATION THROUGH AN INTERACTIVE STELLARIUM.

1. In the pilot project we investigated the extent to which the learning process will be influenced by such computer applications. We chose the interactive computer program Stellarium, which is a product of the European project EURO-VO (The European Virtual Observatory). We focused on the possible inclusion of certain topics from astronomy to physics and worked out simple tasks using Stellarium. For the pilot survey, two first grade classes of the secondary school in Snina were selected, where in the physics curriculum astronomy was included. Students solved problems involving several virtual observations - according to the covered thematic topics – the orientation of the Solar System in the sky and Kepler's laws. Students in both classes were comparable (23 students in the class where the program Stellarium was used, and 25 students, where the topic took on the traditional way). The conclusion was made by a knowledge test of the topics covered. The test results clearly show that students who have taken over the curriculum using the computer program Stellarium acquired much more basic terms.

2. Regarding attitudinal questions, 75% of the pupils who worked with Stellarium answered that learning astronomy was interesting for them (in the experimental classes such statement was given by 50% of pupils).

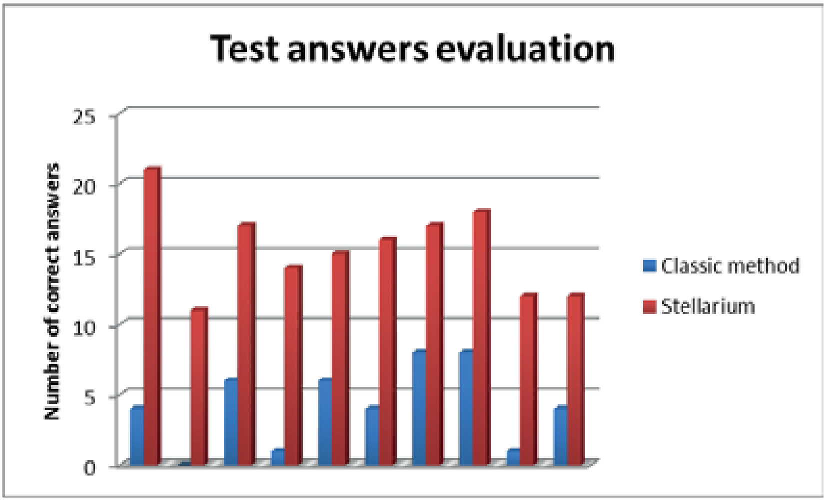

Fig.4. Test answers evaluation

CONCLUSION

The results of our pilot survey confirm that the inclusion of interactive computer programs in teaching supports increasing the knowledge level in the field. We can conclude that teaching with Stellarium was also very interesting for pupils. The active work aroused greater interest in them in the discussed topics than in students who took the traditional way. Moreover, as demonstrated by the final test, they showed more acquired knowledge than students in classical teaching. It turns out that the inclusion of topics from astronomy to physics teaching using Stellarium is a motivator for learning and may be one of the factors that will help determine further orientation of pupils towards studying natural sciences.

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V. SOCIALLY SENSITIVE ISSUES

GAME THEORY IN SECONDARY SCHOOL

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ABSTRACT

Game theory gives a general mathematical framework to quantitatively describe real life situations and to characterize the interactions between players representing humans, groups of humans, animals, plants, bacteria, etc. The knowledge of the concepts and results of game theory can help us identify clearly the different types of interactions and to apply the known solutions in order to improve the life level of individuals and the economical efficiency of the societies. The terminology and the useful messages of game theory will be demonstrated by discussing a simple set of matrix games. Finally we summarize arguments justifying the importance of teaching game theory in the secondary school.

INTRODUCTION

Most of us use dozens of devices (e.g., mobile phone, computer, and LED lights) and enjoy the comfort provided by the modern buildings, cars, mass transportation, etc. All these things are the products of high technology utilizing the results of natural sciences including physics, chemistry, and mathematics. In the last century we have understood the structure of atoms, how materials are built up from atoms, and we can determine their macroscopic behaviour in the knowledge of microscopic interactions. At the same time, there are many other systems (human societies, ecological systems, biological species, languages, etc.) that are composed of many interacting objects.

The elementary interactions between the mentioned small objects are complex in comparison to those determining the behaviour of physical or chemical systems. In many cases, however, these interactions can be quantified by payoff matrices introduced in traditional game theory [1]. For example, in biological systems the strategies represent species and the payoffs quantify the effect of their interaction on their fitness measuring the capability of creating offspring. Evolutionary game theory [2], [3], [4] gives a general mathematical basis for investigating living systems and for understanding phenomena and mechanisms controlling human behaviour [5], [6], [7] and Darwinian evolution [8].

The application of the relevant results of game theory at different levels (from the individual behaviour to the decision of managers and law makers) is generally prevented by the absence of knowledge of the fundamental concepts of game theory and of the general nature of interactions described by games. Game theory quantifies a wide scale of situations we face day by day. Sometimes there exist many solutions (Nash equilibria) favouring different players. For example, in the coordination (or anti-coordination) type interactions the players benefit when choosing the same (or opposite) options whereas the difference in their payoffs may be the source of further conflict. For the so-called social dilemmas the individual interest suggests the players to choose options that are considered as “the tragedy of the community” because they could receive higher income with collaboration.

For the illustration of the terminology, concepts, solutions, and messages of game theory we first study the donation game and then a simple set of matrix games will be surveyed in the following sections. Finally we will discuss briefly experiences of teaching game theory in the secondary school and summarize additional arguments supporting the teaching of game theory.

DONATION GAME

Social dilemmas occur in a simple way in the donation game where two players (*X* and *Y*) have two options ("no" and "yes", in short *n* and *y*) to choose. More precisely, they must decide simultaneously (without communicating to each other) whether they wish to pay 1 euro to the co-player for receiving 2 euros. The pure incomes of players should be reduced by their investment as it is given in Table 1 for both players for all the four possibilities (called "strategy profiles" in game theory).

Table 1. Payoffs for player X and Y for the donation game.

X \ *Y*	No	yes
no	(0,0)	(2,-1)
yes	(-1,2)	(1,1)

The intelligent and rational (selfish) players recognize that their own investment is beneficial only for the co-player and the maximization of their own incomes advices both to choose "no". Here we have to emphasize that in traditional game theory the players assume that the co-players are also intelligent and rational players who wish to maximize their own payoffs irrespective of others. Thus the strategy profile (*n,n*) is a single Nash equilibrium that is the suggested solution in traditional game theory. In this case both players are satisfied because they cannot increase their own income by choosing another strategy unilaterally. At the same time the strategy profile (*y,y*) would provide them higher payoffs, and hence the dilemma.

The above Nash equilibrium can be found by determining the direction of edges in the flow graph for which the nodes represent strategy profiles and the edges connect those strategy profiles which differ in only one of the players' strategies as illustrated in Fig. 1. The directions of arrows point towards the strategy profile providing a higher income for the active player. In this directed graph the node without outgoing edges represents the Nash equilibrium.

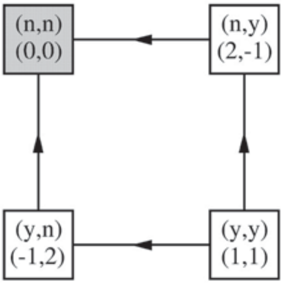

Fig.1. Flow graph of the donation game. The strategy profiles (nodes) are denoted by boxes indicating the strategy labels (upper rows) and payoff pairs (lower rows). The Nash equilibrium with only incoming edges is denoted by the gray box.

In real life situations the donation may be money, food, solicitude, transfer of knowledge or experience, and encouragement that has some cost *c* (here *c*=1) for the donator while the benefit b (here *b*=2) of donation exceeds the value of cost (in short, *b*>*c*). The essence of this game remains unchanged if the donations are not synchronized within a pair or when similar games are played by randomly selected pairs of a large population of players. At the same time, the repetition of these games implies a possibility to react to the previous decision of the co-player. In the latter (repeated or iterated) versions of these games the mutual donation can be enforced by following suitable strategies (e.g., tit-for-tat) [5]. Human experiments [6] have justified that in general people help each other in similar situations. Evolutionary game theory has explored several mechanisms supporting the maintenance of altruistic behaviour in similar situations [2], [3], [4].

SYMMETRIC MATRIX GAMES

In the above-mentioned donation game there are two equivalent players with both having two options what will be denoted henceforth as *D* and *C* strategies. Now we extend this 2x2 matrix game by introducing the bi-matrix notation. In this notation instead of the tabulated payoffs (see Table 1) the game *G* is defined by the following bi-matrices as

$$G = \begin{pmatrix} (P,P) & (T,S) \\ (S,T) & (R,R) \end{pmatrix} \rightarrow \begin{pmatrix} (0,0) & (T,S) \\ (S,T) & (1,1) \end{pmatrix}, \qquad (1)$$

where the payoff pairs for each strategy pair are arranged in the same order as in Table 1. The equivalence of players for the symmetric games is reflected by the facts that the players receive the same payoff if both choose the same strategy and they exchange their payoffs when exchanging their strategies. As a result, all the symmetric 2×2 matrix games can be defined by four payoff parameters. The number of relevant parameters, however, can be reduced by identifying that the rank of payoffs (order of preference) remains unchanged if we add a constant payoff to each payoff component. Consequently, we can choose P=0 without any loss of generality. Additionally, we can modify the payoff unit by choosing R=1. The games with these rescaled payoff parameters are defined by only two parameters. Thus on the T-S plane each point represents a game. When evaluating the flow graph we can then distinguish only four types of the symmetric 2×2 matrix games separated by dashed-dotted lines in Fig.2.

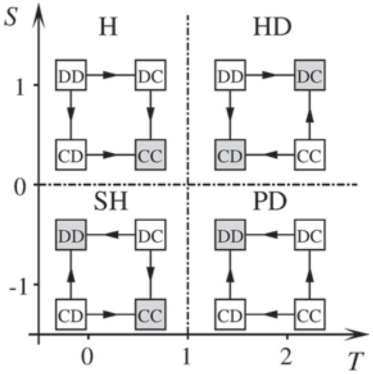

Fig.2. Flow graphs in the four quadrants of the T-S parameter plane where the gray boxes indicate Nash equilibria as in Fig. 1.

In the region of Harmony (H) games ($T<1$, $S>0$) the system has a single Nash equilibrium when the maxima of individual and common incomes coincide. In this notation the above-discussed donation game is located in the region ($T>1$, $S<0$) of Prisoner's Dilemma (PD) for which each game has a single Nash equilibrium. In the latter case, however, the choice of Nash equilibrium provides the same (zero) income for the players that is less than what they would get when choosing the opposite strategy mutually. Unfortunately, the original story of the prisoner's dilemma [9] masks and suppresses the importance of this serious social dilemma we face frequently day by day. For example, such situation can occur in the recent level of specialization (division of work) when the workers decide whether they execute their duty fairly or not. Similar situations can be observed among bacteria having two mutants (considered as strategies) producing (or not) enzymes that catalyze the extraction of food from the environment [10]. The disarmament negotiations and many other examples of social (or prisoner's) dilemmas indicate clearly that the exploitation of others is not a human invention rather it should be considered as an existing type of interactions between living objects.

The Stag Hunt (SH) game represents an interaction where the players do the best when choosing the same options, consequently, this game has two Nash equilibria. At the same time their income may depend on the strategy they choose mutually and the difference in their payoff may be the source of an additional conflict. Examples for these real life situations are cases when the players have two options (to use meter or inch as length unit, to install Linux or Windows on their computers, to select one of the possible technologies in their work, etc.) and some advantage can be realized when choosing the same one. This is the reason why these games are frequently termed as coordination games.

Using the latter terminology the Hawk-Dove (HD) game is an anti-coordination game because here the system has two Nash equilibria when the players should choose the opposite options (see Fig. 2). Such situations occur also frequently in the mentioned systems. In biological systems the symbiotic behaviour exemplifies this type of interactions. In human societies the division of work (or specialization) can create extra profit for the players if they divide the task(s) into complementary parts. Anyway, this is the game that two players play when entering a room through a narrow door as both player have two options: to be the first or second to enter.

Fig.1. illustrates that we can distinguish only four types of symmetric two-player two-strategy games whereas we can draw $2^4=16$ different flow graphs for the non-symmetric games. The reduction in the number of distinct types is related to the symmetry ensuring the same payoff variation for both players when deviating unilaterally from the DD or CC strategy profiles. The latter symmetry implies an additional consequence, namely, the sum of the payoff variations (of the active players) is zero along the four-edge loop of this flow graph. On the analogy of the potential energy in physical systems here we can also introduce a potential for each strategy profile that can be given by the potential matrix ***V***. In the present example the payoff matrix ***A*** and the potential matrix ***V*** are expressed as

$$A=\begin{pmatrix}0 & T\\ S & 1\end{pmatrix} \quad \text{and} \quad V=\begin{pmatrix}0 & S\\ S & 1-T+S\end{pmatrix}, \qquad (2)$$

where the matrix components, defining payoffs for the first player and potentials for the pair of players for all the strategy profiles, are arranged in the same way as in Table 1 and Eq. (1). In fact, the potential summarizes the individual incentives along a series of changes in the space of strategy profiles when only one player can modify her strategy. The latter property is reflected by the equivalent payoff differences in the corresponding columns of ***A*** and ***V***. Notice that ***V*** is a symmetric matrix. The largest component of the potential matrix plays a distinguished role as it identifies a preferred Nash equilibrium. More precisely, the corresponding strategy profile is analogous to the ground state (minimizing the potential energy) in physical systems. The left panel of Fig. 3 indicates the preferred Nash equilibria as a function of the payoff parameters. The mentioned preference selects one of the Nash equilibria in the region of SH game whereas the equivalence of the DC and CD Nash equilibria is reserved for the HD games. It is emphasized that the state of the "tragedy of the community" (gray territory in Fig. 3) emerges within a large region of parameters.

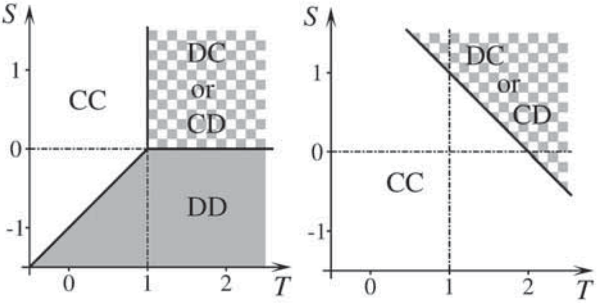

Fig.3. Left panel: Preferred Nash equilibria for selfish (rational) players on the T-S plane. Right panel: Nash equilibria for fraternal players for the same payoffs.

The right panel of Fig. 3 illustrates a way how the "tragedy of the community" can be avoided by fraternal players who represent the behaviour of family members or friends. The fraternal players agree to share their total payoffs equally. In that case the individual and common interests coincide and the dilemma vanishes.

Two Nash equilibria exist in the regions decorated by checkerboard patterns in Fig.3. In these solutions the players receive different payoffs, namely, *T* and *S*. The latter differences, however, can be eliminated for iterated games if the players alternate the strategy profiles CD and DC.

In the multi-agent spatial evolutionary games [11] the players are distributed on a lattice and they play games with their neighbours. Sometimes the players are allowed to modify their strategy by following a dynamical rule. In contrary to the traditional game theory [1] here the intelligence of the equivalent players is limited. In biological models the unsuccessful players are replaced by the offspring of the more successful ones in the spirit of Darwinian selection [2]. This approach is adapted for human systems with assuming that players with low payoffs imitate/adopt the strategy of a more successful neighbouring co-player. The so-called logit rule assumes a higher level of intelligence, because here the players are capable of evaluating their payoffs for their possible strategies at a fixed strategy profile in the neighbourhood. In consecutive elementary steps they choose one of their strategies with a probability increasing exponentially with the payoff. This stochastic rule drives the systems into the Boltzmann distribution that validates the concepts and mathematical tools of statistical and solid state physics [12], [13], [14].

Fig.4. illustrates a process that exemplifies the close relationship (analogy) between the physical and social systems (for a more detailed discussion of this analogy see [15]). The physical system is the ferromagnetic Ising model where atoms are located on the sites of a square lattice and the magnetic moments of atoms can be oriented upward (↑) or downward (↓). For the ferromagnetic materials the interactions between the neighbouring atoms favours the same orientation, namely, ↑↑ or ↓↓. At low temperatures we can observe and ordered state when all the magnetic moments point to the same direction. In the presence of an external

magnetic field, however, one of these ordered states is preferred. Fig.4. show a reversal of magnetization when initially most of the magnetic moments point to downward despite of the presence of an external magnetic field preferring the opposite ordered arrangement. Due to the stochastic events atoms with ↑ state occur occasionally but their moments are reversed back by the neighbouring atoms within a short time. Sometimes, however, an island of ↑ atoms can be formed, and if its size is sufficiently large then the size of this island grows with a velocity proportional to the strength of the external magnetic field. The related phenomena are well described in the literature of magnetic materials and this knowledge is utilized in magnetic hard discs, electric motors, and transformers.

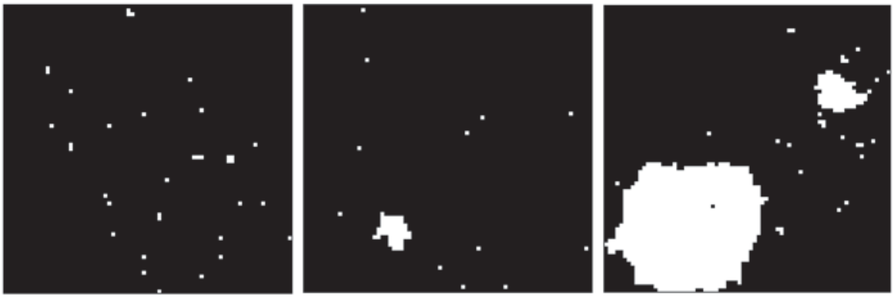

Fig.4. Evolution of strategy distribution for the evolutionary stag hunt game on a square lattice for S=-0.4 and T=0.5 at a low noise level. Initially almost all the players use D strategy indicated by black boxes on the left snapshot. The system remains in this state until the formation of a sufficiently large colony of C players denoted by white boxes in the middle snapshot. The territories of these C islands growth and finally (right snapshot) the system evolves into the preferred Nash equilibrium where some defects can be present due to mistakes in the imitation.

In social systems the above process can be interpreted, for example, as the spreading of a new technology in a society where initially the members (players) use an older and less efficient one. In these models the strength of noise quantifies the frequency of mistakes in the strategy refreshments and its role is analogous to the temperature in physical systems.

Besides the above examples there are many other potential games even with more than two strategies that can be mapped onto a suitable physical model [12], [13]. It is known that the presence of cyclic dominance in the payoffs prevents the existence of potential [14].

The cyclic dominance is represented by the matching pennies and rock-paper-scissors game for two or three strategies [2], [3]. The presence of these components in the interactions can help the maintenance of cooperative behaviour in the social dilemmas. Anyway, the games with cyclic dominance exhibit some other surprising and general laws (e.g., unexpected consequence of external influence [16] and parity effects [17]) that are also worthy of teaching.

MESSAGES OF GAME THEORY

The above examples have illustrated how game theory can be used for the quantitative explanation and classification of phenomena affecting our life directly. Now we underline several properties that are not detailed previously.

First we emphasize the difference between game theory and decision theory that can be considered as the first lecture in a course of game theory. Decision theory deals with cases when we should select one of the possible options whose utilities are quantified by real numbers (the better choice is quantified by a larger payoff). Here we can recognize that the valuation of utilities may depend on the player. Furthermore, the determination of the optimal choice is based on the rank of payoffs that simplifies the quantification of utilities.

In non-cooperative game theory we study situations where *n* players choose one their possible options simultaneously (without collaboration or communication with any of the others) and the quantified utilities depend on the choices of all the participants. For most of these normal games the players cannot choose the strategy providing their highest individual income because of the counter-interest of the co-players. The traditional game theory assumes rational and intelligent players who wish to maximize their own payoffs (irrespectively of what happens to the others) meanwhile they also assume the same levels of selfishness and intelligence for the co-players. For normal games the Nash theorem [18] states the existence of (at least one) so-called Nash equilibria from which the unilateral deviation is not beneficial for the players. In many games (e.g., matching pennies or rock-paper-scissors) only one mixed Nash equilibrium exists when the players choose one of their pure strategies with probabilities depending on the payoffs. In these cases the game resembles gambling.

Fundamentally different difficulties arise for games having two or more Nash equilibria because here we need further criteria to choose one of them. The most important problems, however, are related to the social dilemmas that exist in a large region of the payoff parameters for the normal games. As mentioned above, in social dilemmas the individual selfishness enforces the players to choose a Nash equilibrium that may provide a low income in comparison to those suggested for their collaboration. At the same time for the latter strategy profile(s) some of the players can benefit when deviating unilaterally from the collaboration and these possibilities destabilize the collaboration.

In the light of game theory the mentioned features can be considered as natural laws characterizing the interactions between living objects. The systematic investigations of the models of evolutionary game theory have already explored relevant effects and consequences of these types of interactions [3], [4], [11]. Different mechanisms are discovered that can help the society to avoid the trap of social dilemmas. For example, the application of the tit-for-tat (TFT) strategies was suggested by Axelrod [5] for repeated prisoner’s dilemma game at fixed partnership in the absence of noise. The TFT strategy algorithm chooses C strategy in the first step, afterwards the TFT players repeat the co-player's previous step that can be interpreted as a punishment of defection and reward of cooperation. In the presence of noise (mistakes), however, the use of the forgiving TFT strategy is more beneficial [3], [4], [11]. Nowak and Sigmund [3], [4] have evaluated the probability of forgiving (when the defection is not reciprocated) that depends on the payoffs. In the absence of forgiveness the strict TFT players would punish alternately each other after an occasional mistake.

Other possibilities [e.g., punishment, reward, and voluntarism] are also explored and can be efficiently used in repeated human interactions. Some of the mentioned methods require additional cost to be paid by the players favoring the maintenance of cooperative behavior that is beneficial for the whole community. This is the reason why the altruistic punishment is considered as a second order donation game.

The limited length of this article does not allow us to discuss other general laws and relationships that can be analysed with using the concepts of game theory. Instead of it in the following section we briefly survey other arguments supporting the importance of teaching game theory in high schools.

ADDITIONAL ADVANTAGES AND CHALLENGES IN TEACHING GAME THEORY

Children enjoy games. In the ancient ages as well as today games have helped us develop skills in order to find a good solution quickly in every-day situations. Theachers [15], [19], have reported significant increase in the activity of students in courses of game theory. A relevant portion of students have modied their opinion of learning math and other natural sciences as they found the related problems attractive and useful. In other words, the teaching of game theory has generally improved the reputation of natural sciences including the approaches and methods of physics.

Computers and internet ensure an excellent background/facility for everyone to play the games of game theory against each other. In the last years Alvin Roth (Nobel Memorial Prize Laurate in Economics, 2012) and his team has launched a softver that is already used in several universities in teaching game theory [20]. Teachers and students can register themselves and play games under the conduction of their teacher. When playing repeated games against each other or against the computer the students can experience personally how to use mixed strategies in the matching pennies or rock-paper-scissors games.

For the repeated social dilemmas the players can do a series of experiments in order to find good solutions against opponents following unconditional cooperation or defection, different versions of TFT, random, or win-stay-lose-shift strategies. The necessity of forgiveness between to TFT players can also be well demonstrated in situations where mistakes are present.

The investigation of social dilemmas cannot be separated from ethical questions because the unconditional cooperators and defectors can be considered as good and bad members of the community. The mentioned games illustrates the usefulness of the fraternal behavior. Here it is worth mentioning that the importance of altruism and trust in human behavior are also investigated experimentally and the results are justified by mathematical models of evolutionary game theory.

For example, in the two-player ultimatum game [21] the first player proposes how to share 100 dollars between them and the second player can accept or reject it. If the proposal is accepted then both players recieve the proposed portions, otherwise the players receive nothing. In this game the Nash equilibrium is to propose only 1 dollar for the co-player who should receive it as it is more than nothing. On the contrary, the human experiments indicated that a large portion of players suggested approximately equal sharing. The latter result is related strongly to the experimental fact that most of the players rejected the proposal less than 20 dollars. These experiments are performed by students who know nothing on game theory and social dilemmas. Otherwise the preliminary knowledges modify the behavior of players [22]. In other words, the acceptance of social norms (here the fair sharing of income) can be trained by playing similar games.

It is worth mentioning that the necessary trust in human collaborations can also be improved by playing the so-called trust game [23]. In this experimental game the players are located in two rooms (A and B) separately. Players in room A have to decide how much of their 10 dollars is invested and sent to a counter-player (in room B) who receives a tripled sum. Afterward players in room B have to decide how much of the tripled money to keep and how much to send back to their respective coplayer. The experiments indicated a wide scale in the behavior that is improved when the game is repeated by the same players later.

In traditional game theory cooperative games are addressed to study the formation of strategy associations that can provide higher total income for the members of collaborators. In evolutionary game theory [10], [11] dozens of models have justified the spontaneous emergence of strategy associations via the Darwinian selection. For example, in sports the success of the specialization of players in a football or handball team is well demonstrated. Additionally the latter examples illustrate both the importance of high level training (teaching) and of finding the best persons for all positions.

Finally we have to mention briefly the challenges and difficulties coming from the absence of traditions and methodology in teaching game theory. Playing different types of games can be adjusted to the evolution of the human brain. The experimental investigations of children's behaviour [24], [25] have clearly indicated that human egalitarianism and parochialism have deep developmental roots, the inequality aversion and other-regarding preferences develop (and can be trained) strongly between the ages of 3 and 8. The mathematical knowledge of high school students makes them capable of analysing the above-mentioned problems and phenomena with the help of game theory and also discovering the similarities between different living systems. The above mentioned examples have demonstrated the application of some simple mathematical concepts and methods that can motivate students to learn more on vectors, matrices, and graphs. At the same time it implies the necessity of collaborations between teaching mathematics, physics, chemistry, biology, and ethics.

CONCLUSIONS

Game theory originally was developed to find the solutions in some traditional games (like poker and other card games, nim game, table games, military games, etc.) with using the tools of mathematics. It turned out, however, that the concepts of game theory can be efficiently used to study the general features of phisical and living systems where the complex interactions are characterized by payoff matrices representing social dilemmas, cyclic or hierarchical dominance between the distinguishable players. Modern game theory and evolutionary game theory give us a tool for explaining analogous phenomena occuring in different fields of sciences. All these advantages can be utilized if students learn the alphabet of game theory at the level of their knowlegde of algebra and geometry.

The efficiency of teaching game theory can be increased significantly by applying the tools of informatics as detailed above. These facilities can maintain and enhance the interest and activity of students int he high schools and will help them to improve the level of cooperation/collaboration in their future life.

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COLOUR BLINDNESS AND SCIENCE – 50 SHADES OF MUDDY GREEN INTERSPERCED WITH BLUES AND YELLOWS

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ABSTRACT

Colour blindness or colour vision deficiency (CVD) is the most common genetic disorder in humans affecting 250 million worldwide. About 8% of males have colour vision deficiency, i.e. 1 in 12 boys in schools. Despite its prevalence many teachers do not realise that it is more than 'getting colours mixed up'; it is a problem with distinguishing colours across the spectrum. This can impact on the engagement, understanding, and attainment of a pupil. Without correct diagnosis at an early age a child's motivation will be seriously affected.

INTRODUCTION

Colour, something we take for granted, is often a far more complex phenomenon that we realise. There are several experiments which can demonstrate this. Our perception if affected by many factors including background colours, previous exposure of the eye, and of course the physiology of our eyes.

Teachers are aware of that "colour blindness" is a problem for some students, but rarely have any training in dealing with the issues, rarely know who is colour blind in a class, and therefore rarely make any adjustments to lessons. 40 to 50 years ago when some of the research was carried out, often quoted to justify inaction by authorities, the world was a very different place, white chalk on a black board, black and white TV, and textbooks with little colour. However the 21st century children are brought up in a very different environment full of colour.

There is little consistency across Europe in either assessment of CVD or strategies to deal with it, particularly in schools. Children and parents are often unaware that they are colour blind, and many teachers do not have a clear understanding of the special needs of colour blind children. Hence pupils can be severely disadvantaged and incorrectly diagnosed as being inattentive, underperforming, or requiring other types of special education needs support.

There is very little information readily available as to how best to deal with this issue.

WHAT ARE THE DIFFERENT TYPES OF COLOUR VISION DEFICIENCY?

Our colour sensation is determined by the three different cones in our retinas, commonly called the blue, green and red cones. However this is a slight misnomer, as each cone is sensitive to a wider range of wavelengths, as will be understood from Fig.1.

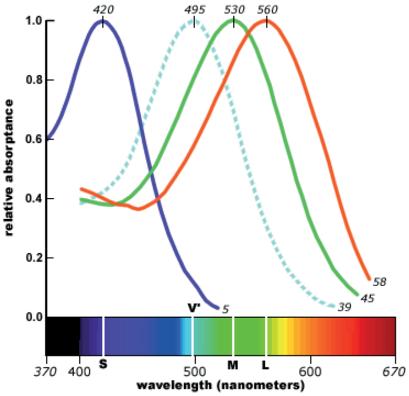


Fig.1. Diagram showing sensitivity of the three cones in the retina

The technical terms are as follows:

- *Trichromacy* describes ‘normal’ vision which is the 3 cones working together.

Those with Colour Vision Deficiency may suffer from

- *Protanopia* which is “Red” cone deficiency
- *Deuteranopia* which is “Green” cone deficiency
- *Tritanopia* which is “Blue” cone deficiency

Often the first two are groups together simply as “red/green” colourblind as the effects can be perceived as quite similar, as can be seen by looking at the computer generated simulations.

Birds and animals have visions which differ from what we regard as “normal human vision”. Many mammals are what we would call “colour blind”. Dogs for example work with only two different cones. Surprisingly, to many, a bull does not “see red” so is attracted to the toreador’s cloak by its movement rather than its colour.

Thankfully, modern technology enables us to simulate what someone who suffers from CVD may see when confronted with different colours (Fig.2.).

Fig.2. Coloured pencils as seen by someone with deuteranopia (left) and with normal vision (right), from Colour Blindness Awareness Association simulation by “vischeck” [1].

The effect is often hidden of course because a child has always been taught that that "muddy green" he sees is called "red" and so will call out "red" when asked. In fact the vast majority of children with CVD leave primary school without realising, and a staggering 50% leave secondary school in a similar state of ignorance. Even if they are capable of many tasks, those tasks may be much more difficult than for someone with normal vision, or even impossible. There are many tales of adults who have little colour sense when it comes to choosing clothes etc., and it is quite likely that some of these have CVD but are undiagnosed.

Two 17 year-old Dutch schoolboys were given a holiday job to pick tomatoes, but sadly one lost his job after one morning. He hadn't realise he was "colour blind" and did not distinguish between green unripe, and red ripe tomatoes:

Fig.3. Green and red tomatoes as seen in normal vision (left) and with deuteranopia (right), simulation by "vischeck" [1].

EXAMPLES IN THE SCIENCE CURRICULUM

Where colour is a factor, there may be issues for some children in a class. Remember 1 in 12 boys suffers from some form of CVD, that is one in every mixed class of 30 pupils (the condition is much rarer in girls, 1 in 200, but nevertheless likely to be at least one in every school). The degree of severity varies considerably child to child which make diagnosis more difficult. However it is estimated at 25% of those with CVD have it in its severest form, i.e. a missing cone type, whereas others may simply have a shortage in the balance of cones.

So as teachers as a first step we should watch out for students who have difficulty identifying species, using pH and other colour tests, or identifying colours of the spectrum. Apart from using CVD friendly colours, we could do a great service by alerting someone to a problem they have but which goes unrecognised.

Many physics teachers in the UK recognise that the colour coding on wires was changed several years ago to enable recognition of the different wires to be more reliably done by everyone. The example below shows just how effective this has been:

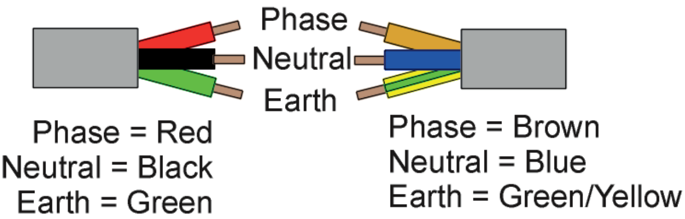


Fig.4. Electric wiring in the UK, before and after the change (NORMAL VISION)

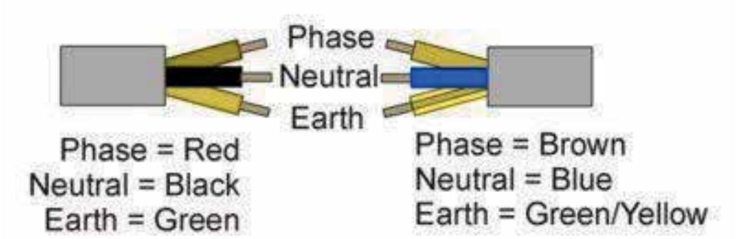


Fig.5. Electric wiring before and after the change simulated for *deuteranopia*

It is clear how easy it would have been before the change to confuse the Phase or Live wire with the Earth (as illustrated by Fig.6, too).

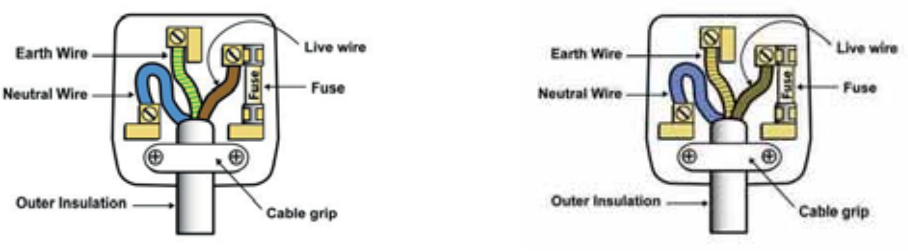
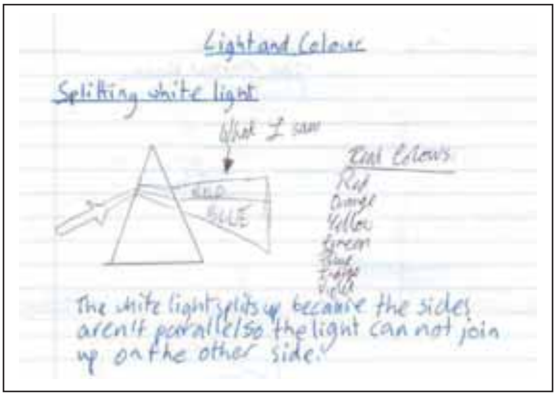


Fig.6. Wires in plugs, normal vision (left) and deuteranopia (right).

Fig.7. illustrates the difficulty experienced when reading a pH test. The diagram illustrates a liquid as seen by a CVD student and his pH test paper to compare with the liquid. Not an easy task... although it must be said that the majority of CVD students will have a heightened sense of the minor differences in shading that those with normal vision may not spot.

Fig.7. Testing for pH value, a *deuteranopia* student's view

This all presents interesting challenges not just for the student but also for the teacher. How for example should a physics teacher mark a CVD student's description of a spectrum from a prism, in which he/she genuinely only sees two colours. Should he mark as correct the division into two colours, or encourage the students to mark in his book different colours even though he/she doesn't see them? Figures 8 and 9 illustrate this. Note that the student labels the muddy yellow green as red… which of course some of it is!



Light and Colour

Splitting white light

The white light splits up because the sides
aren't parallel so the light can not join
up on the other side.

Fig.8. A page from a student's notebook. Is making a student record what he doesn't see educational dishonesty?

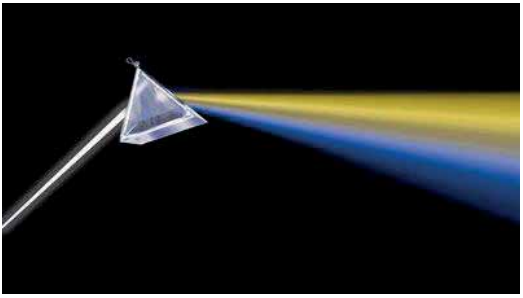


Fig.9. Spectrum as seen by someone with protanopia (red blind)

Interestingly the student in Figure 8 labels what we see as dull yellow/muddy green (in Fig.9.) as "red" presumably because he has always been taught that that colour is red.

The danger is that a teacher may diagnose the student's difficulties as what he or she perceives to be a silly mistake, laziness, lack of ability, lack of effort or inattentiveness rather than offering the necessary support. Students may become frustrated, and consequently disruptive. Teachers should therefore be alert to possible triggers – any colour confusion – that could help them identify that a students may have CVD that can then be easily tested.

Areas which may cause problems for students with a degree of CVD:

- Reading litmus paper accurately
- Undertaking chemical titrations in practical chemistry
- Identification of metals by the colour of the flame produced when the metal is burnt
- Accurately reading stained slides under a microscope
- Carrying out dissections in biology
- Identification of species of plants or insects correctly
- Fully understanding coloured diagrams in textbooks, particularly in biology, nature
- Use of prisms in physics
- Wiring of plugs in electricity, etc.

HOW TO HELP STUDENTS WITH CVD

Being aware of their challenges is the first step, but also the following strategies are helpful:

- Use Natural light
- **Secondary** indicators, e.g. signs on labels, or underline words
- Use yellow, blue and white for contrast in labels or charts, not green and red
- Have a sympathetic students as a Colour buddy
- Make clear boundary between colours
- Us a set of labelled pencils to indicate true colours
- Use large objects, held apart, when demonstrating if possible
- Use contrasts, e.g. red on a white background but not red and green together on a white background

Photographs may be checked using the simulation programme "Vischeck" [1]:
http://www.vischeck.com/vischeck/vischeckImage.php

The teacher simply needs to check any photographs used against the type of CVD. An even more useful app to help teachers see how difficult it may be is "iDaltonizer", which enables a teacher, on his phone, to see just what the students may see. I would recommend that all teachers download this free app.

It does seem that companies are beginning to develop products that will aid someone with CVD too. Spectral Edge, for example is able to help someone produce enhanced images by EYETEC technology. These emphasis slight contrasts between the colours of different objects.

A close friend has made with her son who suffers from *protanopia*, a short video which shows how he sees the world [2],
"Colour Blind Awareness #1ineveryclassroom Rainbow Song".

Further information can be obtained from the colour blind awareness organisation [3]. @colourblindorg (on Twitter).

I am grateful to Kathryn Albany Ward of the colour blind awareness group, who has provided much detail for this seminar and permission for photographs.

I would be very interested to hear of science teacher's experience in this field, either with students who have CVD or if they themselves have this challenge.

The author also has due to be published this year (2016) two extensive articles on CVD one in the International Journal of the Institute of Physics, Physics Education, and the other in the European Journal Science in School (publication dates are not yet known).

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SCIENCE EDUCATION PROGRAM IN THE SUMMER CAMP “BÁTOR TÁBOR”

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ABSTRACT

In a summer camp for chronically ill children, I have devised a science education program. All programs in the camp are organised to provide a feeling of success, which positively influences the children's self-esteem and recovery process. Thus the presented programs are planned to focus on playfulness, experiential activity, creativity and personal revelation. Considering the time and financial constraints, I compiled experiments and activities mainly in the field of hydrodynamics and electricity. I designed specific programs for smaller children and teenagers and trained the volunteers to mentor the programs. I present the structure of the programs, and with the help of some examples show how I built playfulness and creativity into them.

INTRODUCTION

Bátor Tábor, a summer camp, is a member of the Serious Fun Children's Network that was founded more than 25 years ago by the actor, Paul Newman [1],[2]. The international camp association has 16 members all over the world, all of which treats children with different chronic illnesses (cancer, diabetes I., Chron’s diseases, juvenile idiopathic arthritis, haemophilia, muscular dystrophy, etc.) by a method called therapeutic recreation. Bátor Tábor is the regional therapeutic recreation centre for Central European children, and thus its invigorating adventures are available for Hungarian, Slovakian, Czech and Polish children.

Fig.1. Mosaic of life in Bátor Tábor

The camp is situated 60km northeast of Budapest, next to a town called Hatvan, in Hungary. Every building and facility had been constructed to meet the needs of children with serious illness. Up to 70 children can sleep in the cottages, and the dining hall can seat 160 guests. The volunteer's cottages can host up to 66 people, with medical attendance backed up by a friendly and well-equipped medical building. The camp facility includes a high-ropes course, a rowing lake, an archery field, a horse-riding hall, a sports hall, etc., which together provide an excellent basis for the recreation therapy (Fig.1). The camp hosts about 1000 campers per year: one-week sessions for children aged 7 to 18 in summer, long-weekends for smaller children with their families in autumn and sessions for the ill children together with their siblings in spring. Camp-life is intense, colourful and well organised, and at the same time supporting by presenting new challenges and successes. The therapeutic recreation method used in the camp has some key elements that we use through the sessions: Children experience a positive, receptive social environment which helps them in fitting into their groups, making friends and developing connections with the volunteers. The camp programs are designed to adapt challenges to the children's personal abilities, thus all of them attain personal success. Volunteers continuously give verbal and non-verbal, positive and trustworthy feedbacks for the real successes. Furthermore, they reinforce and enhance the cooperative attitude of campers with specific games and activities. Since these children usually have a negative self-image because of their illness, it is important to mark them with positive labels to counterbalance this and to strengthen their self-confidence. Scientific investigations confirmed the significant positive effect of these camps [3], although long-term follow-up studies are still missing [4].

THE RENEWED "MAGIC WOOD" PROGRAM

Among the other programs there is a so-called „Magic Wood" thematic program in Bátor Tábor. The program is situated in a woody part of the camp, and this is where its name comes from. Earlier, this program focused on cooperative games and experiences connected to nature. Since this program seemed to be less attractive for the children, the management of the camp asked me last year to work out a new program, where science is in the centre of the activities. For the program development I had to take into account the following circumstances: (i) There are sessions for children aged 8 to 13 (children cohort) and aged 14 to 18 (teenagers) in the camp. (All campers attend school but most of them had to skip it for shorter or longer periods.) (ii) Three different programs were needed for both children and teenage cohorts, two of them had to be 80 minutes and one of them had to be 160 minutes long. (iii) The programs are visited by children with limited moving abilities, and they have to be completely safe (iv). Only about 5 hours are available to train the volunteers (with different backgrounds) to be expert instructors in these programs in the summer camps. (v) The foundation pledged about 350 EUR (100.000 HUF) for the innovation, and this amount of money had to cover all the materials and accessories we needed for the new programs. Knowing these constraints, I decided to develop programs based mainly on physical experiments, supplemented with brainteasers and new cooperative games. Biological experiments I had to exclude because of their longer timescale and because of financial reasons. Similarly, chemical experiments are generally more expensive than physical ones, and sometimes are not sufficiently safe for a camp like this. As I will show later, some applied activities and experiments have biological or chemical basis as well, but these are the exceptions.

The selected physical experiments can be classified into two groups, they are either experiments studying complex systems, or they are experimental systems based on simple physical laws, which behave spectacularly or counterintuitively (Table 1.)

Table 1. The applied physical experiments. References denote videos which present the experiments in detail.

Complex systems	**Spectacular experiments**
magnetic chaotic pendulum [5]	Colouring milk using detergent [6]
Convection of warm and cold water (in simple and rotating tank) [7]	"Take the coin on dry" [8]
Instability of warmer salty water (fingering) [9]	Carthesian diver [10]
Tornado bottles [11]	Lava lamp [12]

Further, I intended to offer the campers the opportunity to meet physical laws in action, hence I looked for activities where they can build or hack toys or instruments based on physics or chemical physics (Table 2.).

Table 2. Activities based on physical laws. References denote videos which present these activities in detail.

Electricity	**Mechanics**
Making homo-polar motor [13]	Making paper rocket [14]
Making Faraday train [15]	Making rubber band helicopter [16]
Making lemon and soil batteries [17]	Moving boat by Marangoni effect [18]

PROGRAM STRUCTURE, EXAMPLES

Every program is managed by two trained volunteers (a program leader and an assistant), and there are 2-4 additional volunteers present to motivate and support the children and help them if it is necessary. All programs have a background story that everybody is part of: the dressed program leader, the assistant, and the children as well. Thus the program is placed into a funny and motivating context. Every program starts with a warm-up game which can be a cooperative game or a brain-teaser for the group. Then the program leader and the assistant give instructions about how to prepare the experiment or build the instrument, while they present the safety instructions too. (Naturally, all information is transferred by the characters they play in the background story.) After a series of experiments or activities the group arrives at the end of the story, which generally starts with a challenging situation and is solved with the assistance of the children. The program finishes with a closing process where volunteers and children focus on the individual and group successes, and volunteers give positive feedback to the children's personal successes. After presenting the general structure of the programs, I will show now a specific program for children in detail, and present another one which was designed for teens in a less detailed manner.

So let us see how an 80-minute program for children looked like: *Introduction, background story:* An "alien" arrived at the camp (program leader) and a "scientist" (program assistant), specialist of exotic languages, can communicate with her/him. The scientist introduces the situation to the children and interprets the alien's problem. *Warm-up cooperative game:* The alien made a lot of pictures about the birds living in the camp and recorded their songs but she/he does not know the name of these birds and could not pair the birds' pictures with the recorded songs. The children now have to work in pairs and collect the pictures of the birds and the cards with their names in a cooperative game: One camper is blindfolded and the other directs her/his vocally (Fig.2.).

After collecting the pictures they pair the bird names with the pictures together. The next game is to pair the bird songs with the bird pictures. We start with the simplest songs (e.g.

Fig.2. Collecting the bird cards cooperatively

owl, cuckoo) to make the decision easier for the more challenging songs (e.g. great tit, nightingale). A solution is accepted only if all of the children are convinced that this is the good solution. (Sometimes it was not so easy to attain this state, thus in these cases the volunteers helped to reach the correct solution together.) The main activity: The alien is very happy because she/he learnt a lot from the children, and as a return she/he teaches them how to build a rocket. (The alien is an expert in it, since she/he arrived by a rocket to the Earth.) Then the alien presents a ready-made paper rocket to show how and why it flies if one blows it out with a help of a straw. After that the volunteers show the children, step by step, how to build the rocket (Fig.3. left, detailed description in [14]). When all of the children have finished building the rockets and decorated them as well, they put the rockets in action together (Fig.3. right).

Fig.3. Building and blowing out the paper rockets. Left panel: The alien (the author of the paper) shows the children how to build the paper rocket. Right panel: Rockets on fly. The Magic Wood cottage is situated in the background

Closing: The children and the volunteers form a circle. The assistant announces that the alien has to leave now, and since the rocket is ready, she/he can. The program assistant asks the children to think a bit about what they have learned from the alien and what they can teach her/him. Then everybody has a chance to answer these questions. Volunteers control this process and give positive reinforcements both to the individuals and to the group as a whole.

In the program designed for teens, after telling the background story and finishing the warm-up game, the group (10-12 campers) is separated into two parts. One part of the group goes back to the Magic Wood cottage and all of them install their experiment of magnetic chaotic pendulum with the help of a trained volunteer. The moving of the pendulum is visualised by LEDs fixed on a 3V button battery at the end of the pendulum. The motion is recorded by long exposure photographs in the dark room. Children have the opportunity to try different number of magnets and initial conditions, several different colours of LEDs and different exposure times on cameras (Fig.4).

Fig.4. Experiment with magnetic chaotic pendulum. Left panel: The experimental set up. Right panel: Motion of chaotic pendulum visualized by yellow LED in 8 sec. exposure time

At the same time, the other half-group prepare experiments based on hydrodynamics. First they study the convection of warm and cold water in an aquarium, which is a simple but impressive experiment that children can actively take part in (Fig.5).

Fig.5. Some experiments in the program for teenagers. Top left panel: Mixing of coloured hot and cold waters. Top right panel: Tornado bottles in action. Bottom: Colouring milk by food colour and studying the effect of detergent

Then they prepare their own water tornado experiments and consult the volunteers about their observations on the motion of water and air in the bottles. At the end they make the well-known milk-detergent-food colour experiment (Fig.5). All experiments are preceded by a short explanation of the physical background and a discussion about its role in our every-day life. The two subgroups change their positions in the half-time. Again, to make the experiments successful means that the children manage to overcome some obstacle or help the program leader and assistant to attain some sort of a funny goal.

CONCLUSIONS

Programs based on scientific experiments and activities are naturally fit into the general aims of Bátor Tábor. According to my experience and feedbacks from children and volunteers, youths generally are interested in science, we just have to find the right platforms and methods to make it enjoyable. Focusing mainly on physics-based experiments and activities helped me to work out relatively cheap and safe programs within the time frame of 80 or 160 minutes. The most important conclusions from this first series of renewed Magic Wood program is that the playful and supportive social environment opens children's creativity and cooperative attitude, and science thus becomes fun for them. The good indicator of the success of the programs is that a lot of children chose Magic Wood as a facultative program in every session, despite the fact that canoeing, archery or horse-riding were among the alternative possibilities. Further, the management regularly collects feedbacks from the children and the volunteers at the end of the sessions about the camp-life and the programs, and these reports unambiguously confirmed the success of this program.

ACKNOWLEDGMENTS

The author thanks the Bátor Tábor Foundation for initializing the presented innovation and the volunteers for following and mentoring the program. Special thanks to Zsóka Vásárhelyi for correcting my English.

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EXPERIENCES IN TEACHING GAME THEORY IN THE HIGH SCHOOL

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ABSTRACT

Investigations among primary and secondary school students indicated that young people know neither the concepts of game theory, nor its application to different sciences. This motivated us to start teaching game theory at an elementary level for three groups. According to our experiences the students were open and active participants mostly due to their emotional relationship to concrete life situations. In addition to traditional games we discussed some social dilemmas and cooperation-type games. At the end of the course the interest shown by the students and the knowledge acquired by them were analyzed by a questionnaire. In the future a more detailed teaching of game theory is planned in study circles to overcome the limitations of regular courses.

INTRODUCTION

The idea of teaching game theory in high schools has been continuously emerging for several decades due to books [1], [2], [3], [4] and articles emphasizing the importance of the concepts of game theory in the explanation of biological and economical processes and of human behaviour. Despite several promising initiations in Hungary [5], [6], [7] and abroad [8], [9] game theory does not belong to the standard topics in the high schools. Recently this activity is mainly limited to special interest groups.

When planning the teaching process, the importance of the structured knowledge and its relations to other topics (like biology, ethics and social sciences) are taken into consideration. As the distorted latent knowledge elements can prevent the acceptance and the integration of new information [10], [11], [12], [13].

The first impressions indicated that the students' knowledge about game theory is generally poor and incorrect. The quantification of these investigations are detailed in the next section. The subsequent courses of game theory are extended by playing several types of games, meanwhile the student reactions are also quantified by questionnaires. In many cases the introduction of game theory is preceded by a short discussion of decision theory when the students' reactions are investigated. In this work I report on the student's behavior during different "games" and also on their opinion developed by the end of course.

PRELIMINARY KNOWLEDGE

In order to explore students' knowledge about game theory I designed a questionnaire. The first series of questions are related to the concept itself, more precisely, to relationships between game theory and toys, gaming, gambling, role play, round robin games in sports, etc. The second series of questions are addressed to clarify its application/relevance in mathematics, physics, sociology and economics. In the questionnaire the students have to mark “yes” if they find existing connection(s).

These questionnaires were filled by 35 primary school students and 57 high school students. The statistics are shown in Fig.1. Accordingly, the respondents indicated the connections between game theory and concepts related directly to different types of games. All the students found a link between game theory and some branches of mathematics, however, they knew nothing about the application of game theory in biology. At the same time they marked connections to physics, sociology, and economics with a decreasing portion of responders as denoted on the right panel of Fig.1.

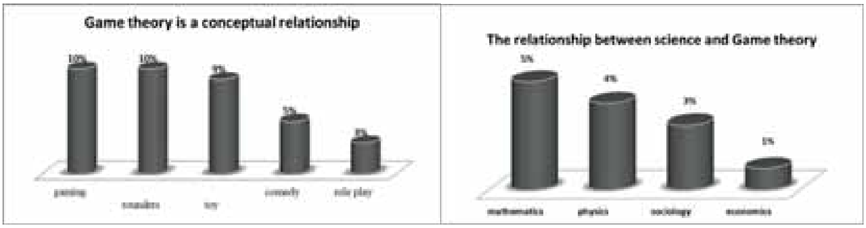


Fig.1. Mapping relationships; Left panel shows the portion of responders who found relationship between game theory and the corresponding items. Right panel illustrates the portions of students marking the connections.

In the interpretation of the above results we should keep in mind that young people have no clear picture of the structure of sciences and the rising importance of multidisciplinarity. It is conjectured that most of the marked connections are denoted by students who are familiar with physics and mathematics. The quantitative analysis of the latter conjecture can give us arguments supporting the importance of teaching natural sciences in high schools.

BEHAVIOR IN A PARTY

The second investigation was performed to study the students’ behaviour when they participate in a party and face the quantification and consequences of their decision.

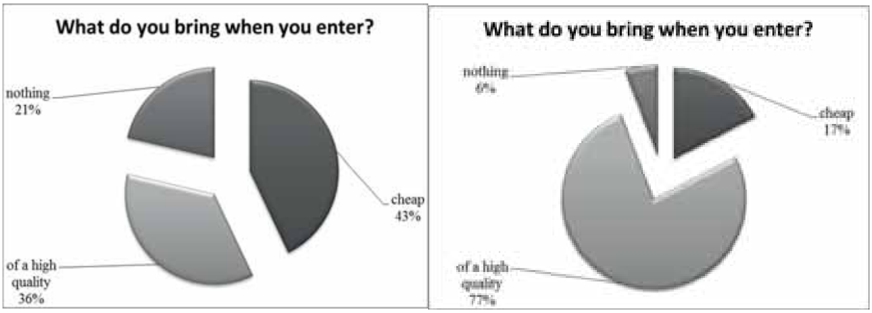
In the basic situation the students have to assume that they are going to a party in which a part of the consumption is covered by the ticket. When showing up the ticket, they can add offerings to the organizers who divide it among all the guests equally. The question was: What do you bring with yourself?

The second situation was similar to the previous one. The only difference is that now the organizers bring your offerings to the table at which you sit, and during the evening they serve the table company with this. The question is the same: What do you bring with yourself?

In both cases three options were distinguished: 1) nothing, 2) cheap, or 3) expensive one. The results in both cases are summarized in Fig.2. The statistical analysis is based on questionnaires filled out by 57 people who received a short time for marking their answer that was not allowed to be modified later.

The left panel of Fig.2. illustrates that students chose the three options with almost equal frequencies in the first case. On the contrary, the portion of altruistic students increased significantly in the second case. Simultaneously, the frequency of parasitic behaviour decreased.

Discussing the students’ choices allowed us to explore the valuations that motivated the students to choose one of the possibilities. At the same time the students recognized the possibility and advantage of systematic and quantitative analysis of situations. This was a fruitful first step in the process of teaching game theory.


What do you bring when you enter?

What do you bring when you enter?

Fig.2. How unselfish young people are? Left panel: first situation; Right panel: second situation

The most important message of the present example is related to the social dilemmas [3], [4] when the individual and common interest dictate opposite choices. Namely, selfishness prefers nothing to any other options while all the members at the same table benefit if they give something to the public goods. The latter choice is enforced by the possible punishments and rewards in the same community during the party. Such situations and methods to maintain the cooperative behaviours are well discussed in the literature of evolutionary game theory [3], [4], [14], [15].

CHEATING

The present situation is adopted from the students' lives in the school when the wrong decision can be avoided routinely by following one of the behavioural schemes developed after a sufficiently long learning procedure that is recorded in the right hemisphere of the human brain [10], [14].

The students are requested to imagine the following situation: Exam is coming and you are not prepared. When you enter the room, a classmate gives you a cheat sheet, which contains his name on it. He asks you to give it back at the end of exam, because he will need it later. If the teacher catches you cheating, he takes it away, and you can continue the work. Each student's dilemma: Are you going to use the cheat sheet?

In the second version of the previous experimental game the basic situation is slightly changed by setting the consequences more serious: If the teacher catches you cheating, he takes the cheat sheet away, and sends you to the director’s room.

The third round contains the prospect of an even more severe punishment. If the teacher catches you cheating, takes it away, and sends you and also the owner of the cheat sheet to the director’s room. In all three situations the students should answer the same question mentioned above. In these analyses 74 people participated and the results are demonstrated in Fig.3.

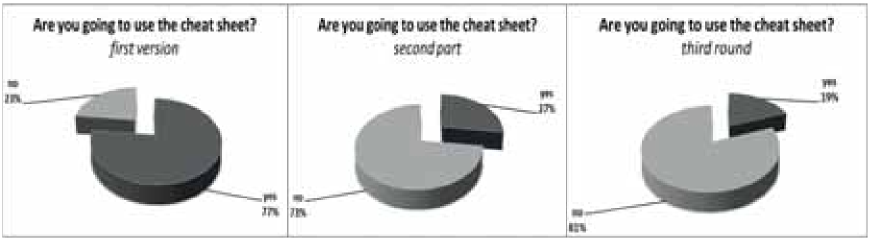


Fig.3. How responsible are young people?

The above results are also consistent with those described in the literature of evolutionary game theory and human behaviour. Recently, for the experimental investigation of the human behaviour, the personal reactions are considered by creating a real-life situation by playing suitable games. Consequently, the spirit and approaches of physics can be well recognized in these multi-disciplinary research fields. Namely, the general laws are approximated by mathematical formulae, mathematical tools are used to extract quantitative consequences and general relationships that are contrasted with experiments.

TALE AND MATH

After playing the above games and discussing their consequences as well as the direct applicability of the results in our every-day problems, the students accepted the relevance of mathematics. Waking up their interest, they become active in learning math. As a result, the students mastered the basic concepts of game theory: players, decisions; possible strategies; decision chart, payoffs, quantification of payoffs, and dilemmas. The possible modes of representation applied: the matrix and graph forms of representation were introduced in normal and extensive games. Examples used in the class prepared for high school students were drawn from book of membership clubs [16].

It is observed that the quantitative investigation of situations in life has improved significantly. Students apply the matrix form with pleasure. Although the analysis of a fable is time-consuming, it is instructive and enjoyable. One example for this is the well-known fable: The fox and the stork. Fig.4. shows the transformation of this tale to the terminology of game theory.

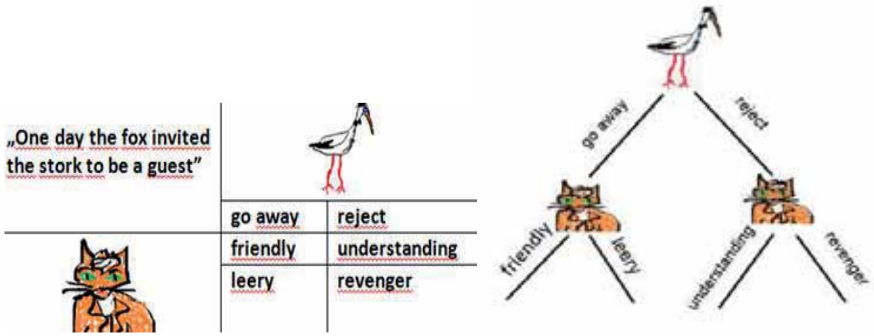


Fig.4. One fable in matrix and graph form

In addition to this advantage, the game theory gives us possibilities to extend their mathematical knowledge.

The group that took part in the survey faithfully reflected the displayed standards of social behaviour. Increasing the penalty appears free-riding dilemma on the game theory [7].

Beyond the present theme for processing I found a lot of other interesting ideas to help the kids in understanding. In lessons the students were involved in real interactions, and then the situations was analysed, interpreted. The life situation affected the teaching and the social relationships, and the analysis of literary works equally [1].

In accordance with the summary measurements the students learned a significant part of the processed topic. Because the durability of knowledge is influenced also by the experience, such processing of science provides a good opportunity for experience-based learning [2]. The topic contains mostly unknown parts. Data processing does not make a significant difference in topic processing.

GENERAL IMPRESSIONS

The reactions of the students demonstrated clearly that they enjoyed the participation in these types of lessons where they were involved in real interactions as well as the subsequent mathematical analysis and interpretation of situations they experienced.

Here I have to mention the reaction of one of the students who participated in these lessons. A participating student told me the following words about the work: *"During this time, we learned how to address certain situations by applying a set of rules. It is noteworthy that these things are "standards", because people often do not consider and decide on their own and others' positions and the opportunities under the current momentary mood. And so perhaps we could be more effective people."*

The above opinion reflects clearly the interest of this young generation in understanding problems related to fairness, cooperation, cheating, and exploitation. They easily understood the necessity of strategies (punishment, reward, reciprocity of both the cooperative and defective strategies in repeated games) that support the maintenance of cooperativity in the human societies.

It was nice to see in the classroom how easily the students applied the game theoretical concepts for the analysis of problems they were deeply involved (e.g., the divorce of their parents).

Depending on the high school's ICT equipment, some tests of simulations could also be implemented. If the students' background knowledge in mathematics are satisfactory, some situation analysis is possible, too. In the good case the social sensitivity of the students changes positively with the help of the tests and concrete examples.

CONCLUSIONS

Teaching game theory in the high schools is enjoyable for both the students and teachers. The combinations of playing games with subsequent mathematical analysis are found to be extremely useful. The students easily learned and applied the basic concepts of game theory.

Additionally a relevant increase in the reputation of the quantitative analysis (in contrary to the hand-waving discussion) is observed. The variations in the viewpoints and opinions of students are accompanied with an improved activity in lessons of mathematics, physics and other natural sciences.

One of the main aims of teaching game theory is to promote the social integration of students by the enforcement of keeping social norms. Recently we are at the beginning of utilizing the concepts and results of game theory in the education in order to increase the level of cooperative behaviour in the human societies.

In the light of the above advantages we wish to continue these efforts. The goals involve improvements in methodology, to find further games and simple mathematical methods that can be studied in high schools.

ACKNOWLEDGMENTS

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GROUP DECISION TAKING, AS VIEWED THROUGH SOCIOPHYSICS

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ABSTRACT

After a short introduction to statistical physics, the Ising model, and its Monte Carlo simulation, we discuss the insight offered by such modelling to decision taking in small social groups.

INTRODUCTION

Sociophysics is a relatively new branch of statistical physics that became a field of active research in the last decades. The name has been given to it by the French physicist Serge Galam, eventually called the "father of sociophysics" [1]. Below we introduce sociophysics through the example of how a community takes some decision; we would like to convince our readers and through them their students, too that a well-chosen physical analogy, in this case the Ising model of magnetic ordering, may offer some unexpectedly interesting insight to such a human game.

We begin with a quick look at the broader physical background. Statistical physics came into being in the second half of the 19th century, as serious indications appeared that matter around us is composed of tiny particles – atoms, molecules – interacting with each other and their environment. Because of their small sizes, all we see as material properties is actually expressing a statistical average of an enormous number of atoms, molecules, or their still smaller components, like electrons in a metal.

By now all that became one of the most extensive fields of physics, describing a wide variety of phenomena, using a huge mathematical apparatus [2]. However, it has a simple core that can be thought in the secondary school, requiring only some acquaintance with the exponential function. Maxwell was the first to calculate the velocity distribution of atoms in an ideal gas, flying around, eventually colliding and exchanging energy and momentum among themselves. That was extended by Boltzmann to the case when the atoms, still statistically independent, are moving under the action of an external force, controlling only the sum of their kinetic and potential energies; he was the first to write down that the probability for an atom to be in a given state (place and speed) depends only on its energy E in that state, and the absolute temperature T, in the form

$$f(E) = \frac{e^{-\frac{E}{kT}}}{Z} \qquad (1)$$

("Boltzmann distribution"), where $k = 1.38 \cdot 10^{-23}$ J/K is the Boltzmann constant, whereas Z is a normalization constant ("partition function"), assuring that the sum of the probabilities of all possible states should be 1 since the system certainly has some state. Looking at the above formula, one sees that matter prefers to be in the states of smaller energy, however, high temperature is against such a statistical selection by energy; everything is determined by the ratio E/kT.

A major step forward was taken by Gibbs who discovered that the above formula refers not only to ideal gases but also to strongly interacting systems; however, then E denotes the energy of the whole system, not just an atom of it. Of course, for statistics to make sense, we have to imagine the system in many copies ("Gibbs ensemble"), or since to actually manufacture or just buy many copies would be too expensive, let it be just one of the copies, but do the same measurement a number of times on it, and evaluate the statistics of the many measurements.

One of the simplest examples for it, the Ising model explaining ferromagnetism, offers good chance to present the satistical physics way of thinking at high school and give it a quick test. Let us take a permanent magnet, e.g. a cube of magnetized iron, and imagine we are able to look inside and see its atoms carrying magnetic spins. According to the model, the magnetization of the iron cube depends on whether these spins are arranged to point in the same direction; those materials are called ferromagnets (iron, cobalt, nickel, and a few insulating crystals), for which that ordering happens spontaneously. It has been discovered by Pierre Curie that on heating up, the spontaneous magnetization decreases, and at a sharply defined temperature ("Curie point") it vanishes.

The source of spontaneous magnetization is the interaction between atomic spins; the simplest model for it, now called Ising model, has been presented in the PhD thesis of Ernst Ising. According to the model, a spin can take just two directions: up or down; for the i-th spin that is described by the number S_i = +1 or -1. The energy E of the system of interacting spins depends on the orientations of all spins, as described by the formula

$$E = -\sum_{\langle i,j\rangle} J_{ij} S_i S_j - H \sum_i S_i \, , \tag{2}$$

where J_{ij} is the coupling between the i-th and j-th spin, H being the external magnetic field. If each J_{ij} is positive (that makes a material ferromagnetic), without external field (H=0) the energy will reach its minimum if all the spins are oriented in the same direction – it doesn't matter which, $S_i S_j$ is positive anyway. That kind of ordering is found by the material, if the temperature is not too high.

As for people, like atoms or their spins, there are a lot of them, and they can be coupled to each other and their environments in various ways. You can call it an analogy between the two kinds of systems, although interactions between people are of course qualitatively different from those between atoms. That cannot stop us from applying the methods of statistical physics to social systems. Of course, human relationships are by far more complex. Social processes are determined by individual as well as collective behaviour. To study the latter, one needs insight into human relationships, a major subject of sociology. Similarly to statistical physics, where one is not interested in individual atoms, just their collective behaviour, sociologists study the collective behaviour of people. In the case of small groups – students in a class, or inhabitants in a condominium – collective behaviour is often dominated by pairwise interactions between people, which gives us a chance to use Ising-type models to get insight into the life of human communities.

Forces exerted by one atom on another depend on the distance between the atoms, as well as some of their physical properties, like electric charge, magnetic moment, or mass. Irregular motion of atoms is characterized by temperature: warming up means faster motion, which disturbs the ordering effect of forces. Analogously, "faster motion" of people means they are subject to many side influences, "they have little time" to pay attention to each other; in collective behaviour that means weaker interaction (weaker communication, less attention); they follow many other things, loosing contact to each other.

The environment influences a system not only through the noise of thermal motion; sometimes it exerts ordering effect on the system. For atoms, that can be an external electromagnetic field or gravity; in ferromagnetic ordering, an external magnetic field. For human communities, that can be a dominant personality, or some special knowledge of a member of the group.

Returning to the example of magnetic ordering, with Equation (2) in view, one can use Equation (1) to calculate the probability of a given configuration of spin orientations; all you need for it is the absolute temperature *T*. Once you know the probabilities, you can calculate mean values (statistical averages), e.g. the mean value of the magnetization $M = \sum_i S_i$ under vanishing magnetic field (*H=0*), and you can check under which critical temperature will the average magnetization be different from zero: that is, the temperature under which spins are oriented in one of the possible directions with high probability, which makes a magnet be a magnet.

If spins are arranged into a one-dimensional chain and only neighbours are coupled by the same positive coefficient *J*, it is easy to calculate everything in simple formulas, as done in Ising's thesis; however, the results are not too exciting. For the case of spins sitting on a two-dimensional lattice, Onsager carried out the same calculation in a horribly complicated way; don't worry if you have never learned how. In three dimensions, there is no solution in the form of closed formulas, however, there are efficient methods of numerical calculations; that is what we propose below for our readers and their students.

COMPUTER SIMULATIONS

Since we want to follow the probabilities of random motions, we use the Monte Carlo method, applying random numbers [3,4]. That general method can be applied by students to obtain interesting results by not too complicated tools. Within the Monte Carlo method, we apply the ingenious Metropolis algorithm that starting from some initial spin values, iteratively visits all spins in a lattice, repeating several times; individually flips a spin or not (see below); after each round calculates the magnetization, and repeats all that until reaching thermal equilibrium, in which – apart from tiny fluctuations – the magnetization does not change any more.

Whether in a given round a given spin flips over or not is decided within the Metropolis algorithm in the following way:

- assuming that the actual state of the spin has flipped from -1 to +1 or from +1 to -1 resp. (according to which state it has been found in), from Equation (2) we calculate the energy change ΔE accompanying the flip, which determines the acceptance probability *W*:

$$W = \begin{cases} 1 & \text{if} \quad \Delta E < 0, \\ e^{-\frac{\Delta E}{kT}} & \text{if} \quad \Delta E \geq 0, \end{cases} \tag{3}$$

- generate a random number between 0 and 1, and decide if we accept the assumed flip or not:

accept if the random number $\leq$ *W*,
reject if the random number $>$ *W*.

The easiest way to illustrate the Metropolis algorithm is through Excel macros written in Visual Basic language. Students can write the program themselves; the results are seen immediately.

Let us take a square lattice of size 25×25, having one spin in each cell. Except those on the boundary, each cell has 4 neighbours, interacting with each of them by the same coupling constant *J,* and not coupled to non-neighbouring cells. The different behaviour of the boundary cells is responsible for surface energy; it is a complication for the calculation that can be avoided by applying a periodic boundary condition, turning the square lattice into a torus. It is easy to build that into the simulation program: the lower and upper boundary lines, as well as the left and right boundary columns, become neighbours to each other; thus each cell has 4 neighbours: the iteration can be carried out under the same conditions for each cell.

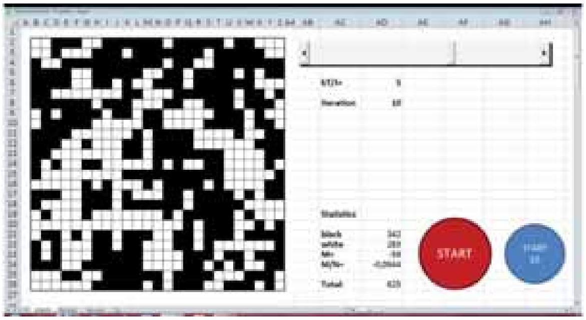

Fig.1. Excel worksheet for the simulation

It is easy to display spin values in each cell by painting the corresponding Excel cells white (*S=+1*) and black (*S=-1*). This simulation is not too fast (painting makes it still slower) but offers students the chance to follow visually as spins keep flipping during the steps of iteration. As output, we evaluate *M*/*N*, where *M* is the total magnetic moment of the square lattice (on the surface of the torus), whereas *N* is the number of cells: *625*. The value of the parameter *kT*/*J* can be changed by a scrollbar; *k* is Boltzmann's constant. As the initial state, we assign a random spin to each cell; spins are updated in each round of iteration according to the Metropolis algorithm (see Figs.1.,2.).

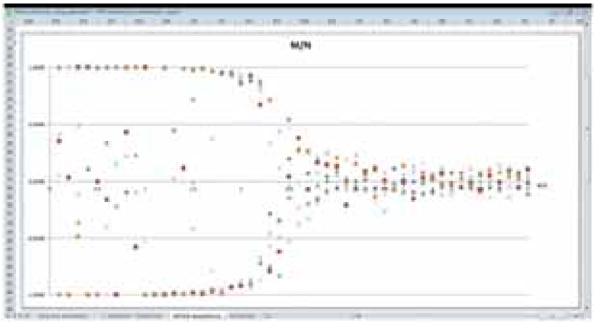

Fig.2. Spontaneous magnetization as a function of temperature, calculated from the Ising model by Monte Carlo method with no external magnetic field (*H=0*) in 7 different runs of 100-step iteration, *kT*/*J* changing from *0.1* to *5.0* in steps *0.1*. The phase transit-ion from ferromagnetic to paramagnetic state is clearly visible; its temperature agrees well with Onsager's prediction for the Curie point, $kT_c/J = 2.27$. Similar calculations can be done with external magnetic field, causing non-zero magnetization for $T > T_c$, too.

THE SOCIOPHYSICAL APPLICATION: COLLECTIVE DECISION TAKING

Now we turn to our main topic: utilizing the model for the study of social systems. We recall that the Ising model can be applied in cases where there are but two options: "yes" and "no", corresponding to "spin up" and "spin down" [5,6]. A convincing collective "yes" or "no" decision would correspond to magnetic ordering.

A simple situation open to Ising-like modeling is this: the community of a school class has to decide whether their next excursion would be directed to a mountain or to a lakeside. They are assumed to decide by majority voting. Any decision is acceptable; no decision would be a trouble.

The basic analogy is clear: if the students pay attention to each other's preferences, it helps them in reaching a decision favourable to many of them. Still, in connecting the case to a ferromagnetic model, to choose the right parameters is the critical step. Majority voting corresponds to measuring magnetization: if +1 point is given for a vote for mountains, -1 for lakeside, the majority outcome is decided by the sign of the sum M. However, for a class of N students, it is the ratio M/N which characterizes how convincing the decision is.

In the magnetic model that depends on the temperature; more exactly, on the ratio kT/J. It is not easy to tell what "sociological parameter" would correspond to that ratio in our decision taking problem. The answer is not unique, so it is worth asking students what they think about it, how should one characterize the strength of the connections among them (e.g. the average number of a student's friends), and the factors detracting their attention from the question to decide (e.g. the number of topics they used to discuss among themselves in a break, or a forthcoming test exam). You may try various suggestions and compare the results. In the model there is one more parameter: the external magnetic field H. In the social case that might correspond to an extra possibility of sporting activity, or a cheap lodging at one of the possible destinations; eventually just the lack of it, which may influence the decision for some or many of the voting students.

Leaving the school, other minor social groups may get into similar situations. An example is a condominium – a house of separate flats, each owned by its inhabitants – where from time to time collective decisions have to be taken. If it is a binary decision, say, there is a hole on the roof: fix it now or save the money and put there a washbasin for some time, you can use an Ising-like model to analyze the situation. Again, the question is how to characterize the strength and character of the human connections, as well as the attention devoted to the particular problem, all influencing the decision. That is a problem of sociology, and physical modeling can help get insight to the outcome of the decision process. Again, there are "external fields": various factors influencing the opinion of each inhabitant.

While encouraging our readers to invent more and more examples of social decision taking, we emphasize the limitations; in particular, larger communities – like a bigger city – can take collective decisions on questions of extreme importance, like communal traffic; however, in questions of minor importance, it would fall into smaller units (districts or even streets) taking their own decisions on the same issue. If you just think how different we people are, it is very surprising to obtain any insight into social problems at all through simple models. A deeper reason for that can be that there is little cross-talk between the levels of organization: chemistry is played by electron clouds, utterly insensitive to fine properties of atomic nuclei; minor chemical differences between people play no role except under the extreme circumstances of transplantation, and in many, many questions of the society, the multiplicity of opinions matters only in the exceptional moments one counts which answer is given by more of us about some deliberately posed question. On occasion, a clever simplification successfully expresses the essential points of what happens, and results in functional models; sometimes – like in the case of failed economical predictions causing small or big collapses through the things omitted from the model – in sour disappointment: the world now and then reminds us that we are adult persons, so we should better not mix up fairy tales with reality. Still, simple models help us surprisingly often to get some orientation about various problems of our narrow or broader human enviroment, and good statistical physics analysis may eventually offer you some help that would be hard to get otherwise.

THE SYMMETRY ISSUE

In the Ising model the interaction is symmetric: spin "*i*" spin acts on spin "*j*" by the same strength J as "*j*" acts on "*i*". Human connections are usually not symmetric. Beyond physics, we have tried the model for asymmetric interaction (its theory is quite complicated, see [7]). We assume coupling *J* to the right and upwards, and *qJ* (*0<q<1*) to the left and downwards. Figure 3. is an illustration; the main property is that magnetization first seems to reach thermal equilibrium, then flips over in a random way. In human decision taking: once a decision seems to be taken, it may turn into the opposite if you keep on discussing.

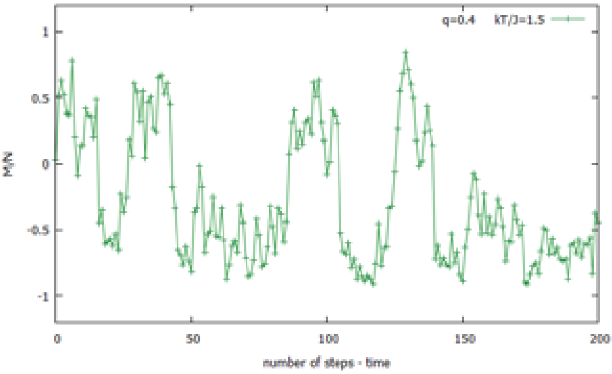

Fig.3. Time dependence of magnetization under asymmetric spin-spin coupling

CONCLUSIONS

Passages between remote fields of science are sometimes surprisingly fruitful, e.g. a lot can be learned about complicated social problems if you use simple physical models. That is the object of the recently opened branch of science called sociophysics. A relatively well clarified part of it is decision taking in small communities, to which one of the emblematic simple models of statistical physics, Ising's model of magnetic ordering, offers interesting insight. The topic can be taught in high school using simple numerical tools. Social phenomena are usually more complicated than the systems studied in physics, therefore attention should be paid to the limitations of a given model; an example is asymmetric coupling.

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ENERGY, FOOD AND SUSTAINABILITY

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ABSTRACT

Food satisfies a basic need of living beings, but in human society it has assumed many other meanings (cultural, social, ritual, etc.). The supplied energy to the human body is trivialized by the indication of the calories on the packaging but it is completely disconnected from the students' scientific knowledge. Some learning path focused on the energy aspects related to food is proposed. Starting with the most obvious ones (how much energy is available to the body by eating some food and how it can be related to the calories listed on the package) the students can explore the most hidden aspects of the topic, such as the energy cost for food processing, packaging, distribution, preparation and consumption. How much fossil fuel was consumed for the production of a portion of spaghetti? The concept of sustainability is introduced and the evaluation of the dietary practices according to this criterion is suggested, helping to form better informed citizens who are more aware about energy sustainability.

INTRODUCTION

The choice of designing learning paths in which energy, food and sustainability are interlaced arises from motivational reasons. Theoretical and empirical studies on the relationship between interest, motivation and learning process are widespread in educational research [1, 2]. From the educational point of view, it is essential to understand how and why students are involved in new topics and such approaches are effective [3-5]. Motivation and interest may facilitate the learning process increasing student involvement both in laboratory and in class discussions. Food plays an important role in students' everyday life, it allows to encounter complex systems and to examine them from an interdisciplinary point of view. Moreover, the intertwinement between energy and food is rarely deepened in school education.

The exploration of energetic aspects tightly related to food enables to design activities in laboratory which are much more interesting for students than the usual ones. Furthermore, energy is a relevant issue in physics and in science education and it can enhance the scientific literacy of people.

The main goal is to introduce to sustainability [6, 7] by using a scientific sight. In nature, when an animal population manages natural resources in an unsustainable way, the final outcome frequently leads to extinction. When a human society makes use of environmental resources in an unsustainable way, the main effect can be its collapse [8].

Since sustainability plays a central role in present and future for human societies, United Nations are promoting the 2030 Agenda for Sustainable Development containing Sustainable Development Goals [9]. In August 2012, UN Secretary-General Ban Ki-moon launched the Sustainable Development Solutions Network (SDSN) to foster a global network to mobilize academia, research institutes, civil society, and the private sector in pursuit of practical solutions for sustainable development. The regional hub for the Mediterranean of the Network is coordinated by the University of Siena [9].

In this context, educational pilot actions were developed in order to promote knowledge in sustainability and they are summerized in the next section. During the implementation, new learning paths in physics and science were developed showing how this topic can be useful for clarifying some relevant disciplinary knots in science education.

These early experiences were reserved to small groups of motivated students and few teachers were involved in laboratory. A relevant outcome was the request of developing learning paths for integrating these issues into ordinary didactic at school. An interdisciplinary learning path, articulated in activites in science and physics laboratories, involved all students of a small high school. The most significant aspects of this experience are reported in the following section. Results and conclusions are presented in the last section.

EDUCATIONAL ACTIONS IN PHYSICS FOR SUSTAINABILITY

Sustainability is an unavoidable issue of citizens' curriculum and scientific literacy, too often used and abused by mass media. It is increasingly present in contemporary society and recurrent in the media, in advertising and in the policy guidelines of organizations such as the EU and the UN. Physics can be useful for clarifying the scientific context in which many relevant issues of real world can be quantified.

Physics education can contribute to introducing sustainability by showing how investigation of the physical world is an unavoidable step in finding sustainable solutions, In particular, many methodologies and skills developed by physicists can be useful. A minimal list in this sense contains at least problem posing [10] and solving in complex situations, technical skills (like measurements, estimates, approximations, modelling) and how to interact in an interdisciplinary context.

Moreover, the Scientific Method is a powerful methodology at the base of physical description of nature and it is central in finding effective solutions in real complex contexts through the iterative process oscillating between hypothesis on which theoretical models are developed and experimental verification in the real physical world.

On the other side, for physics education in secondary school, sustainability can be like a Trojan horse that conveys the interest from everyday reality to scientific concepts, involving the students in new laboratory activities. Moreover, teachers can be engaged in professional empowerment and in active applied physics educational research.

Since 2014, educational activities were designed to introduce the concept of sustainability through meaningful activities in physics education. The main ones are the following:

Summer Schools of Physics [11, 12] briefly presented below,

USiena-Game [13], a match of a competition between 3-5 secondary schools performed at the university on specific themes (Stem cells, Sustainability, Europe). Educational tools designed in this contest were useful for the assessment in other actions,

Fostering best practices in school, supporting teachers in designing and realizing learning paths in physics and sustainability. An example is reported with some details in the next section. In each action one or more educational materials on energy and food were designed and tested with students.

Since 2006, 35-40 students from high school are selected every year to attend a full immersion summer school of physics in Siena countryside (the Pigelleto Natural Reserve or a historical small town, Pienza). The students (age 16-17) are proposed within the National Plan for Science Degree [14] by a network of schools in southern Tuscany. The focus of the summer school is always on physics laboratories, active and cooperative learning, peers communication. The 2014 edition, entitled Physics for sustainability. Science and knowledge for a better world, was focused on energy, food and marine plastic debris. There was an excellent feedback by students and teachers. The edition of this year was entitled Let's measure the world. Physical tools for finding sustainable solutions and reached the same results.

The sustainability was introduced in both summer schools by using analogies for visualizing concepts, for example to distinguish between oversimplifications, sustainable situations near to a breaking point, stable sustainability subject to changes in boundary conditions that can destroy it and finally to a sustainability based to natural laws and active practices (see Fig.l.)

Fig.1. Different types of sustainable situations are visualized by using the analogy of a system in stable or unstable equilibrium in gravitational field in various situations.

As example of activity, a laboratory on problem posing and solving is presented. The initial problem was to estimate a physical quantity in a real context relevant for the theme, then it had to be modelled, approximated, checked and the model had to be refined. Are there hidden variables? Which experiments can be performed for validating or confuting the hypotheses? Is the scale factor relevant? Search for problems related to the theme in local, intermediate and macroscopic scales. Is it possible to find sensible solutions? Which action could mitigate the actual unsustainable situation by involving my family and my friends? Or the whole school, or which other community can make the difference by assuming a responsible behaviour? The students discussed for choosing the problem and assess the physical impact. Is the proposed solution significant, economically viable, socially acceptable? Some teachers attending the summer school suggested to realize a learning path on food, energy and sustainability in their school for all students.

A PILOT IN A SECONDARY SCHOOL

An interdisciplinary learning path was designed and realized in a small high school (50 students aged 14-18, two physics teachers and a science teacher, a lab technician) in collaboration with the university.

The starting point was that the supplied energy to the human body by some food is usually trivialized by the indication of the calories on the packaging but it is completely disconnected from the students' scientific knowledge. Activities were introduced by open questions like: How much energy is available to the body by eating a portion of food and what is the relationship with the calories listed on the package? How much energy is needed for food processing, packaging, distribution, preparation and consumption? How much fossil fuel was consumed for the production of a portion of spaghetti? Or a banana? Can we measure these energies in laboratory or estimate them by looking for information in database or elsewhere? Is my favourite menu sustainable? What is its carbon or water footprint? The answers were searched by a preliminary discussion in class and followed by activities of problem posing and solving and/or through experimental activities in laboratory.

A science laboratory in which a device designed by students (see Fig.2.) was realised for measuring the calorie content of small quantities of an aliment. The apparatus consists of a metal support for the food, the combustion is initiated by a piezoelectric gas lighter away from the test tube in which there was a known amount of water. The measurings of the burned mass, the initial and final temperatures of the water allowed to estimate the calories in the food. Discussion on the results obtained by different groups for the some kind of food clarified that the apparatus gave only an estimate and not a quantitative result. On the other hand, a qualitative analysis for different food outlined a relevant boundary condition for the following measurements: the humidity.

Fig.2. Left panel: the experimental apparatus for evaluating the calories of foods made in the science lab, where a student was starting the combustion. Right panel: the apparatus during the combustion.

Since the beginning of the last century [15], calories in foods are measured by using a bomb calorimeter [16] to carry out the complete combustion of a solid or liquid substance in the presence of excess oxygen. The combustion reaction is initiated with electrical ignition. This type of constant-volume calorimeter, shown in Fig.3. on the left, consists of a small cup to contain the sample, oxygen (pressure 20-30 atm), a stainless steel bomb, water, a stirrer, a thermometer, a Dewar flask or an insulating container (to prevent heat flow from the calorimeter to the surroundings) and ignition circuit connected to the bomb.

The teachers and the technician soon agreed that this apparatus was not safe to use in an educational laboratory and too expensive. Thus, a modified bomb, shown in Fig.3. on the right, was designed, realized and tested by the university group.

In the modified bomb calorimeter, food samples are partially burned in a metal cylinder, immersed in a mixing calorimeter with water [17]. A constant flux of compressed air allows combustion, blasting hot flue gases through the water. The food sample is wetted by a small quantity of alcohol whose vapour is ignited by electric wires.

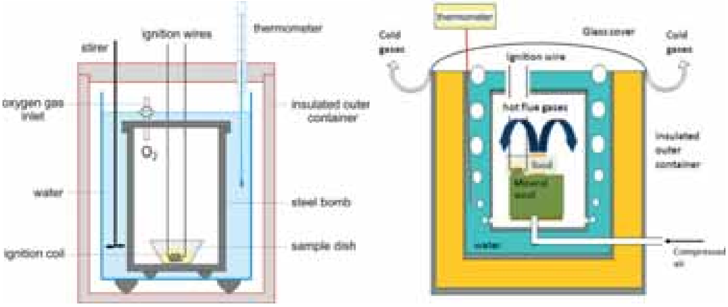

Fig.3. Left panel: Section view of a bomb calorimeter [18].
Right panel: The modified bomb calorimeter.

The heat balance is described by

$$\sum_i Q_i = Q_s + Q_{ign} + Q_{cal} = \Delta mX + Q_{ign} + C(T_{in} - T_{eq}) = 0. \qquad (1)$$

where Q_s is the heat generated by the combustion of the sample, Q_{ign} the heat from ignition (electrical energy and heat from alcohol's combustion), Q_{cal} the heat exchanged by the calorimeter, Δm is the burned mass, X allows to determine calories content, T_{in} and T_{eq} are the initial and final temperature of the water in the calorimeter, and C is the heat capacity of the calorimeter, determined by a calibration and usually referred as its "water value". The heat generated by ignition was determined by a series of measures with no samples, the electrical energy necessary for starting ignition resulted negligible while the contribution from alcohol's combustion was been determined. The new device (Fig.4.) allows to obtain full reproducibility in measurements and quantities are in good agreement with calories in database.

The learning path shows clearly that the science lab is focused on qualitative observations (useful and good for distinguishing the main contents of food, in terms of lipids, sugars and proteins). In school practice, a science teacher never proposes to estimate uncertainties or compare measured calories with food nutrient database. On the other hand, a physics lab is focused on quantitative measurements, uncertainties are estimated almost every time. The two devices explore complementary experimental aspects and together give a much deeper insight in natural phenomena.

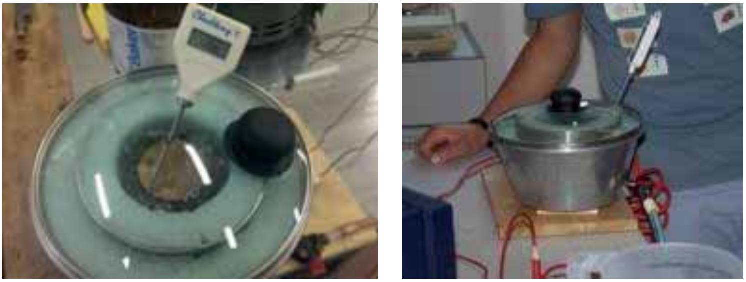

Fig.4. Left panel: Prototype of the modified bomb calorimeter showing the flow of air bubbles in the water. Right panel: the apparatus used by students for a measurement.

CONCLUSIONS

Food and energy are a good choice for introducing students to sustainability. Motivation and interest were enhanced in students and in teachers, too. New paths in laboratory were designed and remained available for curricular education. A clarification in basic topics was achieved, such as differences in estimates and measurements, or in qualitative lab compared to quantitative lab. The main result was the comprehension of the concept of sustainability in this context. All teachers are continuing and expanding these activities in the current year.

ACKNOWLEDGMENTS

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VI. MULTIMEDIA AND ICT

NEW POSSIBILITIES IN PHYSICS ASSIGNMENTS AND IN FACILITATING SOLUTIONS – THE QR CODE

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ABSTRACT

Smart phones offer new opportunities in assigning physics exercises, in experimental illustration of the problem occurring in the exercise or, in making results be descriptively proven. Exercises printed on paper or given electronically can have a QR Code attached. The user will be able – with the help of a QR Code read through a phone – to get immediate access to the desired website. There, depending on the given exercise, we will be able to upload photo or video illustrations, data charts, namely, many exercises can be started based on reality or even, prove correctness of results with a simple phenomenon-presenting video-experiment. The QR Code can also be used to offer our weak-performance students optional help at the critical steps of the complex difficult exercises.

OPPORTUNITIES OF THE QR CODE IN EDUCATION

The QR Code was invented by Japanese programmers in 1994 (it means Quick Response). This two-dimensional grid of dots is based on the idea of the barcode, but can store much more information than the barcode itself. The codes can also be read by smartphones, independently from their screen rotation [1].

Students spend more and more time with their mobile phones. But just like with any common equipment, we can convert our environment with mobile phones, too. However, we need to set objectives.

Application possibilities of QR Codes in teaching:

- To download extra exercises e. g. from the school notice board
- To download auxiliary materials
- For lexical addenda
- To check the results of the exercises
- To download films to support the Physics exercises
- For demonstration purposes

Exercise sets printed on paper are hardly motivating for students. However, the use of mobile phones, even without specific goals causes “functional joy” for them. Touching and pressing the phone screens convey a certain message: “We belong to a newer generation!”. When we use mobile phones in teaching, besides motivating, our goal is to wrap up the appropriate content [2], [3], [4].

How to generate our own QR Code?

Naturally, we do not need to devise this pictorial information incomprehensible for the human brain, because there are QR Code generator programmes (Fig.1.) to conveniently create them. We can find online QR Code managing sites, and there are free downloadable software, too.

Fig.1. The online software transforms the content of the text window into a QR Code [5]

Teachers can easily create QR Codes and direct their students to the sites they choose. In the case of films the free video sharing portal YouTube is readily applicable, and teachers can upload sets of their own films there. They can put small icons in the middle of the QR Codes (Fig.2.) to indicate the content, and with the help of the small signals suitable for classification, students can quickly select from the codes just by viewing them.

Fig.2. There is a water drop in the picture in the middle of the QR Code, which refers to the theme of the movie to be played

Teachers can send messages to the users with the small icons (Fig.3.): e.g. it is a text note, a link, a video film, some photos, or the process of solving the specific problem, or the result can be accessed with the specific code.

Fig.3. The icons can mean e.g. photo, film, lexical data, help, result

Using QR Codes for solving Physics problems

The exercise:

The speed of the clouds was measured with time-lapse technique in an experiment. This means that pictures of the target object are shot at set intervals with fixed camera position. What is the horizontal speed of a cloud rack in km/h if the camera shoots the pictures of the target object every 15 seconds and we know that the cloud covers 400 metres between shooting the 1st picture and the 10th picture? (Fig.4.)

Fig.4. With the help of the codes students can: watch the time-lapse film, have a look at the typical picture of a cloud set, read about the cloud family and the formation of clouds, receive help in solving the problems, or simply double-check their own results.

We can also create multiple-choice questions with humorous drawings (Fig.5.), which can even be uploaded to a blog. QR Codes will direct the students to the exercises on the blog.

Fig.5. The code helps the user get to the exercise which deals with a classical physics problem

The making of QR Code-accessible films to support Physics exercises

I consider it important that solving problems with calculations should not be only of abstract and theoretical importance in the teaching of Physics, but students should feel that exercises present real situations the results of which can be checked experimentally. I have linked films to the exercises with the help of the QR Code. One group of films show the experiments carried out based on the exercises. Another group of films contain the experimental check of the calculated results. This latter can be such a film that shows the control measuring, or students themselves can measure the time with the stopwatch in their own smart phones while watching the film, and if the calculation is correct, then the two results are the same.

Task: Calculate (with the help of the photo, Fig.6.) the speed of the person sitting on the carousel.

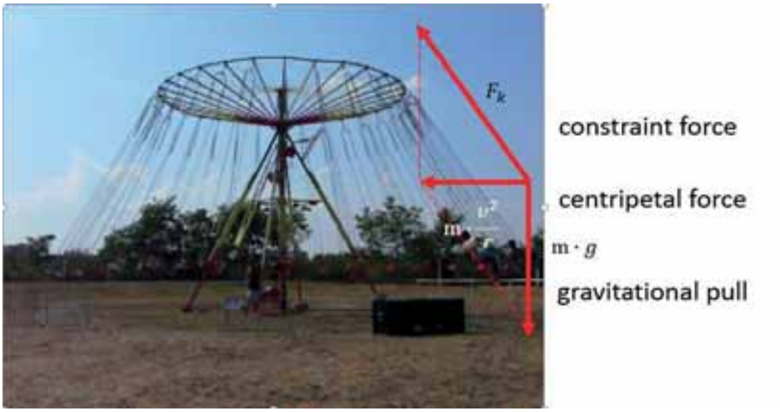
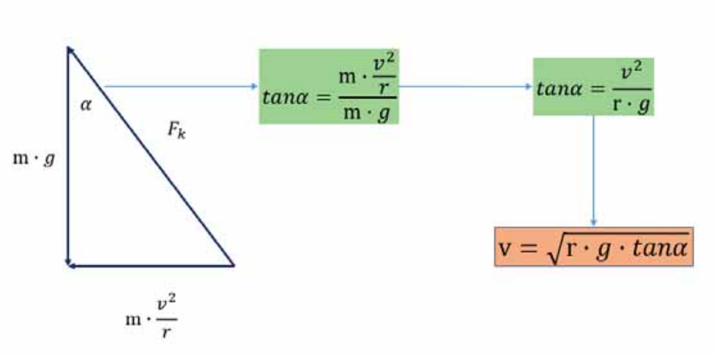


Fig.6. Drawing the forces affecting the person sitting on the carousel into the picture, we can edit a closed vector triangle

The speed can be expressed from the closed right-angled vector triangle:



$$tan\alpha = \frac{m \cdot \frac{v^2}{r}}{m \cdot g}$$

$$tan\alpha = \frac{v^2}{r \cdot g}$$

$$v = \sqrt{r \cdot g \cdot tan\alpha}$$

So we can calculate the speed of the person sitting on the carousel from the radius, the gravitational acceleration and the α angle.

Fig.7. The α angle can be measured with a goniometer, the radius with a pixel bar

To do that, short films would help us, and we can introduce those into our smart phones with the help of the QR Codes seen in Fig.7. The radius can be calculated from the height of the man:

Radius	Man height
293 pixel	54 pixel
r	1.72 m

$$r = \frac{1.72\ m \cdot 293\ pixel}{54\ pixel} = 9.33\ m \tag{1}$$

$$v = \sqrt{r \cdot g \cdot \tan\alpha} = \sqrt{9.33\mathrm{m} \cdot 9.81\frac{m}{s^2} \cdot \tan 36°} = 8.15\frac{m}{s} = 29.34\frac{km}{h} \tag{2}$$

One calculation error is due to perspectival distortion. If we drop a line perpendicular to the plane of a two-dimensional angle through its vertex and have a look at the angle from any point of this perpendicular line, we see the real size of the angle. However, if we look at the angle from any other point, the size of the angle looks different. Since we have looked at the carousel slightly from below, the angle looked bigger than its real size (Fig.8.).

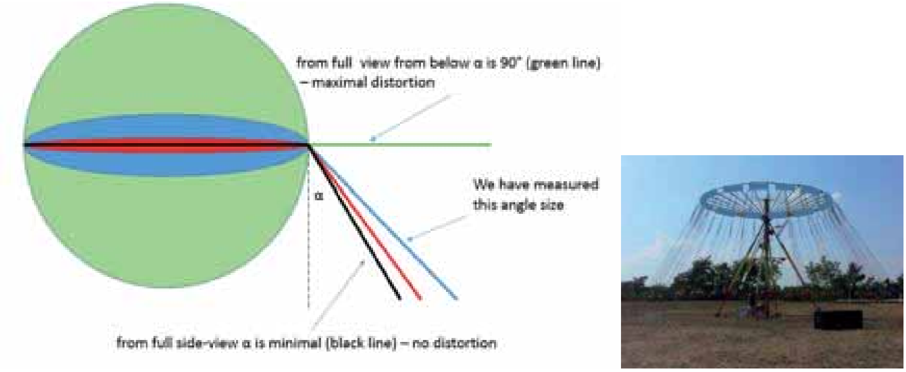


Fig.8. Left panel: the possible angle-value ranges resulting from perspective distortion Right panel: in the picture the carousel is like as seen a bit from the bottom sight

It is clearly seen that the measured angle is greater than the real one, thus we have measured a greater speed, too.

$$v < \sqrt{r \cdot g \cdot \tan\alpha} = \sqrt{9.33\mathrm{m} \cdot 9.81\frac{m}{s^2} \cdot \tan 36°} = 8.15\frac{m}{s} = 29.34\frac{km}{h} \tag{3}$$

$$v < 29.34\frac{km}{h} \tag{4}$$

Double-checking the result with the video

If we dispose of not only a photo but also of a film, then the speed of the person sitting on the carousel can also be defined through another procedure (Fig.9.). This way checking the previous calculation will also become possible.

- Let's measure the period (the measurement will be more accurate if we measure 10 rounds and then divide the result by 10)
- Let's substitute the radius defined earlier in the following formula:

$$v = \frac{2r\pi}{T} \tag{5}$$

$$v = \frac{2r\pi}{T} = \frac{2 \cdot 9.33\, m \cdot 3.14}{7.3s} = 8.03\frac{m}{s} = 28.91\frac{km}{h} \tag{6}$$

Fig.9. The QR Code seen in the picture helps us play the film and - with the help of a chronograph - measure the period time. The short film will also provide the measurements with further necessary information

If we compare it to the value calculated based on Fig.7., see Eq.(4), we get a more accurate smaller value:

$$28.91\frac{km}{h} < 29.34\frac{km}{h} \tag{7}$$

CONCLUSIONS

The QR Code is a popular information carrier surface, its use in education will not only be important in motivating students who use modern technics but also can play a sort of virtual support in individual problem solving. This way the QR Code plays a kind of a mediating role between the teacher and the student.

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5. http://goqr.me/

COMPLEX SMARTPHONE-BASED EXPERIMENT CARRIED OUT BY STUDENTS

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ABSTRACT

Experiments which are carried out by the students themselves play a crucial role in the process of teaching physics. Smartphone includes a number of sensors and the data received from the installed software can be used in the place of various physics laboratory instruments. The mobile phone was thus used to determine the acceleration of different types of movements (damped oscillation, pendulum, circular motion). All measurements were made by applying the "Accelerometer monitor", which can be downloaded free of charge from the internet onto a mobile phone. The project illustrates the most important features of project-based learning in as much as the students were expected to organize the process on their own, meanwhile the teacher acted as a "coach", merely supervising the students' work.

METHODS OF TRACING MOTION

In the process of teaching physics, kinematics is of utmost importance as it, actually, introduces the students into a quantitative approach to physics and makes them acquainted with the overlapping chain of thoughts related to observing, experimenting, measuring, building notions and elaborating theories. It is, therefore, necessary for this process to be grounded on convincing and easily repeatable measurements. By all means, it is not a simple task at all to define experimentally the position of an extended body in motion within a given system of coordinates even though the range of applicable procedures has ceaselessly evolved in the course of time. The rapid development of technology and the turn-out of computers have made fundamental changes in this area. Besides the classic methods – such as air cushion table (Fig.1.), electrostatic track recording, stroboscopy, photo gates with picket fences mounted to carts etc. – new modern techniques, such as laser and sonar based distance detection (e.g. V-Scope, Fig.2.), the GPS and procedures based on video technology (e.g. Videopoint, Webcam Laboratory, Fig.2.) and smartphones have also appeared.

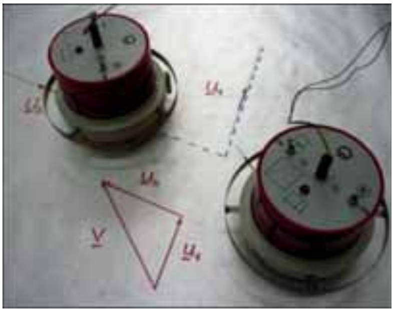

Fig.1. The air cushion table

Some of the aforementioned applications are perfectly suitable for being used by the students either individually or in pairs, maybe even in small group experimenting activities that involve measurements. Nevertheless, we have to highlight the fact that by skipping the principles outlined by the classical methodology of measurement and by switching over to the modern procedures directly, one would surely cause the loss of physical contents.

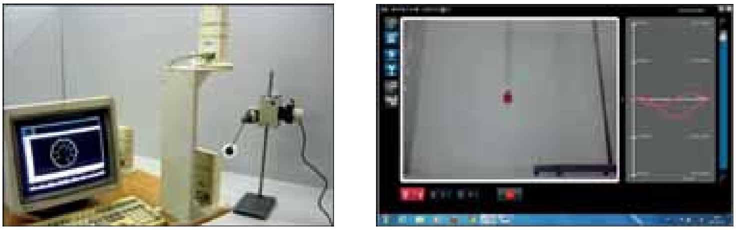

Fig.2. Investigation of circular motion using V-Scope and of an oscillating object with the Webcam Laboratory software

THE CRUCIAL ROLE OF PHYSICS EXPERIMENTS

It has already been acknowledged as a proven fact that the possibility of independently accomplished experimenting in the process of teaching physics is one of the best tools for raising the students' interest and awareness in natural phenomena, as well as the development of natural science-based thinking. Demonstration experiments which are presented by the teacher and experiments carried out by the students (Fig.3.) themselves or in small groups are equally important. What the students see with their own eyes is likely to be better retained in the mind, and thus it could be more easily recalled later and associated with other phenomena. It makes possible for the students to follow the path of researchers and thus grab hold of the basics of natural sciences and, furthermore, to consolidate their theoretical knowledge, to gain experience and to develop their practical skills. Experiments are known as being the "engines" of research - as they are also setting the grounds for the methodology of the teaching process in physics [1].

Fig.3. Student experimentation

Experiments may, of course, be grouped into different categories, and one sub-category that provides the students with the possibility to carry out experiments either individually or in small groups is called *student-centered experimenting*. Actually, this is the most beneficial option as it facilitates the students' activities meanwhile it also turns them from mere observers into active participants of the experimenting process.

THE PROJECT-BASED LEARNING (PBL)

In this paper a project work is presented which was shown at *the second Győr Science Festival* in the Mobilis Science Centre. During the measurement we want to put forward the most important characteristics of *project-based learning*. Project-based teaching, also known as the project-based teaching method is one of the newest and the most up-to-date methods, as the teaching process itself focuses on the students, aiming to develop their competencies necessary for the successful accomplishment of any practical task that they may have to cope with in their daily lives. The most important advantage of the method is that - should they be involved in either individual and/or group-work during the learning process - the students feel highly motivated, meanwhile the teacher becomes the co-ordinator – or, better to say, the moderator of the learning process instead of preserving his/her traditional role. The approach to the task is, therefore, characteristically interdisciplinary. Due to its pragmatism, as well as to the fact that both observation and laboratory experiments motivate its use in the process, project-based teaching is more than adequate for the teaching of natural sciences [2].

“Not a step without my mobile” These words are well-known to all of us. Smartphones and tablets have become organic parts of our lives and 85% of the children aged 12-13 have their own mobile phones. Getting used to them in their early childhood, the very young generation has become a full-time user of the available modern technical devices [3].

The use of digital technologies should receive a more important place in the curricula of various school subjects. Therefore, we have to teach our students that the aforementioned tools can be used for a lot more than just staying in touch with each other on social sites and/or via different chat programs. Quite unfortunately, some of the teachers are still reluctant to use any modern technologies because they either have difficulties in coping with them or they simply cannot find the time to get acquainted with the newly emerging means and methods. However, even these teachers must accept the fact that the new tools have given us exciting possibilities in our classroom activities [3].

The mentioned devices contain many sensors and data processing software that can be used genuinely while teaching physics. Besides the timer and calculator functions available on the older devices, various databases, e.g. the Pocket Physics application (Fig.4.), can be downloaded onto them. One of the most important sensors of any telephone is its microphone, which can be used very well to measure the intensity of the sound depending on distance or to perform the frequency analysis of different sources of sound during physics classes.

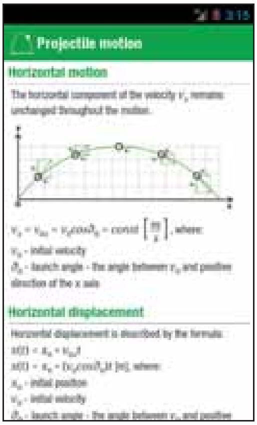

Fig.4. The Pocket Physics application

The already indispensable sensor of the smartphones is the tri-axial accelerometer which can be used to define the tilt of the phone as compared to the direction of gravitational acceleration. Of course, this sensor provides us with an almost infinite number of measurements as there are many applications meant to display graphs or to evaluate the measured data. Therefore, we can determine the measure of acceleration of various objects by attaching the telephone onto a moving body, a vibrating (e.g. a spring) system or a rotating one (e.g. a record player).

As it is rather difficult for the students to follow the measured data on the display of the telephone, it is worthwhile to transfer them, and perform the evaluation either on the monitor of the PC or on a digital board. During small group activities, it is enough to stand around the device or pass it around while analysing the results.

DETERMINING THE LOCATION OF THE ACCELERATION SENSOR OF THE TELEPHONE

The students can examine uniform circular motion in its real environment. A demo of a small-scale acceleration can be performed in the classroom by using a record player (30 cm in diameter). We can use the Accelerometer Monitor android apps, but quite a large number of other applications related to kinematic measurements can be downloaded from the internet free of charge. The sensor provides the values of acceleration along the three axes. Measuring the acceleration of the smartphone in different positions on the record player makes it possible to localise the position of the sensor within the smartphone.

By attaching the smartphone tightly to the record player with a piece of double-sided adhesive tape, we are able to determine the accurate location of the smartphone set in different positions and at various frequencies (Fig.5.).

Fig.5. The record player with the smartphone

We perform the measurement for a limited amount of time and then we stop it, thus having the possibility to read the measured data either on the display of the telephone or on the monitor of a PC - provided previous data transfer, of course. The three curves plotted in Fig.6. show the data related to the speed measured along the axes. The upper curve shows the data measured along the axis perpendicular to the figure (z), namely the value of gravitational acceleration, which we do not make use of presently. The middle curve shows the tangential component triggered during the rotational movement (x), which is now zero due to the steadiness of the rotational movement. The lowest range of data shows the radial component of the acceleration that we are to use subsequently in the course of our measurements (y).

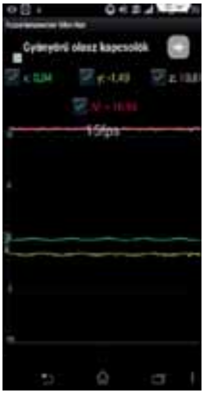

Fig.6. The values of the acceleration

If we know the number of rotations, we can specify the angular speed *ω*. The distance *R* of the revolving sensor from a central axis can be calculated:

$$n = 45\ \frac{1}{min} \qquad f = 0{,}75\ \frac{1}{s}$$

$$\omega = 2\pi f = 4{,}71\ \frac{1}{s}$$

$$R = \frac{a_{cp}}{\omega^2} = \frac{1{,}25\frac{m}{s^2}}{(4{,}71\frac{1}{s})^2} = 0{,}056\ \mathrm{m} = 5{,}6\ \mathrm{cm}$$

The measurement may be performed during extra-curricular programs, too, but by projecting the image of the monitor, we may also perform it during a classroom activity. However, if we make the exact parameters of the mobile phone available, the drawing of the figures may just as well form the matter of homework since the evaluation of the measured data may be done based on the images and by using a simple ruler.

In the course of the project, the children have also measured the acceleration in both the case of damped vibration and oscillation (see Fig.7.). Supported by the measured data, the students may solve several tasks such as finding the spring constant, defining the features of attenuation and calculating the moment of inertia and the resonance frequency. Furthermore, by investigating the "freefall" of the telephone, the students are also given the possibility to measure the local value of the force of gravity.

Fig.7. Acceleration-time graph of the damped oscillation

And, last but not least, we have to mention another great advantage of the smartphones: they are always at hand and their use does not require much previous preparation, just downloading the desired applications.

CONCLUSIONS

Modern technology has a place in the physics classes of high school, however, only when the students have mastered the classical procedures, analysed and plotted different graphs, and performed calculations. It would be a mistake to deprive our students of this experience and of its difficulties. If they can see that they draw a simple distance-time graph with their own hand which normally takes lots of minutes, they will appreciate that it's only a few seconds for a computer program. But the use of computer programs only makes sense if the students understand exactly how the program works and calculates. Therefore we should see that if we switch to the modern procedures without the knowledge of the measurement principle of the classic methods, the procedure loses its physical content. However, with no theoretical knowledge in the field, all of the above methods may be regarded only as simple PC- and/or telephone assisted games.

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COMPUTER-AIDED MEASUREMENT AND SIMULATION USING LABCAMERA AND FIZIKA SOFTWARE IN PHYSICS EDUCATION

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ABSTRACT

Digital transformation of education is an inevitable and a clearly positive process. Use of computers in science education is particularly useful, as it opens new possibilities for teachers in knowledge transfer and experimentation as well as helps students gain deeper understanding of science problems. This paper will show how cutting-edge education technology can be used through a number of practical examples.

INTRODUCTION

All kids are natural born scientists. Even at the very early age of 2-3 years, children tend to be fascinated by the surrounding world. This instinctive curiosity towards natural science often fades away quickly after students start learning science subjects in school. The lack of time for experimenting in the classroom, abstract teaching methods, textbook-based science education often result in the loss of interest in science subjects among children.

LabCamera and Fizika software provide a funny, playful and engaging way for students to carry out substantial scientific exploration at home or in the classroom. Besides providing fun for students, these two software packages enable teachers to carry out spectacular, computer-aided classroom experiments using old instruments or by creating a simulation – this way avoiding the necessity of spending thousands of dollars on the newest data-logging devices [1].

When using these software packages in class, students often do the same experiments in small groups, sharing their results in a discussion session at the end. This way they are encouraged to think creatively, to share their ideas and to develop the art of teamwork.

LABCAMERA

In order to use LabCamera software, all is needed is a simple webcam. Any built-in or USB webcam can be used, there is no need for any special equipment. The software itself is a cross-platform application for Windows, Android and Chrome. LabCamera is a software that is easy to handle: teachers and students can start using it from day zero. In addition to this, it is possible to download a simple manual and over 50 lesson plans from the webpage of Intellisense Zrt [2]. If one is not skilful in carrying out experiments or simply time allowance is tight, it is possible to use pre-recorded videos for further analyzing.

In the following sections we will introduce shortly four of the seven different modules of the program to give an impression about the abundant possibilities the software provides and show how they can be used to improve science classes.

TIME LAPSE MODULE

The Time Lapse function helps students observe and understand better the slow processes in nature, such as the formation and migration of clouds, the growth of plants, etc. The software makes still shots and stitches these images into a coherent stream of video. This video can then be played back or further analyzed in other modules. Depending on the slowness of the observed process, the time interval between subsequent frames can be set to any value between 0.2 seconds and 24 hours.

A typical experiment that can be carried out using this module is the melting of ice cubes (see Fig.1).

Fig.1. Investigating the melting of ice cubes with Time Lapse module

In this experiment images should be captured in 1-2-second intervals. For basic level (primary school) students observing the process is enough fun, but for higher level students it is also possible to carry out different measurements using the recorded time lapse video. One such possibility is to measure the volume of the cube as a function of time.

KINEMATICS MODULE

This module - which offers probably the widest possibilities in carrying out physics experiments - is based on colour recognition. All one needs to do is place a colourful object in the field of view of a webcam and click on the object. This will make the program recognise its colour and follow its motion throughout its movement. The software is capable of capturing a maximum of 3 objects at the same time, allowing for complex kinematics experiments such as collision or coupled pendulums.

Once an object is recognised and followed by the program, selected graphs of the horizontal and vertical components of its motion (displacement, velocity, acceleration) will be displayed on the right of the screen in real time. Such a real time graph situation is shown in Fig.2.

Using the option to visualize more graphs (such as displacement-time and velocity-time graphs) at the same time, it is possible to give students ample experience on the connection between graphs. This helps students gain a better understanding of graphical representation and analyzing, which is one of the toughest parts of the physics syllabus in secondary school.

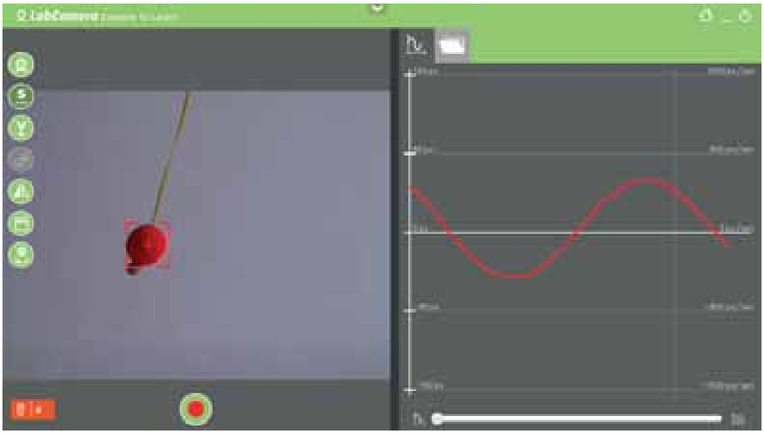

Fig.2. Real-time displacement-time graph of a pendulum, generated in the Kinematics module

A typically good experiment that can be done with this module is the investigation of the connection between uniform circular motion and simple harmonic motion (SHM). This experiment is shown in Fig.3. Since the program graphs the components of a motion, it can be shown quickly that the perpendicular projection of a uniform is an SHM. With higher level students it is also possible to check the formula for maximum velocity and acceleration in an SHM.

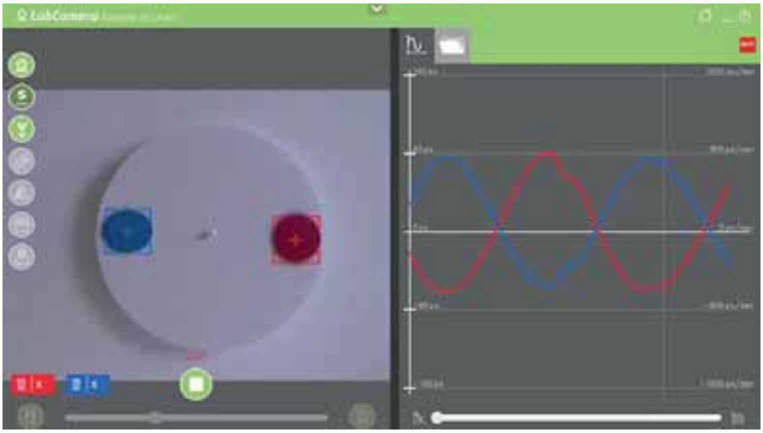

Fig.3. Investigating the components of a uniform circular motion with Kinematics module

A useful option in this module is that in the case of complex investigations, all recorded data can be saved in .csv format and analyzed later (possibly as homework).

There are also additional features, such as background elimination and trail visualization that make Kinematics module an ideal tool to use for observing and investigating various motions, ranging from oscillations to circular motion, collisions and free fall.

MICROSCOPE MODULE

With the help of Microscope module it is possible to explore objects ranging in size from microscopic to astronomic. For best results with this module, a manual focus macro enabled camera is recommended, since this will enable cell level measurement.

Built as a universal measuring tool, the Microscope module enables students to measure distances, angles and areas. Offering the option to load pictures or use a webcam to take a picture, Microscope module can be used to measure objects such as craters on the Moon, buildings, trees or much smaller objects such as sugar crystals, snowflakes or onion cells. Fig.4. shows such possible measurements.

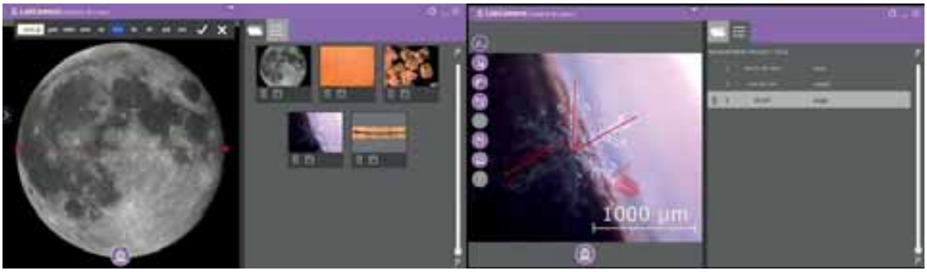

Fig.4. Measuring distances and angles on astronomical and microscopic objects using Microscope module

A typical experiment in physics that can be carried out using this tool is investigating Snell's law. A set of pictures can be loaded in and angles can be measured to collect sufficient data for verifying Snell's law or to measure the refractive index of a given material.

UNIVERSAL LOGGER MODULE

Universal Logger is a unique, real-time data recognition module that can register real-time readings of any instrument that has digital, dial or liquid-in-glass display. All the obsolete measurement devices in school that cannot be connected to a computer can be made useful again with the help of this module. Thus, by simply using this software, schools can save an immense amount of money that would be spent on data-loggers.

Typical instruments - from which data can be obtained - are digital multimeters, liquid-in-glass displays (such as thermometers or simple U-tubes for measuring pressure) and dial displays. The use of these types of instruments is shown below in Fig.5.

Fig.5. Instruments from which data can be logged into a computer with the help of Universal logger module

A typical experiment that can be carried out using this module is investigation of a battery. Once the digital multimeters that measure current and potential difference are calibrated in the program, it takes only 1 minute to carry out the experiment and collect sufficient data. Furthermore, since data can be saved and further manipulated, it takes a few further minutes to graph potential difference against current or power against resistance with a few clicks.

There are 3 more modules (Motion cam, Path finder and Graph challenge) that offer further possibilities in science education, but due to the lack of space we will leave it to the reader to explore those using the website of the software [3].

FIZIKA SOFTWARE

Fizika is a simulation program that models physical processes in an interactive way. It enables students to use preloaded objects or just draw on the screen to create scenes and experiments, then press the play button to get them in motion. One example of such a complex drawing is shown in Fig.6. In this case the consequence of travelling in a car without seatbelts on is illustrated. The wheels of cars are driven by engines and as the cars collide into the walls, the passenger without seatbelts will continue its motion and fly out of the car.

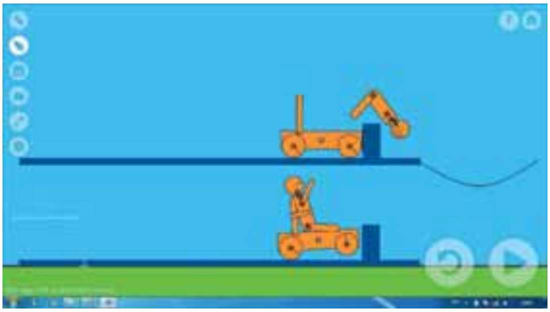

Fig.6. Simulation screen showing a collision with and without seatbelts on

Once a simulation is set up, it is possible to change the properties of the objects by just one click. This way a whole set of experiments can be carried out effortlessly.

Fizika (similarly to LabCamera) offers a real-time graphing option. If a marker is set on an object, it measures the motion of the given object (displacement, velocity, acceleration) and displays it in real-time.

It is possible to change between displacement-time, velocity-time and acceleration-time graphs with just one click, which provides a perfect opportunity for comparing and analyzing graphs. Furthermore, the data obtained in a given simulation can be saved in .csv format and can be analyzed later. Fig.7. shows a simulation screen with the graphs displayed in real time.

Another important feature of this software is that the reference system can be set to any stationary point or even onto a moving object. Fig.8. illustrates how the displacement-time graph changes if the reference system is set to one of the moving cars.

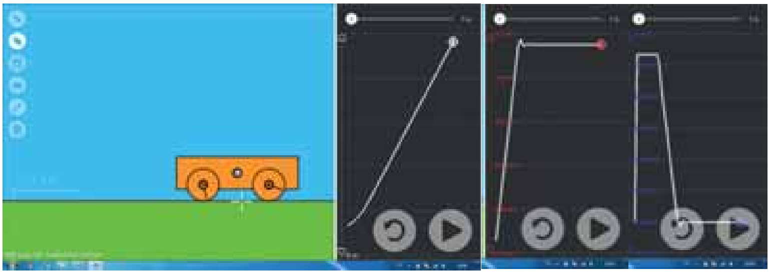

Fig.7. Simulation screen of Fizika. Distance-time, velocity-time and acceleration-time graphs are displayed in the case of a starting car

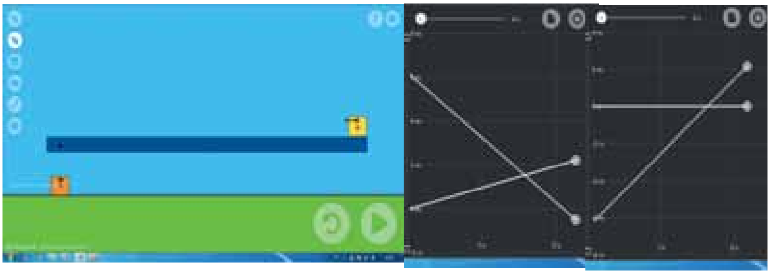

Fig.8. The effect of changing the reference system. The displacement-time graph on the left is measured from a stationary reference system, while the graph on the right is measured from a system fixed to the yellow box

Typical experiments that are recommended to be carried out using this software are the ones which are too complicated to set up in real life or the ones in which the effect of a parameter is investigated, but the parameter can not be easily changed in real life. A good example is the investigation of the effect of the coefficient of friction on the starting of a car.

Further details about this software can be found on the website of the program [4]. A study on the results of a teaching experiment investigating the effectiveness of using Fizika is also available on the website or in this volume [5]. Lesson plans for using Fizika can also be downloaded from “resources” [2].

THE IST PROGRAM

The “Intellisense for Science Teachers” Programme (IST) was called to life to build and support a community of passionate science teachers through creating, sharing exciting science education materials. It provides free software of LabCamera and Fizika for every science teacher in the world and also downloadable materials such as lesson plans and videos. We do encourage every physics teacher to sign up for a free copy and enjoy using these software.

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A SIMULATION-BASED TEACHING EXPERIMENT

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ABSTRACT

In the academic year 2014-2015 several schools from different parts of Hungary took part in a teaching experiment. The experiment was based on simulation program FIZIKA. The program can be used to simulate mechanics problems, and has an option which enables users to visualise and analyse different graphs of the simulated motions quantitatively. In the teaching experiment our aim was to investigate the efficiency of using this program. We wanted to see whether graphical visualisation and analysing helps students to improve their creativity and to develop a better understanding of the basic concepts and theorems of mechanics.

INTRODUCTION

There are many physics teachers all around the world who seek new methods of teaching their subject [1-3]. Conferences are held and experiments are carried out to improve the success of teaching physics. It’s obviously not possible to find a perfect method that will solve all the problems we struggle with, but small improvements can be made step by step. Our teaching experiment was hopefully one of these steps.

PROBLEMS IN TEACHING PHYSICS

In Hungary the main problem we face when teaching physics is short time allowance [4]. Students learn physics during 3 years in only 2 periods of 45 minutes. Although the time is very short, the syllabus is wide and almost impossible to cover.

Unfortunately this leads straight to the problem of lack of experimenting. Although experimenting is the soul of physics, it takes a long time and with such a small amount of time we can’t afford to spend much with experiments. This is why we try to concentrate more and more on computer based experiments that are quick and easy to carry out.

Another problem – that probably arises from the limited number of methods taught in problem solving- is the lack of creativity of students when encountering a new problem. Since there isn’t too much time for teaching a given part of the syllabus, problem solving usually means solving simple exercises. This generates an unfortunate attitude in most of the students: they try to survive physics by solving these simple exercises with a simple mathematical knowledge. All they need is a formula that contains quantities that are given and hopefully only one unknown which is ideally the quantity in question.

In order to change this, we have to challenge the students with problems in which they have to develop a new method of solution, but according to our experiences very few students are ready to accept the challenge – most of them would just give it up at first sight.

An especially problematic part is the graphical representation of motions. A lot of our students can’t cope with graphs simply because there’s too much data in them and they get stuck, because their well developed method of substituting into a formula will not work. This is why we wanted to use a program that saves time for as and at the same time helps students to develop a better understanding of graphs.

A FEW WORDS ABOUT FIZIKA SIMULATION PROGRAM

The question arises: which program should we use? There are many available at low prices or free and therefore it's not easy to choose. I am personally not a great fan of simulations but was convinced about its advantages during this experiment.

The main difference between FIZIKA and the many downloadable simple simulations is that FIZIKA is not a ready-made simulation in which only a few parameters can be changed. It's a program in which it is possible to draw objects (with variable parameters) and therefore set up infinitely many situations and then see what happens. The program in the background solves differential equations to calculate the motion of objects and visualizes the results, which means that we will see the outcome of a given setup as a movie showing the motions of all objects. Although the part of the program that does the calculation is not available for further analysis and the whole program is still under continuous development, about 50 already existing simulations show that the results are reliable enough to be used in high school physics.

It's very important that students establish a relationship between the results of real experiments and their simulation based versions, so that they understand that simulations run in FIZIKA are not simple movies, but give back the results of the real experiments. Therefore it's essential to carry out a few simple experiments (such as dropping a ball) both ways. This way the program gains credit in the eyes of the students and therefore can later be used to investigate more complex situations.

I myself use it in my classroom as a short introduction to a new phenomenon or as a full investigation of a given motion – usually concentrating on graphs. I find this a powerful tool to help the understanding of graphical representation (also the connection between different graphs) and graphical analysis.

THE TEACHING EXPERIMENT IN NUMBERS

The experiment was carried out with the participation of 5 different schools in the academic year 2014-2015. Teachers were asked to volunteer only if they had two parallel groups in which they taught physics, to ensure that we would have the possibility to compare the results with control groups. This way altogether 163 students participated, 80 of them being in the experimental groups.

Teachers got free access to the program for both themselves and their students and were also provided ready-made simulations made by András Juhász and Péter Jenei of ELTE. Although they were encouraged to make their own simulations whenever necessary, it was rarely done due to lack of time. There were also free-access worksheets that proved very useful (from the feedback of the teachers). All these were only used in the experimental groups, while in the control groups the teachers followed the national syllabus.

The part of syllabus taught was kinematics that contained uniform and uniformly accelerated motions along a straight line, free-fall, vertical and horizontal projection. Teaching this part took about 3 months in average (from September to end of November), but it slightly varied between different schools. After finishing kinematics, teachers were asked to make the students write the same end of topic test both in the experimental and in the control groups. The test was therefore the same for all 163 students and we used the results to compare their achievements and to draw conclusions.

EXAMPLE OF A WORKSHEET

To make the reader understand the nature of the simulations and worksheets it's essential to show an example. We will now look at a very simple simulation and at the worksheet connected to it.

In this simulation the concept of average speed was to be practiced. After starting the simulation a car driven by a motor starts to move. While the simulation keeps running it is possible to increase the number of revolutions of the wheels, this way increasing the speed of the car (see Fig.1). Thus we will have a motion in which there are two sections with two different speeds.

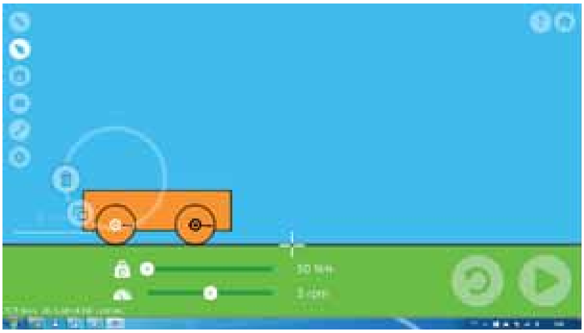
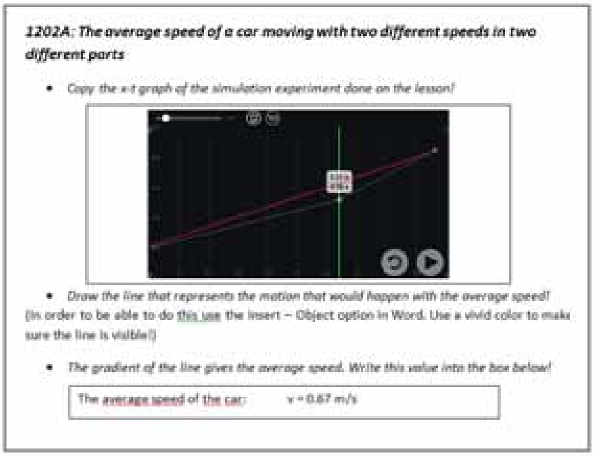


Fig.1. Simulation screen: a simple rear-wheel-drive car. The number of revolutions per minute of the rear wheel can be changed by the bottom slider

The most useful part of FIZIKA is that it can draw various graphs of the motion simulated. This can be used to analyze graphs and also to change between graphs easily and illustrate the relationships, which is typically a very complicated task for the students without such a program. In the first part of the worksheet (shown by Fig.2.) students were asked to copy the horizontal position vs. time (x-t) graph into the space provided (by simply using PrintScreen). The students were then asked to draw a straight line that would represent a motion happening at the average speed (see red segment).



1202A: The average speed of a car moving with two different speeds in two different parts

- *Copy the x-t graph of the simulation experiment done on the lesson!*
- *Draw the line that represents the motion that would happen with the average speed!*

(In order to be able to do this use the Insert – Object option in Word. Use a vivid color to make sure the line is visible!)

- *The gradient of the line gives the average speed. Write this value into the box below!*

The average speed of the car: v = 0.67 m/s

Fig.2. Worksheet on average speed – part 1

The second part of the worksheet concentrated on the velocity-time graph of the motion. Here students had to draw the line representing the motion with the average speed again, and also had to check that the distance covered calculated as the area under the graph equals the distance that can be read from the x-t graph. This way the concepts of average speed and relationship between v-t and x-t graph were practiced.

Probably the biggest gain of working with such worksheets was that students had to take an active part in solving the problem and therefore learnt much more from it than from a simple theoretical lecture.

END OF TOPIC TEST

The test was designed according to the general expectations of the syllabus, no exercises were used that had a direct connection with the simulation program. This was done so to make sure students in the experimental group didn’t get an advantage to those studying in the control groups.

Exercises varied from easy to hard and traditional to non-traditional. Fig.3. and 4. show two examples from these exercises.

The problem in Fig.3. was quite a traditional exercise in which the ability to establish a relationship between graphs was checked. In part a) an x-t graph was given and a v-t graph had to be drawn, which means that students had to calculate slopes to get the magnitudes of velocities. In part b) a relationship in the opposite direction had to be used, the distances covered in two different parts of the motion had to be calculated and drawn using that the distance covered is the area under the v-t graph.

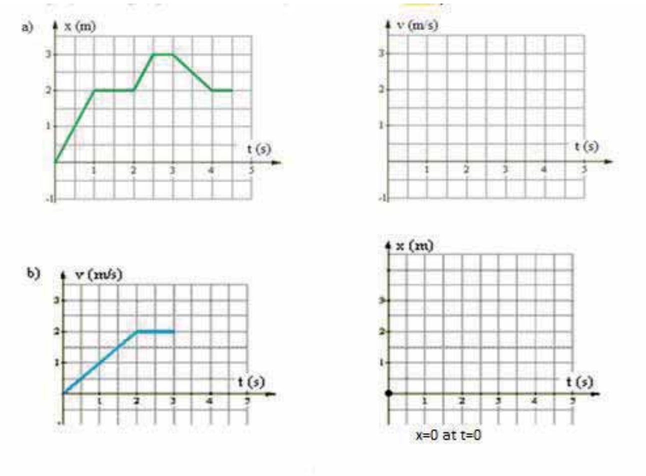


Fig.3. Exercise 3 of the end-of-topic test based on relationship between x-t and v-t graphs

With this exercise we wanted to test our assumption that students who solved several similar tasks while using the simulation program gained a deeper understanding of this type of problem. The results verified our assumptions. The experimental groups reached a better result (63%) with a significant difference (control groups reached 37%).

The exercise shown in Fig.4. is a very unusual exercise compared to normal school exercises. A photo is given with only one additional data: the height of the girl second from the left is 170cm.

Fig.4. Exercise 6 of the end of topic test

Using this information and a ruler students were expected to answer the following questions:

a) How long before taking the second picture did the girl, who is second from the left jump from the bridge?

b) How long did the person on the left took to jump after the girl jumped next to him?

In order to be able to carry out the calculations, students first needed to measure different distances on the photo and then had to use the data given to convert their measurements into real distances. Here we wanted to test whether individual work with the simulation program helped and encouraged students to become more creative in problem solving.

The results verified our assumptions. Although it was clear that students did find this exercise difficult, in the experimental groups more students started to solve it and reached better results. (Fewer students got 0 points and the number of students getting maximum points in the experimental groups was about the double of that in the control groups.)

The overall result of the test (see Fig.5.) was more convincing than what we expected. Students in the experimental groups reached better results in all of the exercises, however the difference is not very significant in the easiest exercises.

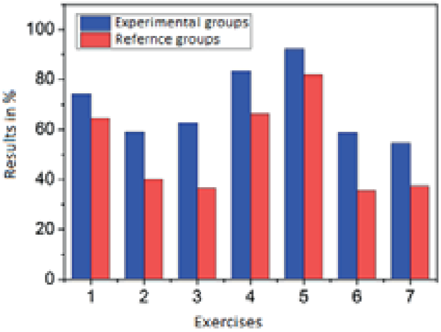


Fig.5. Average result of the end-of-topic test

CONCLUSIONS

By comparing the test results of the two groups we concluded that our hypothesis – that this new computer-based method and in particular quantitative graphical analysis and problem solving tasks connected to several simulations might help the students deepen their understanding in different aspects of the syllabus such as graph-analyzing, graph-plotting, and using graphs in problem solving – seemed to be correct.

The fact that students see and evaluate lots of graphs and get used to new types of problems and thus improve their self-confidence is a clear advantage of this program.

Since this experiment was executed in a small number of schools with relatively few students, we handle these results as possible conclusions giving information for further experiments.

ACKNOWLEDGMENTS

I would like to thank András Juhász for his patience in working with me and for producing many well-designed simulations and worksheets together with Péter Jenei. We also say thanks to all the teachers who participated in the experiment sacrificing their own energy and time. We are very grateful for their immense amount of work and their valuable feedback.

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THE SLEDGE PROJECT

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ABSTRACT

"Why is it easier to pull a sledge horizontally than up a slope?" It is a well-known question often asked by physics teachers. This is an issue in the classroom when we analyze friction and motion on a slope. The answer is simple; at least it seems to be. Our little group made a deeper study of the question. We did a Newtonian analysis by giving the equations of motion. This led us to a function of two variables. The analysis of this function goes beyond the secondary school curriculum. We numerically analyzed it with a program written in C++. We measured typical tilt angles of sledging hills and typical friction coefficient values of snow-sledge surfaces. "It is easier to pull something on level ground than up a slope." Is this statement generally or exclusively true in the case of specific conditions?

INTRODUCTION

While travelling home from a physics competition with eager students, we discussed some issues that arose during the event. A well-known question came into our focus: "Why is it easier to pull a sledge horizontally than to pull it on a slope upwards?" (Fig.1.)

Fig.1. Pulling a sledge

Some of the students paid special attention to the problem and showed interest to participate in a deeper study. I chose the Aristotelian (often called peripatetic) way of education to mentor or guide this little group. It is a teaching method that roots in the ancient times and points towards Inquiry Based Learning. This method builds on the students' skills, also reinforces these. It is open between subjects. It supports inductive teaching, gives an active and constructivist approach of learning. It is one of the most motivating and effective ways of education, it also matches best the age characteristics of the high school students. Our group achieved surprising results in the study.

A STUDY OF THE TYPICAL QUALITATIVE ANSWERS

We met answers in the Hungarian literature of physics competitions and methodology that are similar to this reasoning: "In both cases we need to exert a force against friction, plus on the slope we must exert force against a component of gravity as well." The problem is as follows: We agree that the force against gravity is an increasing value as the tilt angle of the slope is increasing, whereas the force against friction is a decreasing one. When we add up these two, the sum is not necessarily an increasing function.

Some of the answers we read are similar to this: “Besides energy dissipated in friction, extra mechanical work must be done to give “height”/ “positional”/ “potential”/ “gravitational” energy.” When talking about an “easier pull”, we associate it with forces rather than with energy. Work, energy, and force are different notions. If we want to make a connection, we need to study distance as well.

THE NEWTONIAN ANALYSIS

We used Newton’s laws, which are also well known as basics of classical dynamics for the theoretical analysis of the case. Our solution is often studied also in upper secondary physics courses. We apply the standard notation of dynamics and use the symbols F, m, a, μ, α, etc. Quantities characterizing pull on a horizontal surface are marked by *. Vectors are set in bold.

Based on Newton’s 2nd law the force needed for a uniform motion…

… in case of horizontal pull is as follows:

$$*\boldsymbol{F}_{\text{pull}} = -*\boldsymbol{F}_{\text{friction}} \tag{1}$$

since

$$\sum * \boldsymbol{F} = 0\,, \tag{2}$$

so

$$*\boldsymbol{F}_{\text{pull}} = \mu \cdot m \cdot g \tag{3}$$

… in case of pulling up on a slope (see Fig.2.) is as discussed below:

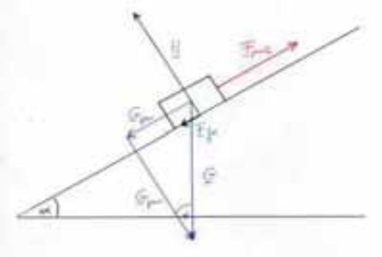

Fig.2. Study of forces on a slope

Newton’s 2nd law is a law of vectors. Often we need to use two simultaneous equations for the components. These are for the components parallel and perpendicular to the surface of the slope. The + directions are perpendicularly away from the surface of the slope, and crosswise up.

- Studying the components perpendicular to the surface provides **H**, the force that is exerted by the slope

$$\mathbf{H} = -\mathbf{G}_{\text{perpendicular}} \tag{4}$$

therefore

$$\mathrm{H} = \mathrm{m} \cdot \mathrm{g} \cdot \cos\alpha \tag{5}$$

- So we can calculate friction

$$\mathrm{F}_{\text{friction}} = \mu \cdot \mathrm{H} \tag{6}$$

so

$$\mathrm{F}_{\text{friction}} = \mu \cdot \mathrm{m} \cdot \mathrm{g} \cdot \cos\alpha \tag{7}$$

- The parallel component of gravity can be given as

$$\mathbf{L} = -\mathbf{G}_{\mathbf{parallel}} \tag{8}$$

that means

$$L = m \cdot g \cdot \sin\alpha \tag{9}$$

Based on Newton’s 2nd law the force of pull is

$$\mathbf{F}_{\mathbf{pull}} - \mathbf{F}_{\mathbf{friction}} - \mathbf{L} = \mathbf{0} \tag{10}$$

which gives us that

$$F_{pull} = \mu \cdot m \cdot g \cdot \cos\alpha + m \cdot g \cdot \sin\alpha \tag{11}$$

$$F_{pull} = m \cdot g \cdot (\mu \cdot \cos\alpha + \sin\alpha) \tag{12}$$

To compare the force of pull in these cases we form a function

$$\psi = F_{pull} - {}^{*}F_{pull} \tag{13}$$

We receive that

$$\psi = m \cdot g \cdot (\mu \cdot \cos\alpha + \sin\alpha - \mu)\,. \tag{14}$$

If we study the sgnψ function, we can figure out whether our original statement is true or false. We need to face a problem: analysing a function like sgnψ is not in the secondary school curriculum. A few decades ago we could not have coped with this analytical task.

NUMERICAL ANALYSIS, A STUDY OF THE SGN Ψ FUNCTION

Two of the students participating in the project were senior students of a secondary IT software course at the time. Relying on their choice we wrote a programme in C++ using SDL, which works in 1000x180 pixels [1]. Since $0^{\circ} \leq \alpha \leq 90^{\circ}$, on the vertical axis we can easily represent the tilt angle, α if $1^{\circ}=2$ pixels. So, on the horizontal axis we can represent μ. With a multiplier we can adjust the maximum value to what we want to study. Our programme works in two cycles. This means 90,000 data pairs to calculate with. We presented the results according to our purpose in a colour code (see Table 1.)

Table 1. Colour code

Pull on slope	Pull on level ground (*)	sgnψ	Colour code
bigger	smaller	+	red
smaller	bigger	-	blue

We were very excited to see the results. If a blue area appears, it means that the original statement is not necessarily true in all circumstances. Our results in the numerical analysis:

1) For all possible angles, if $0 \leq \mu \leq 0.25$ see Fig.3.

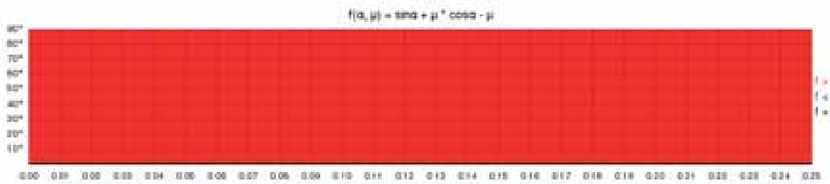

Fig.3. Sign for small μ values

2) For all possible angles, if $0 \leq \mu \leq 2.5$ we present Fig.4.

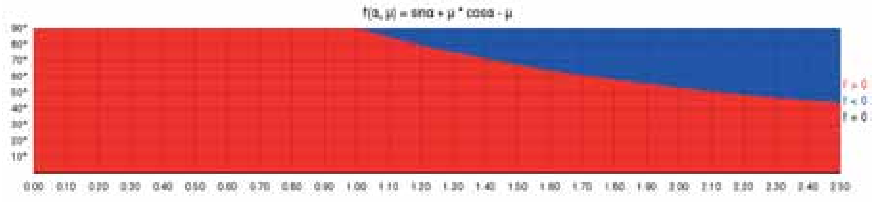

Fig.4. Sign for bigger μ values

3) For all possible angles, we allowed μ up to 50, you can check Fig.5.

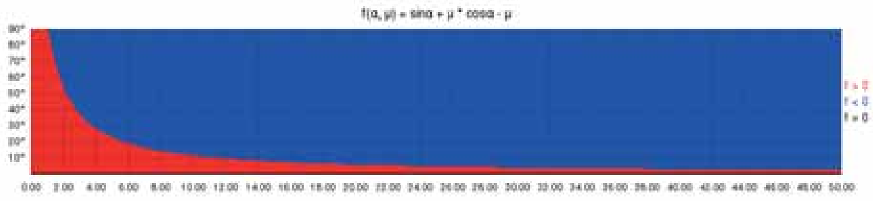

Fig.5. Sign up to extreme μ values

We can conclude that α and μ are the main quantities that define motion on a slope. The blue area appears only if $\mu > 1$. We left the question open whether there is a significance in physics of $\mu = 1$.

HANDS-ON MEASUREMENTS

We wanted to see what the typical values (for μ and α) are, when riding the sledge.

Measuring the coefficient of friction

We pulled the sledge on level ground at constant speed. We used an 80213-141 Kamasaki digital scale (dynamometer) that we bought cheap in a fishing shop. We also needed a bathroom scale and a sledge. We made measurements on 3 different occasions, which means 3 different circumstances. We decided to note 3 readings each time. We formed the mean value by calculating the arithmetic mean. Our results are in Table 2.

Table 2. Our results for the coefficient of friction

measurement (Budapest XXI. ÁMK)	$F_{gravity}$ (N)	F_{pull} (N)	$\mu = \frac{F_{pull}}{F_{gravity}}$	μ_{mean}
9th Febr. 2015 late evening with a young girl on	351+51.7= 403	45.15	0.112	0.118
		49.46	0.123	
		47.88	0.119	
10th Febr. 2015 afternoon	51.7	9.88	0.191	0.178
		9.20	0.178	
		9.45	0.166	
16th Febr. 2015 early morning	51.7	4.90	0.095	0.092
		5.10	0.098	
		4.35	0.084	

In the 1985/5. issue of the Hungarian journal "KÖMAL" we found that the friction constant measured with a different method is $0.02 \leq \mu \leq 0.3$. Our results match those we found in the literature.

Measuring tilt angles in 2 ways

Our first problem was that we could not get an inclinometer. Since this instrument is not cheap, we worked out a conventional method for measuring α. We needed a bubble level (0.8m), a 1-meter rod, and a pendulum (string & load). Figs.6. and 7.demonstrate how we used our tools. We also used another apparatus to measure tilt angles, the GPS system. We worked with the two versions that were available free.

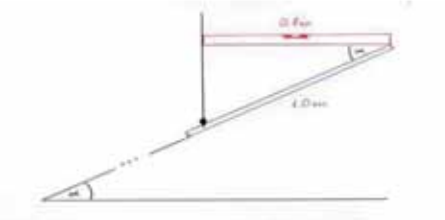

Fig.6. Our "inclinometer"

We made our measurements in different playgrounds in Budapest on 23rd June 2015.

Fig.7. "In-situ" measurements

Table 3 contains our results. We denote by * our results with the GPS system.

Table 3. Our results for α

	spot	$l_{projection}$ (cm)	cosα	α_{actual}	α_{mean}	$^*\alpha_{actual1}$	$^*\alpha_{actual2}$	$^*\alpha_{mean}$
Slope 1 Bp., 1095 Petőfi u. 2.	1/1	84.0	0.9524	18^o	**15^o**	16^o	13^o	**15^o**
	1/2	85.0	0.9512	20^o				
	1/3	80.5	0.9938	6^o				
Slope 2 Bp., 1091 Kékvirág u. 2.	2/1	80.5	0.9938	6^o	**11^o**	11^o	14^o	**12^o**
	2/2	81.5	0.9816	11^o				
	2/3	83.3	0.9639	15^o				
Slope 3 Bp., 1107 Bihari u. 3-5.	3/1	83.5	0.9581	17^o	**17^o**	15^o	14^o	**15^o**
	3/2	85.0	0.9412	20^o				
	3/3	82.5	0.9697	14^o				

Our results range from 6^o to 20^o, and a characteristic (mean) value is 14^o. We consider our result as a good estimate only, based on "in-situ" measurements.

INCORPORATING THE RESULTS OF OUR THEORETICAL AND PRACTICAL STUDIES

„Why is it easier to pull a sledge on level ground than to pull it up a slope?"

We provide two answers:

1) Since $\mu < 1$, from the theoretical study we learned that there is no need to give a typical value to α. (Fig.8.) A correct answer is: As typically $\mu < 1$, it is easier to pull a sledge on level ground than to pull it up a slope.

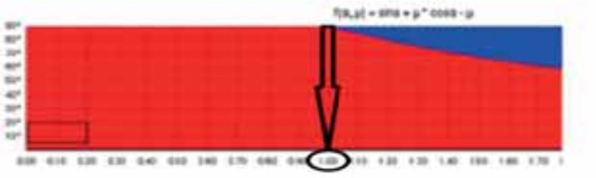

Fig.8. The case when $\mu < 1$

2) We studied the area denoted by the typical values based on our measurement (Fig.5.). Another correct answer is: It is easier to pull a sledge on level ground than to pull it up a slope, because of the real values of α and μ.

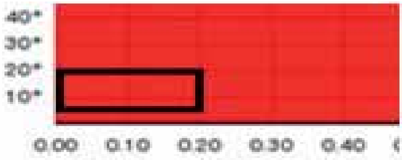

Fig.9. Real sledging values

CONCLUSIONS

In a mentor class the teacher and the students studied a question that had been studied before only in a qualitative way in public education. First, we have found that the typical answers in this case are not correct. Then we asked a "why?" question to a "yes-or- no" type question. Easily we acquired a function of two variables. From this point on computing skills were needed to carry on with our project. Our mentor class turned into an interdisciplinary forum of science. We could find real answers for a classical physics question, where the qualitative answers based on experience do not capture the scientific essence of the phenomenon.

ACKNOWLEDGMENTS

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DATA LOGGING IN THE SCIENCE LABORATORY OR ANYWHERE ELSE

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ABSTRACT

In the past few years there has been a growth of interest in how computers can be best harnessed in order to improve the efficiency and effectiveness of education. The use of the ICT toolkit is restricted by the limited infrastructure and the attendant high costs of access (e.g. software, updating). Data logging is a central feature of practical activity in the modern science laboratory. In my study I discuss the vital parameters of data loggers, which must be considered in the case of shopping. I show how all the measuring activities may be readily performed using only a data logger. It is hoped that the experiments will make it easier for teachers to introduce data logging to students in a meaningful manner.

INTRODUCTION

With the sponsorship of the European Union, in many schools a professional science laboratory was developed. This is Öveges Programme. This programme provides the possibility for 10 elementary schools of the district of these labs to do natural science experiments as they are having lessons in the lab, too. With this renewal the schools received new IT equipment, for example data loggers which can be used for Physics, Chemistry and Biology as well.

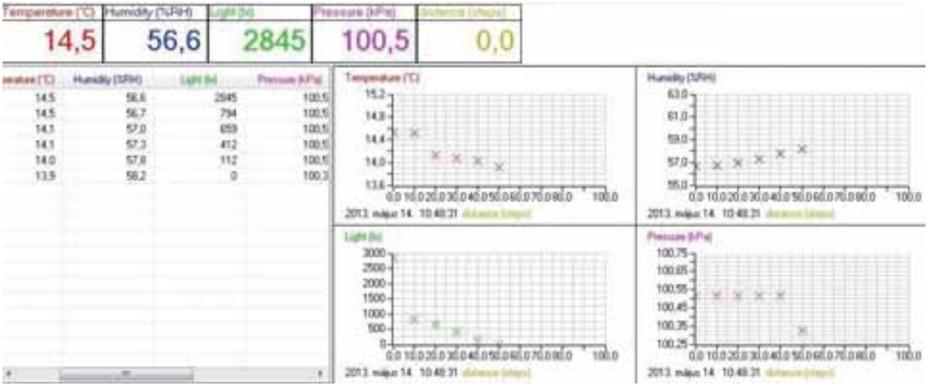
We hope that this programme will go on and other schools will get the possibility to improve their toolkit. In this paper I give some practical advice to those who have the potential or chance to obtain IT tools. My work in this programme was to help schools in getting all the tools which they really need and want. I met the expectations of the teachers, and now I would like to share my experiences.

THE COSTS OF DATA LOGGERS

We all know what the situation is between students and Science classes, so we have to reach an improvement in student attitude towards science. Modern apparatus in the lab offering many new and exciting features is a good possibility to reach this aim [1].

Nevertheless, our financial possibilities are limited. There are many types available on the market. Everybody wants to get professional and cheap tools. Based on resources, the first characteristic of these items that we usually check is the price. In some cases this amount does not contain the price of the software. The cost is raised a lot if the software and the updates must be paid separately.

Another financial problem can occur if we have to buy a PC to run the software of the logger. It is useful to choose a cost saving product with a built-in computer and rechargeable battery. This solution is cheaper, and you can also use these portable data loggers for out-of-school experiments, or you can smuggle them for Science in class trips [2]. Fig.1. shows a class trip experiment conducted in a forest. Humidity, temperature, light intensity and air pressure were measured while the students were walking on a path farther and farther from the highway. Before the trip they were asked to decide which four parameters to check. They carried out the experiment using only a data logger. They also made notes with the device during the process, so no paper sheets or pencils were needed. If the graphing and analysis tools normally only found on the PC are built in, we really can get a stand-alone data logger and analysis tool.



Temperature (°C)	Humidity (%RH)	Light (lx)	Pressure (kPa)	Distance (steps)
14,5	56,6	2845	100,5	0,0

erature (°C)	Humidity (%RH)	Light (lx)	Pressure (kPa)
14.5	56.6	2845	100.5
14.5	56.7	794	100.5
14.1	57.0	659	100.5
14.1	57.3	412	100.5
14.0	57.8	112	100.5
13.9	58.2	0	100.3

Fig.1. Abiotic factors measured in a forest

Incidental malfunctions, damages and warranty should also be mentioned. The chosen product must be resistant to the shock, percussion, overload or impact caused by the users. The connection lead or the plugs are used to be a critical point. In turn, generally we don't have to worry about computer viruses. Basically the software of the loggers are programmed in their own system, they are not threatened by Windows or Mac viruses.

LEARNING PROCESS

Besides the cost of the new apparatus, educational aspect shall also be concerned thoroughly. Teachers are overloaded, but the weekly number of the science sessions is so low, so we have to get as much as possible into those hours. Teachers' work can be grouped into 3 parts. First, the preparation before the lessons (planning, setting up the experiments), then managing the students' work during the lessons, and thirdly the evaluation (homework, practical work, tests). The logger is expected to help the teacher in this total work. How is it possible?

To be able to use a new item, some learning and practice must be performed. The simpler the platform and the software, the easier it is to learn the operation. Simple menu also supports the students in their work. However, it can be scary for the children if they see a lot of icons on the screen, the device must be able to carry out many different data collecting and analysing processes, as you can see in Fig.2.

Fig.2. Icons on the screen for quick data analysis

It is preferred if we can choose from different levels of the software, offering different expanded possibilities, according to the age and preparedness of the students.

ATTRACTIVE PROPERTIES MAKING LIFE EASIER

The first meeting of the pupils with a tool determines their attitude towards the device. Students use their smart phones continuously. Fig.3. indicates an item having its own fully coloured high resolution LCD touch screen, similar to tablets and smartphones, which helps us to bring the students into a familiar relationship with the tool.

Fig.3. A logger with a touch screen

The best for students is if they can do the experiments themselves, but in many cases the teacher's demonstration is needed. It's a benefit if it can be connected to a projector or monitor. This is absolutely relevant, required whenever the teacher needs to present a demonstration or introduce an experiment to a class, even to provide training on how to use the device.

To get on well with Science is a hard work for the students, we could make it easier if they can carry out their experiments in their own language. The possibility to choose an alternative language is a helping hand for the teacher, too. Also a detailed user's manual must be enclosed in the mother tongue of the teacher. Furthermore, there should be teaching materials and booklets with experiments developed especially for the given device. In some cases, loggers are supplied with built-in setup files matching these documents.

Teachers would like to carry out hundreds of experiments with their logger, it's important to choose a manifold type, with many sensors, which can be built-in, or which we can buy separately. To decide what sensors to buy, collect some information on the available ones from the manufacturer or the distributor, and have a discussion with your Biology, Chemistry, Geography colleagues. Teachers don't have to bother with the calibration of the sensors, if it is done by the manufacturer. The sensors should also have a built-in protection against overloading.

COLLECTING AND ANALYSING DATA

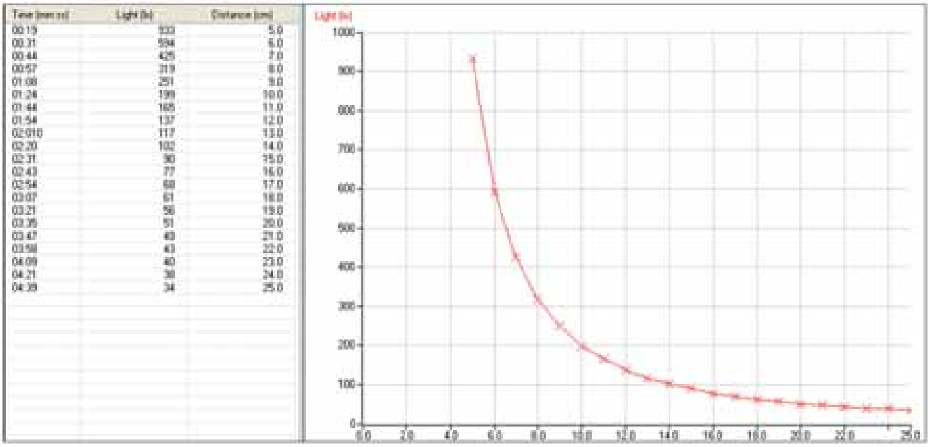
Measuring activities may be readily performed using a data logger, so students can record their captured data in a table and plot the results on a graph quickly. It's interesting to examine a live graph, for example the increasing of CO_2 level in the classroom during a lesson. Or we can leave the operating logger in the classroom for some days, and measure the changes of the light level and the temperature with the variation of day and night.

If we are talking about long-term remote data logging, then we should mention processes which are too quick to observe with human sensory organs. A professional logger is able to manage short measuring time with a small intersample time, at a range of some microseconds. Fast data logging is necessary for Physics, and is also used in Biology, in checking pulse or heart rate, for example. Fig.4. shows how the current changes in a light bulb after it is switched on. The measurement time is 200 ms.

Fig.4. Current falls according to the increasing resistance [3]

Besides data collection, we also need the possibility to analyse the graph plotted from the captured data. Related to the type of the experiment, we plot our data as the function of each other, or simply as the function of time. So we need an x-axis that can be changed according to our expectations.

Different processes are observed with different methods. Our logger must be able to meter and plot discrete and continuous data. For example, let's check how the light intensity changes with the distance from the light source. To get data, we position the light sensor against a ruler so that we can measure the distance from the light bulb to the Light Sensor. With this process we get a discrete graph. The fitted curve indicates the inverse square law. Results are shown in Fig.5.



Time (mm:ss)	Light (lx)	Distance (cm)
00:19	933	5.0
00:31	594	6.0
00:44	425	7.0
00:57	319	8.0
01:08	251	9.0
01:24	199	10.0
01:44	165	11.0
01:54	137	12.0
02:010	117	13.0
02:20	102	14.0
02:31	90	15.0
02:43	77	16.0
02:54	68	17.0
03:07	61	18.0
03:21	56	19.0
03:35	51	20.0
03:47	48	21.0
03:58	43	22.0
04:09	40	23.0
04:21	38	24.0
04:39	34	25.0

Fig.5. Light intensity as the function of distance from the light source

To see the correlation between the different variables many transformations need to be applied. For example, if the change of the pressure of a gas is measured with the change of the volume of the container, it is not enough to plot the p(V) graph. To get the well-known Boyle's law data is treated to produce a 1/V or a 1/p plot, which gives a straight line. With the function wizard we can display that the volume of gas is inversely proportional to the pressure (provided that the mass and the temperature remain constant).

If we do the transformations in Excel, we have to plot the new columns again and again, which is a waste of time. With a logger the required graph appears after only a few clicks. Of course, there is the possibility to save each graph before the transformations, title them and make notes at the same time, without any sheets of paper or a computer, using only the data logger.

It is not a dream to have enough tools for the class. Each measuring pair should use a data logger, carry out the experiment and do the analysis parallel with the others. And when they are ready, they just connect the logger to a printer and have the final graphs printed. In this way the teacher can easily check the overall work of the students in only one step, and the pupils can glue the graph into their writing pads.

STUDENT WORK AT HOME

Basically a normal class is 45 minutes long. It is almost impossible to carry out the experiment and do the total analysis process in this short time. Having a multiuser PC software included in the price is also a benefit that provides students with a wide range of PC-like functionality. This way the logger can still be used with a PC when required. Students can take their measurements at home, they can analyse, work on their own PCs with a software which looks and behaves just like the stand-alone one. It is also essential to have the possibility to save data in xls format, so pupils can easily export data into a spreadsheet. In this way, homework can also be solved.

CONCLUSIONS

- With a professional logger we can collect and analyse data quickly and easily. The price of the tool and the software are important so many factors and aspects must be considered.
- All in all stand-alone loggers are cheaper because no PCs must be bought for the operation.
- When we start to use a new equipment, it is beneficial to have a software with optional languages and user's guide in every individual's mother tongue. After all, maybe worksheets should be provided too.
- There is quite a wide range of variables which should be measured in a science class. The more sensors are available, the more experiments can be done with the chosen device.
- Multiuser software running on the kids own PCs is a good point, giving also the possibility to do their pieces of homework.
- There is no need for any calibration or setup, simply choose a type which is already calibrated and able to do automatic setup.
- With a complete measuring system, we get accurate and real-time data, it allows long-term studies and quick measuring. In addition, it provides portability and options for homework. All these things result in students good at science and satisfied teachers.

ACKNOWLEDGMENTS

This project is a result of my work in Öveges Programme, with which many school laboratories have been supplied with data loggers. It gives me immense pleasure to prepare this report on the expectations and experiences of the teachers involved in the programme.

I would like to thank Almus Pater Ltd. for providing me an opportunity to use the equipment, loggers and sensors offered for testing and demonstrating. I sincerely thank my students for their contribution to the student experiments. I wish to express my sincere gratitude to the Graduate School for Physics of ELTE University and its Partners for the possibility to share my thoughts with the international Science teacher community that participated in the conference titled Teaching Physics Innovatively.

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VII. PHYSICS EXPERIMENTS AND METHODOLOGICAL INNOVATIONS

THREE STAGES OF THE STUDENTS' RESEARCH SKILLS DEVELOPMENT AT ECYGDA LABORATORY

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ABSTRACT

The work is dedicated to the good practice examples and some difficulties of extracurricular physics trainings for the secondary school students aged from 7 to 16. There are three stages how students' experimental skills are developed. To teach students how to make simple research, extracurricular courses have been organised at the Educational Centre of Youth Gifts Development (ECYGDA) which is situated at the Department of Physics and Technology at the premises of Karazin Kharkiv National University. During such training students gain special profound knowledge of physics and seriously improve their experimental skills by doing self-made experimental projects using recycled materials, simple household objects, ordinary toys by means of real tools.

INTRODUCTION

The problem of students' experimental skills developing during informal physics education has been mentioned in the works of some Ukrainian and European authors [1], [2], [3], [4]. It is well known that physics is an experimental science so the goal of the physics teaching does not refer only to remembering the main formulas, it means not only reciting and enumerating basic laws of physics but also stimulating interest in experimental work [4], [5]. However, during the last decade bringing up the use of modern computer technologies, an application of up-to-date computer programmes, modeling of physical processes by means of computer onone hand and the lack of financial support for Ukrainian education on the other hand resulted in the displacement of real physics experiments from the lessons at 80% of Ukrainian schools. Moreover, at ordinary secondary schools in Ukraine physics experiments during the lessons or beyond are usually carried out with pre-assembled equipment. Moreover, in most schools the experiments are run using pre-assembled instructions [6]. Those activities are definitely valuable and justified. But students who are interested in physics, technology or engineering as their future career should also have the opportunity to carry out projects they have planned, thought up and elaborated themselves. For that reason the Centre (ECYGDA) which offers special support for realising those projects has been created. Besides, the primary and secondary school students (from 7-16) are encouraged to take part in local and international annual Conferences, Competitions and Tournaments for secondary school children, their parents and university students with their experimental projects where they can "touch science" and find out about very serious topics in an entertaining way. ECYGDA's motto is "Teach to Research with Pleasure!"

ECYGDA LABORATORY

ECYGDA Laboratory was created in 2004 as an institute of additional physics education. There are different types of informal learning facilities like science museums and exhibitions, field trips, science centres and entertaining shows established throughout Ukraine [6]. In these institutes, school students usually participate in one-day excursion or lectures, which are still informal in comparison to school instruction.

Our Centre has agreements with 23 Kharkiv Secondary schools, where we regularly demonstrate Physics Theme Shows, which have the common name Paradox Show connected with a content of the Official School Physics Curriculum. During those shows the lecturers are able to select and choose the students who have capabilities for experimental work and invite them to join the regular trainings on Saturdays at ECYGDA. These selected primary and secondary school students have regular (once a week) short theoretical lectures (45 or 60 min), held by university teachers accompanied by practical training (90 min) under the leadership of university teachers or students. In addition, all our students have a special English course (two hours a week), where they learn physics and maths in English. It is a very important point of their preparation as future scientists. It is considered that there are three stages of experimental skills development.

The first stage is for primary school pupils aged 7-11. At our theoretical training we proposed them 13 interactive physics theme lectures which have been elaborated by the teachers of the Centre. All of them have been adopted to the primary school pupils to be understandable for children of that age range. Every Saturday at the premises of the Centre one of the lectures (dur. 45 min) is presented to our visitors. The topics are interesting for children: Physics in Toys, Wonderful Mechanic, Travelling in Sound Land, Physics in the Kitchen, Light and Colours, Paradoxes of Magnetic Field, Wonders of Electricity etc. At the beginning visitors become acquainted with simple principles and laws of physics and then they are able to do simple experiments themselves. After 5 months of training they choose the topic and prepare their own simple research projects. They usually report about their first "scientific results" at the annual University Conference "Junior Scientific Start-Up" in May. At the first stage they usually do simple experiments which are demonstrated and explained to the audience at the Conference. This new approach is a successful attempt to show that it is possible to change pupils' and secondary school students' views about physics with a relatively short but explicit methods (Fig.1.).

Fig.1. Simple research project Sound Waves at the first stage

The second stage is for students aged 11 to 14 who are selected by methods mentioned above from Kharkiv schools and lyceums. They are also involved in regular extracurricular (once a week on Saturdays) short theoretical lectures (45 min) and more serious practical training (90 min). During such experimental training students are taught to operate with simple tools like handsaw, boring mill, perforator, Vernier callipers, tester. They design and help to produce some exhibits for the Physics Exhibition [6] or for the events which are organised in their schools (Week of Physics, Science Picnic, Night of Science) under the leadership of university students and university research engineers from the Department of Physics and Technology. They gain a lot from such kind of practical trainings and their experimental skills are seriously improved by doing self-made experimental projects using recycled materials, simple household objects or ordinary toys (Fig.2.).

Fig.2. Working with real tools and the example of hands-on Heron Fountain from the plastic boxes as a second stage project

The third stage is research skills development (see Fig.3.). The prevailing lack of interest in physics matters among adolescents aged 13 to 17 is obvious and common not only for Ukraine but also for all developed countries [7]. It most notably manifests itself in the steady decline in the number of students at Physics Departments in all Ukrainian universities. ECYGDA with its location at Karazin University, combined with the possibilities associated to this fact – use of the machine laboratories and the electronics repair laboratories at the Department of Physics and Technology, subject-specific support by scientists, lease of equipment has got lots of advantages not only in Kharkiv Region, but also in Ukraine.

Every year the Centre staff works with 5-6 groups of students. There are 6-8 students in each group. They are divided according to their age range or secondary school forms. We also take into consideration their theoretical knowledge in physics and mathematics. Before they start, they have to pass specially prepared short tests in Physics and Math (for the students aged 13-16). It helps us to divide them into the appropriate and convenient teaching groups. There were 10 research projects in years 2014-2015. The best ones are the following:

– Simple experiments with sounds (first stage research project) reported in English by Daria Slobodina (11) and Aleksandra Barkova (10);

– Heron's Fountain (second stage research project) made of ordinary kitchen plastic containers, a non-typical pattern designed and produced by Anton Rusynnyk (12);

– Creation of the experimental set-up and demonstration of a “soap film liquid motor” which was done by students Maksym Peretyaha and Vitaliy Yurko aged 14. All those projects were done at ECYGDA Laboratory where students have the opportunity to obtain an insight into scientific method of investigation, to conduct their own research projects, to promote their activities and demonstrate some of their key competences in science and technology and communication in the foreign language at the different local and international conferences. Usually among them are ICYS (International Conference of Young Scientist), QUANTA Competition, IYPT (International Young Physics Tournament), annual Conferences of Junior Karazin University, Ukrainian Science Festivals, Science Picnics, Research Nights and some other events.

Fig.3. Experimental skills development at the third stage

The third stage projects are usually much more serious and can be compared with real Diplomas at University. The example is “Liquid film motor” [8]. In recent years scientists have become interested in the physics of liquid films. Study of those films is a part of the interesting physics section called “Physics of Surface”. When the films are subjected to the action of various chemical, thermal, structural or electrical factors, they display interesting dynamical phenomena. Investigation of soap films and bubbles is very impressive topic in a lot of student research projects. A soap film should be formed on a flat frame. Place the film in an electric field parallel to the film surface and pass an electric current through the film. The film starts rotating in its plane (it can be seen in Fig.4. below). The phenomenon have been investigated and explained.

Fig.4. Elaborated liquid film motor measurements

CONCLUSIONS

Five self-made devices have been designed and created during 2014-2015 years in the Laboratory. During the extracurricular theoretical and experimental trainings mentioned above students have the opportunity to obtain an insight into the real research methods of investigation, to conduct their own research projects and demonstrate some of their KCs (for example basic competences in science and technology and communication in a foreign language) at the different local and international conferences (Bronze medal at International Conference of Young Scientists, April 2015, Izmir, Turkey). Teaching methods proposed by the authors are not contrary to the existing Ukrainian teaching techniques, they can be considered as an effective supplementation to traditional methods and forms of physics teaching. For more than 10 years of the Centre's existence 98% of the students entered in Kharkiv and some other Ukrainian Universities and became good students and successful scientists both in Ukraine and in some European countries. We are proud of our ex-students who are now working in Germany, Canada, the USA, the Netherlands and Poland.

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PENDULUM WAVE OR LOVE AT FIRST SIGHT

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ABSTRACT

Pendulum wave is the motion of a chain of pendulums in which – if their length is chosen based on an appropriate mathematical relationship – remarkable shapes emerge. What should be the logic of composition? How long should the cords be in order for the pendulums to show nice shapes when they are initiated appropriately? We started to study this topic in more detail with high school students in a physics camp. Students had to develop their chosen project work in a team with the support of a teacher. After clarifying the physical and mathematical background, younger students prepared the tools, while the more senior ones worked on the related computer simulation that facilitated a more precise research.

INTRODUCTION

Few years ago we came across the beautiful phenomenon of pendulum wave, which was absolutely love at first sight. The students of our school dealt with this phenomenon in more detail for the first time in the 2014 physics school camp.

Let's see what the pendulum wave is. Pendulum wave is a series of pendulums in an optional number. If the length of each pendulum and the initial conditions are chosen by an appropriate mathematical relation, the pendulums can shape special formations. Our most important question is what the logic of composition should be. In other words, how long should each cord be in order to show a beautiful formation after releasing them? (It should be noted that the pendulum wave is not considered a wave in physical terms, what we see is rather a joint view of independent pendulums.) You can see in the first color picture (Fig.1.) a snapshot of our pendulum wave. This phenomenon has many nice moments, perhaps the most beautiful is this front view.

Fig.1. Snapshot of a pendulum wave (front view)

Relatively little detailed literature related to the phenomenon can be found [1-3]. You can see videos of our [4] or other's [5] pendulum wave on the Internet. It is recommended to look at them before proceeding with the reading of this article. Two additional snapshots of our pendulum wave are shown in Fig.2. in top-side view. The parameters of the device are the same as the data in the later Table 1.

Its beauty and “obscurity” were the reasons why we would like to share our experiences with others. We hope that this beauty excites you, too.

THE PHYSICAL BACKGROUND

The physical background of the phenomenon is not difficult, but not obvious either. The “trick” is that the pendulums are adjusted in a way that the whole pendulum wave shall return to its starting position after certain time. Then all balls should be at the same position as their starting point again. During this time each pendulum swings with different frequency. For example, during the whole period of the pendulum wave the longest swings 52 times in total, the second swings 53, the next one 54 and so on. If we recognize this regularity, the problem isn’t that difficult mathematically anymore.

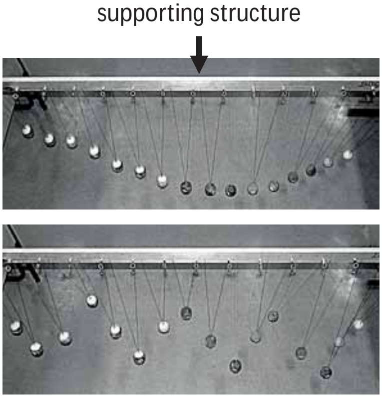

Fig.2. Snapshots of pendulum wave (top-side view)

We enumerate the pendulums: $i = 0,1,2,\ldots n$. The pendulum wave consists of (n+1) balls. Pendulum No. 0 is the longest. We have additional symbols:

- $\boldsymbol{\tau}$ is the whole period of the pendulum wave (so the shortest time within which all pendulums in the pendulum wave return to the starting position).

- $\boldsymbol{T_i}$ is the period of the pendulum No. i (with the assumption of small amplitude swings).

- $\boldsymbol{N}$ is the number of swings made by the longest ($i = 0$) pendulum during the time τ.

So the period of each pendulum is calculated according to this formula:

$$T_i = \frac{\tau}{N+i} . \tag{1}$$

According to the well-known connection: $T = 2\pi \cdot \sqrt{\frac{l}{g}} \;\rightarrow\; l_i = \frac{g}{4\pi^2} \cdot {T_i}^2$, and from formula (1), with a given $\boldsymbol{\tau}$, $\boldsymbol{i}$ and N, the length of each pendulum is found as:

$$l_i = \frac{g}{4\pi^2} \cdot \left(\frac{\tau}{N+i}\right)^2 , \tag{2}$$

where, of course, $\mathbf{g}$ is the gravitational acceleration. Thus, we have to choose the length of the rope No. $\boldsymbol{i}$ to be $\boldsymbol{l_i}$. This is the most important formula for us now.

Table 1. Our demo data

$\tau = 90\,s$	the whole period of the pendulum wave
$\mathrm{n} = 15$	$(\mathrm{n} + 1) = 16$ pendulums
$\mathrm{N} = 52$	no. of swings made by the longest pendulum

CONSTRUCTION OF THE SET-UP

The following points are worth paying attention to during the building and the preparation of the set-up:

- a stable supporting structure (lath supported at both ends, for example by a table)
- the procurement of the balls (or other hanging objects)

- the selection of ropes (it shouldn't be breakable, or spinning), it's really hard to find good rope (the fishing line breaks, the embroidery yarn tears), we can find specialized shops on the Internet with the "twine, rope, cord, yarn" search words, then we must try them out with the swinging of only one ball
- an accurate suspension
- fine tuning and synchronization, this is the most important and the most difficult

To ensure this, set the lengths manually as accurately as possible, let the pendulum swing, and fine-tune the length of each pendulum by eye-measurement (extend or shorten). Small screws at the suspension of the pendulums are applied for this purpose. The tuning can be done with a computer method (for example: Webcam Laboratory Program), with that we are able to measure exact periods, but based on our experience, it isn't much better or easier. You should try it out, we don't have an exact recipe.

THE USE OF THE EQUIPMENT – THE INITIAL CONDITION

Figure 3. shows how we initiated our experimental runs. Initially, we displace the pendulums with a long, straight lath. However, based on our earlier calculations, the swings shouldn't be done with the same amplitude, but with the same starting angle for each. This does not make a large difference with the parameters we've used in practice, a line is a good approximation of the extremes' envelope. This we may not notice by just looking at videos, but can be found easily by watching a simulation based on exact mathematical formulae (as shown in the next paragraph). This means, that the lath should be long enough, to be able to start the system, but there is no real need of special equipment for this purpose.

Fig.3. The experiment at start (front view, data as in Table 1.)

COMPUTER SIMULATION

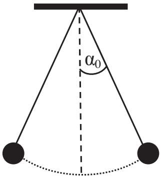

Fig.4.
The initial angle

As a further analysis of the pendulum wave, we implemented a simulation of it. To create an animation, we simply redraw the whole picture very frequently. To be able to draw it, we need to know every pendulum's length and its current angle at any moment. We already know the lengths (2). Assuming that the pendulums start without any initial velocity at time $t = 0$, the angle vs. time function is given as:

$$\alpha_i(\mathrm{t}) = \alpha_0 \cos\left(\sqrt{\frac{g}{l_i}}\mathrm{t}\right). \qquad (3)$$

Here, α_0 stands for the initial angle for all the pendulums (Fig.4). This formula (3) is an approximation, which uses the assumption that the value of $\alpha(t)$ is always small; this applies for all these pendulums. With these, we can calculate the coordinates of the whole system, so we can draw it.

Note that these approximations are considered to be really good with $\alpha_0 \leq 5°$, but that would not be spectacular enough. In practice (in the case of the experimental equipment and the simulation, too) we use angles more or less 10°, which is still good as an approximation, but there is a lot more movement, making it look better. The simulation allows more than 10° for the sake of spectacle, the program will continue to use the approximation.

Our program shows the front and top views of the model set-up (Fig.5. – it's a typical moment, which shows a similar shape for a prolonged period). The program has a feature which makes it possible to export data (rope lengths, etc.) with the current parameters, so that we don't have to make the calculations ourselves. The program is free-to-download as well [4] – directly download and run –, with the pre-requirement of having the Java Runtime Environment 7 installed [6].

The simulation can be stopped at any moment, or even put to an exact timestamp, as it is way more precise than the real experiment. By using the program, the formations are much easier to analyse. Of course, it can't substitute a real experiment.

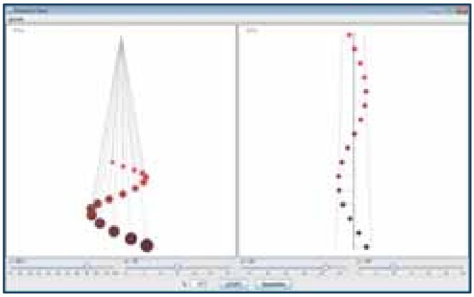

Fig.5. Simulation of a pendulum wave. Left: front view, right: top view ($t = 7.1\ s$, $\alpha_0 = 10°$), with the parameters of Table 1.

ANALYSIS

The moments we will analyse are the half and the one-third of the full period, in our case 45 s and 30 s (Table 2). The first column shows the pendulum's index, the second is the number of swings through the full period. The third and the fourth columns contain the number of swings done during these selected time intervals.

Table 2. Comparison of the number of swings within different time intervals: full (90 sec), half (45 sec) and one-third (30 sec) of period τ

Pendulum no.	**No. of swings ($\tau = 90\ s$)**	**No. of swings during 45 sec**	**No. of swings during 30 sec**
0	52	26	17 **1/3**
1	53	26 **1/2**	17 **2/3**
2	54	27	18
3	55	27 **1/2**	18 **1/3**
4	56	28	18 **2/3**
5	57	28 **1/2**	19
6	58	29	19 **1/3**
7	59	29 **1/2**	19 **2/3**
8	60	30	20
9	61	30 **1/2**	20 **1/3**
10	62	31	20 **2/3**
11	63	31 **1/2**	21
12	64	32	21 **1/3**
13	65	32 **1/2**	21 **2/3**
14	66	33	22
15	67	33 **1/2**	22 **1/3**

If we are at half time (45 s), the first pendulum did an integer number of swings, the next one did an integer and a half, then again an integer number, and so on. In perspective of positions, the number of fully completed swings does not matter, only the fractional part does. This means that every second pendulum is at the same position: the even ones are in their starting position, the odd ones are on the other side.

At one-third of the full period (30s), we can see in Table 2. that there are 3 different positions the pendulums can be in, with fractional parts of 1/3, 2/3 and 0. However, only two distinct positions are visible in Fig.6. (for convenience, the path of the two longest pendulums are also drawn be continuous arcs). This is because the 1/3 and 2/3 positions are the same, but the balls are moving in different directions. The 1/3's are still on the way to the opposite side, the 2/3's are coming back towards the starting position.

Any moment can be analysed like these; we recommend considering the one-quarter (Fig.7.), one-sixth or two-fifths (Fig.8.) of the full period, as the constellations which occur in these moments are quite remarkable.

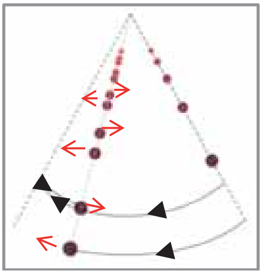

Fig.6. Pendulum positions (front view) at one-third of the full period (t = 30 s) in computer simulation with the parameter data as in Table 1.

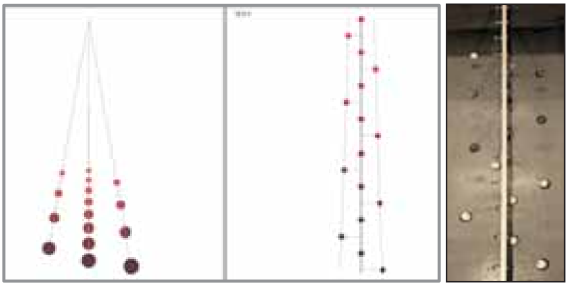

Fig.7. Positions at one-quarter of the full period
Left and middle panel: simulation, front and top views.
Right panel: photo of our set-up, top view, data as in Table 1.

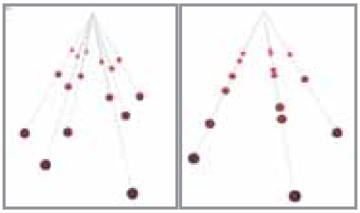

Fig.8. Nice shapes, left panel: 1/6 period, right panel: 2/5 period, simulation, front views, data as in Table 1.

CURIOSITIES

The simulation software did not learn physics: it does not know anything about Newton's laws, or gravitation, it only knows the formula, which is an approximation. Thanks to the missing knowledge of the program, we are able to see what this formula would give for angle values too large, where the small angle approximation does not hold. If we use $\alpha_0 = 120°$, the simulation is very spectacular, it makes shapes like butterflies. This sight can be observed really well on the move (for example in Fig.9. around half period). Even more beautiful, when the n-value is large. (You can see this in our simulation – "Enable great angles" button.)

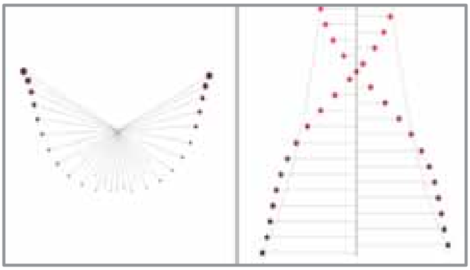

Fig.9. „Butterfly" → $\alpha_0 = 120°$,
Left: front view. Right: top view
$(n = 31; t = 44.1\,s; N = 52; \tau = 90\,s)$

We asked ourselves what would happen if the pendulum wave could "sing". Although building this in real life would be complicated, in the simulation we implemented this feature easily. The pendulums make sound in their leftmost and rightmost positions, and the longest pendulum gives the sound of a small „A", the next pendulum one semitone higher, and so on. The result was a beautiful, or – at least – quite interesting music. (You can hear this when running our program – "Enable sounds" button.)

We raised another question: what if we used a much simpler formula for the lengths, for example an arithmetic sequence. The beginning is very similar to the original one, it starts waving, but later, it turns into a system with no beautiful shapes at all. (You can see this in our program, too. – "Linear lengths" button.)

PHYSICS SCHOOL CAMP

Finally we would like to mention the physics school camp in our high school. Fig.10 shows two selected pictures of the camp. My school organizes a four-day physics camp each year, which forty-fifty students are attending from the school. In 2014, our pendulum wave-project was a great success.

The students have to work in smaller groups on a jointly chosen topic under the supervision of teachers. They present the projects to each other during the camp. The project's framework might contain one or more experiments, measurements, evaluations, building of experimental equipment, preparation of computer simulation, theories or calculations. In the camp, the teachers also hold small group lessons. The programs are completed with invited speakers, team competitions, experiments and constant thought-provoking tasks. The location is usually an open-air school.

Fig.10. Top panel: observing of spectroscope, bottom panel: small group lesson with a physics program

OUTLOOK

You can find other versions of pendulum waves on the Internet [7]. For example a more spectacular version with fireballs, or one which is painted with fluorescent material, so it glows in the dark. We hope that some of you get a feel for preparing the equipment.

ACKNOWLEDGMENTS

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   Directly to the simulation: http://www.berzsenyi.hu/Lendvai/PendulumWave_eng.jar
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6. http://java.com/en/
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   Pendulum wave in the dark: https://www.youtube.com/watch?v=7_AiV12XBbI
   Symmetrical pendulum wave: https://www.youtube.com/watch?v=vDtfWxL-AJg
   Spiral version with sound: https://www.youtube.com/watch?v=JMzB7sLeSbs

VIDEO INSTRUCTIONS FOR UNDERGRADUATE LAB EXPERIMENTS: A STUDENT-TO-STUDENT APPROACH

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ABSTRACT

Lab experiments are an important part in teaching undergraduate physics at universities, in particular in subsidiary courses for engineering students. A lack of preparation time and/or motivation of students affect the ability to successfully perform a given experiment. Our attempt of improvement is providing video tutorials that explain the lab experiments in addition to usual text instructions while giving experimental details to large groups. This adds an interdisciplinary aspect, and the advanced students serve as role models for other students.

INTRODUCTION

Physics remains the fundament of all modern sciences and engineering disciplines. In universities, it is nowadays often absorbed in special courses designed to meet the purposes of the actual major subject; nevertheless, most non-physics science and engineering programs include a first-year module concerned with teaching the fundamentals of physics.

Since the advent of affordable video equipment, attempts were made to implement this new tool for teaching physics [1]. With the rapid development of internet availability and video-sharing platforms during the last years, educational footage has become a widely used source of information. Mobile information technology enables users to quickly find answers to questions of different levels of detail.

In this paper, benefits and difficulties in first year physics courses at universities are discussed and analysed. As a possible attempt to overcome the difficulties, we present our experiences with student-made introductory videos to lab experiments. Instead of presenting the whole experiment in a recorded video, only the introduction to conducting the real experiment is shown [2]. We discuss the additional learning outcome and motivation boost associated with the preparation of such videos and suggest strategies for a proper integration into existing courses.

PHYSICS LABS: BENEFITS AND DIFFICULTIES

All science and engineering courses at Rhein-Waal University include at least a one-semester course on elementary physics. The degrees include mechanical engineering, electrical engineering, materials science and science communication among others. Students enrolling in these courses have often a very different expectation and also a varying skill set with respect to physics.

A typical physics course taught as a minor subject consists of a lecture with e.g. two hours per week presence time, accompanied by a one-hour problem solving unit and a two hour lab course. The latter usually requires students to understand the theory of the experiments, conduct the actual experiment in the lab and present the results in the form of a written lab report.

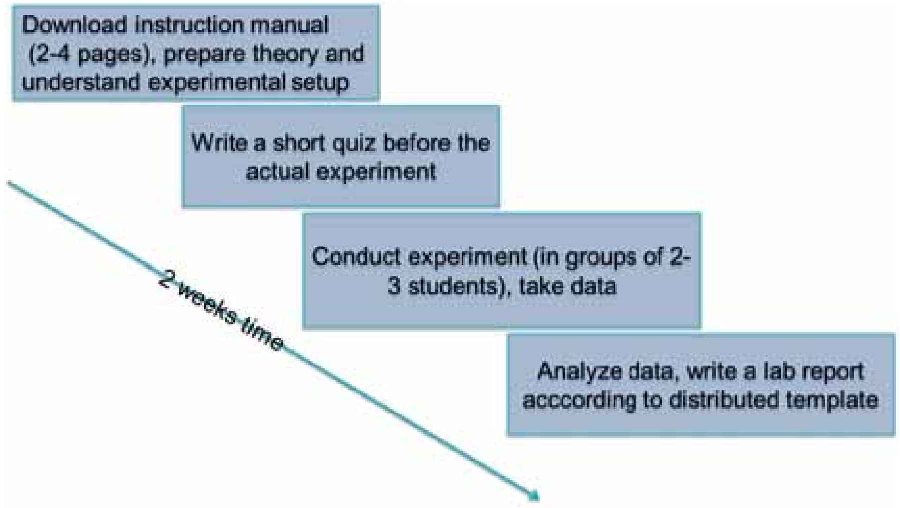

Fig.1. Workload cycle for first-year students in the physics lab courses. Engineering students have to complete five experiments in the first semester.

The physics labs (Fig.1.) play an important role in transferring methodical competence. Students are not only introduced to scientific methods, the art of measurement, data analysis and error treatment, but are also confronted with teamwork, often for the first time.

In many reported cases, the exact sciences like mathematics and physics turn out to be very difficult for students who have to take these subjects only as minors as illustrated in Fig.2. The reason for this is often a lack of motivation, because the students cannot see yet how these subjects are related to their majors. Moreover, even introductory courses often need to rely on the fundamental ability to think scientifically. In fact, even simple approximations require a certain level in mathematical education that cannot always be met by first-year students; important concepts like error propagation and other statistical tools for quantitative measurement analysis are even more out of reach for scientific beginners.

VIDEO TUTORIALS AS SUPPORT FOR LAB INSTRUCTION DOCUMENTS

The expected benefits of video tutorial can be grouped into a technical, a sociological and a pedagogical aspect.

1. Technical aspect

Even simple experiments can have a complex setup that is sometimes hard to describe by a written introduction. In a typical arrangement, various devices are connected in different ways that are visually perceived easily while evading a short description in words. A technical drawing can perhaps visualize the setup but often fails to illustrate the dynamics of the measurement. Very fast or slow events can be presented in different replay modes. Additionally, a video can transport real acoustical features of the experiment, e.g. in collisions of object, friction sounds or humming of transformers. This makes students feel more familiar with the experiment when actually being in the lab. Moreover, artificial sounds can be included to emphasize certain details, e.g. the sound of accelerating cars. This is intended to help students relate to the subject by making connection to everyday experiences. Small details of instruments, fittings and other parts can be filmed in close-up mode and thus can be shared with a large audience. It is also assured that different groups performing the same experiment get identical instructions. Especially in international classes taught in English, the visual outreach of the video can help overcome language difficulties by directly linking pictures of objects with technical terms. Difficult experimental situations can be scrutinized by the audience by individually pausing or rewinding the film. Sharing the footage well before the experiment enables the students to get familiar with the actual equipment even before entering the lab. This saves time for students and instructors and allows for more time to actually do the experiment. The video can be maintained over different courses, improvement and reaction to student feedback can be consistently offered over a long period of time.

2. Sociological aspect

Video instructions designed and filmed by students who have already taken the labs help to establish them as role models for the next generation. Unlike more senior lecturers, they can better relate to new students facing the experiments for the first time. Furthermore, a certain enthusiasm can be stimulated easier from student to student.

Since video clips are part of the students' everyday life, the students can easily be addressed by this communication channel.

3. Pedagogical aspect

Our science communication students have to complete the same physics labs in the first semester as all the other, mostly engineering students. While producing the clips, they can directly apply their recently acquired proficiencies in film making. In addition, they intensify their knowledge about physics and their experimental skills.

There is also a fruitful feedback from students to the lecturers; by actively accompanying the production process, they obtain incentives for improving physics teaching.

MAKING VIDEO INSTRUCTIONS

The videos of five physics lab experiments (Kinematics, Pendulum, Energy and Momentum, Moment of Inertia, and Resonance) and a tutorial on data analysis software were produced by four students studying in the Rhein-Waal bachelor degree course "Science Communication and Bionics", from April to May 2015. The production of the video was completed by June 2015. The aim of the videos was to instruct students how to work with the equipment and what exactly they were supposed to do as part of the experiment. Each video took approximately 2 hours to prepare a script, 2-3 hours to film, and 7-9 hours to cut clips and produce the whole video. The script was based on the written lab guidance to the experiment, on the lab reports written earlier by the team, and on the test-videos developed by the instructors preliminary to the more detailed production completed by the students. Professional equipment, such as TV cameras and video post-processing software, were used for filming and cutting. The length of the videos depended on the content and the amount of tasks which had been completed in the experiment:

- Kinematics (4:50 minutes);
- Pendulum (5:09 minutes); this clip can be seen at [3]

- Energy and Momentum (5:37 minutes);
- Moment of Inertia (4:42 minutes);
- Resonance (6:08 minutes);
- Tutorial on data analysis software (10:49 minutes).

Each video ends with a small, somewhat ironic or funny scene involving presenters and part of the equipment. This entertaining part was created as a 10-30 second closing, in order to encourage students to work hard and to show them that physics can be fun and, more importantly, is closely related to everyday life.

Fig.2. Video production of the experiment on moment of inertia.

CONCLUSIONS

With the help of students from our science communication course a set of video tutorials for physics lab experiments have been created. This tool offers several benefits in teaching first semester students innovatively, although further statistical and pedagogical investigations are required to quantitatively judge the impact of this teaching method. We have already received an overwhelming positive qualitative feedback from a number of students who were using the video tutorials in September 2015. In particular those students, who did not pass the labs during the previous year without video tutorials, were able to judge the new teaching using videos in comparison. We are aware of possible drawbacks of our approach, like a reduced imagination of real setups and processes based on written descriptions. The development of such skills have to be addressed within the curriculum, but not necessarily during the physics labs, so that introduction videos can become a helpful tool for teaching.

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FROM HEAT PUMPS TO HURRICANES: APPLICATION OF THERMODYNAMICS IN SECONDARY EDUCATION

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ABSTRACT

A short teaching unit was devoted to explore and understand the physics behind some natural phenomena and devices the operation of which are connected to thermodynamics. Besides to deepen the students' knowledge of thermodynamics, the aims were to raise their interest, to enhance collaborative work, and to emphasize the importance of environmental mindedness. In the present paper the main discussion points of the teaching unit and the experiences gained during the lessons and afterwards are presented.

INTRODUCTION

The students' decreasing interest for physics is a major problem of physics teaching, and physics teachers worldwide seek the possibility for the change of this tendency [1, 2]. In our opinion the investigation of the physics of the devices used in everyday life might be a good tool for this. Thermodynamics gives a lot of opportunities to raise the interest of students. The basis of the operation of many appliances and machines, (e.g.: refrigerator, air conditioner, heating systems of houses, engines of cars, jets etc.) and even a natural phenomenon, the hurricane can be discussed by some kind of thermodynamic cycles.

With one of my groups of students I spent 8 extra lessons to teach the thermodynamic background of some technical devices and the tropical cyclones. The aim on one hand was to raise the interest of the students. On the other hand, it gave the possibility to address the environmental issues as well. The students had to work in groups, they had to do some research on how the chosen device worked, and they also had to give an oral presentation to their classmates about what they learnt. Finally a questionnaire was given to them, in order to find out how much they learnt.

BACKGROUND AND TASK

In the academic year of 2014-15 I taught the first year of a 2-year preparatory physics course for the University. (The time allocation of the course was four 45-minute lessons per week.) Part of the course was to introduce the students the basics of thermodynamics: gas laws, kinetic gas model, processes (isothermal, isobaric, isochoric and adiabatic) and cyclical processes (including the terms efficiency and COP), and the laws of thermodynamics.

Two 45-minute lessons were spent on the thorough discussion of the idealised cyclic processes of the two most common car engines, the Otto and the Diesel engines.

The Otto cycle is easier, after introducing the equation of the adiabat the efficiency ($\eta = 1 - \left(\frac{V_2}{V_1}\right)^{\kappa-1}$, where V_1 and V_2 are the bigger and smaller volumes of the working substance, respectively, and κ is the ratio of specific heats) of the idealised cycle was derived.

Although the derivation needs some mathematical skills, (maybe in the case of a less able group it can be omitted) but the result is quite simple and it enables us to explain the terms compression ratio ($\frac{V_2}{V_1}$), octane number and the role of the spark plug. The calculation of the efficiency of the ideal Diesel cycle is a bit more demanding, so its formula was just stated, in order to show that (among other factors as well) it also depends on the compression ratio of the working substance [3]. Students can easily understand it, since in the case of Diesel engines air is compressed instead of the air–gasoline mixture, it is more compressible, therefore Diesel engines have greater efficiency. Students can also realise that these engines are heavier because for the greater compression stronger piston walls are needed.

Besides the discussion of the operation of these engines it is also substantial to explain the environmental impact of these engines. Students could be explained to that although Diesel engines have greater efficiency than Otto-engines, their exhaust fumes are more dangerous, because they contain more Nitrogen-oxides and particulate matter, which are both harmful pollutants [4]. After this introduction, students were given the task to research different devices which are operated either as a heat engine or a heat pump. They were given two weeks to work in groups and prepare for their presentations (as homework). Four 45-minute lessons were spent on discussion of these devices, and where it was relevant the environmental issues were addressed as well.

OTHER TWO HEAT ENGINES (EXPLAINED BY STUDENTS)

Two groups of students researched and made presentations about heat engines, one was the Wankel engine, and the other was the Stirling engine. Both groups found interesting details on the operations of the engines, and showed videos (found on the internet) to illustrate their operation.

Wankel engine is a spark ignited engine but it works differently from the usual four-stroke engines. Its common name is rotary engine, since the piston is rotating in an eccentric shaft. Its advantages are that it is small and simple, it has high power to weight ratio. Its disadvantages are that it needs frequent service, it has higher fuel consumption and its exhaust is harmful. The Japanese factory Mazda manufactures cars with this type of engine [5].

Stirling engine is a well-known engine among physics teachers, but not for the ordinary people. It is important because it is an external combustion engine, so it can be operated with any heat source, thus it can be more environmental friendly if the burning process of the fuel is complete. It has high efficiency, but less than the Carnot efficiency [6, 7], (this is stated wrongly in many cases) since the cyclical process consists of two isotherms and two isochors (and not two adiabats). Some disadvantages of this engine are for example that it is big and slow to ignite.

HEAT PUMPS

Before the discussion of heat pumps, it was recalled that heat pumps are reversed heat engines. The schematic figure of heat pumps is shown in Fig.1, where Q_C is the heat released by the cold heat reservoir, Q_H is the heat absorbed by the hot reservoir and W is the external work done.

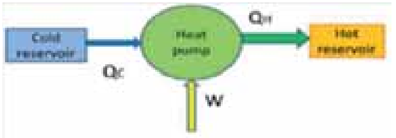

Fig.1. Schematic figure of a heat pump

Their "efficiency" is characterised by the so called coefficient of performance (abbreviated as COP). It was also pointed out that this COP is defined differently if the heat pump is used for heating or if it is used for cooling, depending on what is useful for us.

$$COP_{Heating} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C} > 1 \qquad (1)$$

$$COP_{Cooling} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C} \qquad (2)$$

Taking away (2) from (1) it can be seen that if the same heat pump is used for heating and for cooling, the difference between its COP values is one. In this sense heating is more efficient than cooling [8].

REFRIGERATORS AND HVAC (HEATING, VENTILLATING AND AIR CONDITIONING) DEVICES (STUDENT'S EXPLANATIONS)

For the technical application of heat pumps students found many different devices like refrigerators, the phase-change cooling system of computers, air conditioners, tumble dryers, and the different source heat-pump systems to heat buildings. In this paper only the refrigerators and the heating of buildings are presented.

The most widely used heat pump, which was developed first (more than a century before the first heat pump was used for heating) is the refrigerator. Students introduced the main ideas of both the vapour compression and the gas absorption type refrigeration systems. Although the cyclic process of the refrigerant is too difficult (in both cases), the essence that the refrigerant periodically evaporates and condenses in order to absorb heat from the evaporator and then to release heat in the condenser can be understood well. In the case of the compression type refrigeration system the evaporated refrigerant is compressed by an electrically powered compressor, so the cooling cycle can be repeated. In the case of the absorption type system the evaporated refrigerant is absorbed by some salt solution. This refrigerant-saturated absorber must be heated, in order that the refrigerant evaporates out, and in the heat exchanger it can condense again. Since the vapour compression refrigeration system has greater COP, it is more widely used, but the other is quieter, and can be operated with any type of heat like waste heat or solar power, and not just electrical energy.

The first practical heat pump system which was used for heating was proposed by Lord Kelvin in the 19th century, but heat pumps used for the heating of buildings were only introduced in the 20th century [8]. The operation of heat pumps that are used for domestic heating and air conditioning is similar to the operation of refrigerators. The great majority of these devices are vapour-compression systems. HVAC devices are usually classified according to their heat source: there are air, ground (sometimes called geothermal) and water source heat pumps.

Air source heat pumps are the cheapest, and most commonly used as air conditioners. They can also be used for heating, but since the temperature of air in winter can be very cold, the COP of these heat pumps decreases in the coldest days of the winter. Another disadvantage is that it may be noisy.

Ground source systems are stable, but far more expensive. Fig. 2 left panel shows the sketch of two types of ground source heat pumps. Either long horizontal trenches are dug (the total area where the collector pipes are laid is approximately 2-3 times of the area which is to be heated), or vertical boreholes are drilled (60-100 m deep). Both have COP approx. 4-5.

Fig.2. Left panel: Ground source heat pumps. Right panel: Water source heat pumps

Fig.2. right panel shows the two types of water source pumps. The first extracts the heat of the ground-water. (Two wells must be drilled, one is the source from which water is pumped up, and the other is the sink, into which the cooled water flows back.) This is the most efficient of all with a COP value of 5-7, but not the cheapest, the open-loop circuits need maintenance;

ground-water must be filtered. (In Hungary the Hotel Stáció near Vecsés is equipped with this type of HVAC system.) The last figure shows a system in which heat is extracted from a river or a lake, it is less disruptive than ground source, but the open-loop type may be cut-out in winter.

A simple estimation can be made for the COP of these systems. As an example consider the shallow vertical ground source system. It extracts heat from the ground at a temperature of 10°C and it releases it to the room at a temperature of 20°C. If the Carnot cycle's COP is used for the estimation we gain $\mathrm{COP}_{\mathrm{Carnot}} = \frac{293}{293-283} = 29.3$. In reality the heat pump is operated not between the heat reservoirs of temperatures 10°C and 20°C, but between colder and warmer ones. If the ground is at a temperature of 10°C the trench temperature is approximately 4 °C, the temperature of glycol which is flowing in the collector pipes may be at -1°C. The refrigerant temperature in this case might be only -10°C. Similarly in order that the radiators release heat to the room at a temperature of 20°C, the radiators must be warmer, let us estimate with 50°C, and the condensing temperature of the refrigerant must be even higher, approximately 60 °C. Again approximating the cyclic process of the heat pump with the Carnot COP, but using the -10°C and 60°C temperature values, we gain a much smaller coefficient of performance: $\mathrm{COP} = \frac{333}{333-263} = 4.75$. (These estimations were not calculated by the students, but not too difficult to understand.) [9] What is important to realise, is that heat pumps perform better if the difference between the temperatures of the hot and cold reservoirs is smaller. It means that in the case of domestic heating large heat exchangers are better, therefore wall or underfloor heating should be used rather than radiators.

ENVIRONMENTAL ISSUES TO DISCUSS

Heating with heat pumps is regarded as an environmental friendly way of heating, since it is considered a low carbon technology, but we should be careful. To operate the heat pump we (usually) need electricity, so the carbon emission of the heat pump also depends on how electricity was generated. The installation of the heat pump should be carefully planned, otherwise it may happen that the heat source gets exhausted of heat, its temperature decreases, thus the COP of the heat pump decreases as well, and it uses more energy.

Another important factor that scientists and engineers must consider is the question of refrigerants. In the beginning of the last century chlorofluorocarbons (CFC) later hydro-chlorofluorocarbons (HCFC) were used, but they caused the depletion of the ozone layer of the Earth. Now the most common refrigerants are hydrofluorocarbons (HFC), which do not ruin the ozone layer, but have very big global warming potential. (Approximately 1550 times as much as that of carbon dioxide.) Hydrocarbons (HC), ammonia (NH_3) or carbon dioxide (CO_2) can also be used as refrigerants, but unfortunately HCs are flammable, NH_3 is toxic, and CO_2 is not as efficient as the others [9].

NATURE'S HEAT ENGINE

Finally during two lessons the physical background of tropical cyclones were explained to the students. For the explanation of the formation of hurricanes, the Coriolis force was introduced to the students, and then the necessary conditions for Tropical cyclone genesis were explained [10]. (These are the following: at least 27˚C sea-surface temperature; instability of the air; high relative humidity, it should be at least 500 km away from the equator; surface vorticity; weak vertical wind shear.)

Fig.3. left panel shows the tracks and intensities of tropical storms observed between 1851 and 2006. It can be seen in the figure that there are no hurricanes close to the equator, because the Coriolis force is not big enough to make the air rotate. Also the already formed hurricanes never cross the equator.

The structure of a hurricane is shown in Fig. 3 right panel. If somewhere above the sea there is a depression, then air begins to flow there and then it rises. While the hot humid air rises, it expands and should cool down, but also the water precipitates and rains out, which warms back the air in the eye of the hurricane. The air which flows in above the sea, is rotated by the Coriolis force, in the Northern hemisphere in counter-clockwise direction, while at the top of the hurricane the air spreads out and is rotated in the opposite direction. In the figure it can also be seen that in the eye of the hurricane air is descending whilst in the eyewall it ascends. The heaviest storms occur in the eyewall, while in the eye there is neither wind nor rain. The regions in which air ascends and descends vary almost periodically in space.

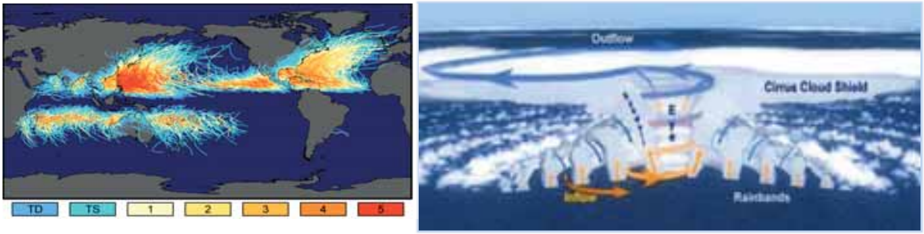

Fig.3. Left panel: Tracks and intensities of tropical storms (TD: tropical depression; TS: tropical storm; tropical cyclones are numbered from 1 to 5 in the order of increasing strength.) (source [11]), Right panel: Structure of a hurricane (source [11])

Meteorologists approximate the cyclic process of the hurricane as a Carnot cycle. The left panel of Fig.4. shows the ideal Carnot cycle of hurricanes, whilst on the right panel the p-V diagram of the cycle is indicated.

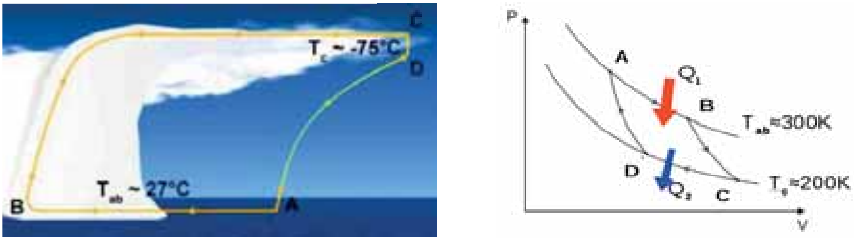

Fig.4. Left panel: the Carnot cycle of hurricanes (in space). (source [11]),
Right panel: the p-V diagram of the Carnot cycle

The processes can be described as follows: A→B (isothermal process): the warm surface of the ocean keeps the air at approximately constant temperature, which begins to flow towards the centre of the hurricane. B→C (adiabatic process): the saturated air begins to rise. During the adiabatic ascent, the air cools down and the water precipitates and rains out. When water changes from the gaseous to the liquid state heat is released, thus the centre of the cyclone remains hot. The ascent of air slows down and the air spreads out and gets far from the core of the cyclone. C→D (isothermal process): the temperature of the air is approximately constant in this zone; the air descends and gives off heat. D→A: adiabatic descent of air. After the explanation my students could easily calculate that the efficiency of the Carnot cycle of tropical storms is 1/3.

ASSESSMENT

At the end of the 8-hour teaching unit the students were given a questionnaire. In the first part the students were asked true-or-false questions based on the covered topics. (There were eight groups of questions, each containing 3 or 4 questions.) The percentage value of the number of students who answered correctly to each question is shown in Fig.5.

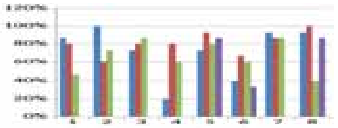

Fig.5. Percentage values of correct answers for the questions

As examples here are some of the questions: (the percentage values after them indicate the ratio of students who answered the question correctly)

2. c) In Diesel engines the pure air is compressed. (True) 73%

5. d) If the same heat pump can be operated in order to cool down and to heat up the room, then its COP is greater when it is used for cooling. (False) 87%

5. c) In the case of the gas-compression type refrigerators the condensing refrigerant absorbs heat from the environment. (False) 80%

6. d) In a hurricane the ascending wet air condenses and heats up the ambient air. (True) 33%

The second part of the questionnaire aimed to find out the students' opinion about the project. They had to give marks from 1 to 5 for the following questions: (1 meant disapproval, and 5 approval; each number after the question indicates the average of the given marks.)

Did you find it useful to prepare for your oral presentation? 4.46
Did you find the presentations useful? 4.15
Did you find the presentations interesting? 4.31
Did you learn from the presentations? 3.69
Would you like to learn this way in the future? 3.42

CONCLUSIONS

A new short teaching unit was elaborated for teaching the basis of thermodynamics with particular regard to its technical applications, and the environmental impact of the applications. The main purpose was to raise the student's enthusiasm to learn physics. The students worked in groups and researched different devices, and finally gave short presentations on their results. Most of the students were enthusiastic, inquiring, and enjoyed the lessons. The topics were worth discussing. Quite understandably the students found their own presentations the most useful, and probably they learnt the most from these. They also found the presentations interesting, but found a bit more difficult to learn from their classmate's ones. It can be seen that the idea of efficiency and COP, (particularly that of the Carnot cycle) has a central part in understanding the operation of the household technical units. However, in numerical calculations students need a bit more feedback and guidance to be able to apply these ideas independently.

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APPLICATIONS IN THE FOCUS: PHYSICS TEACHING FROM A NOVEL TEXTBOOK

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ABSTRACT

The National Curriculum of Hungary and the curriculum frameworks for all subjects were renewed in 2012. The curriculum framework "A" for physics corresponds to the Science Education Standards applied all over the world. Novel textbooks have been developed by the authors for teaching physics in secondary schools according to this curriculum framework. These textbooks were published by the Hungarian Institute of Educational Research and Development in 2015. They contain up to 30% of significantly new material, very close to everyday life, and the newly developed application-led classes. This paper presents the new textbook and some examples of the application-based classes.

INTRODUCTION

According to national surveys, we can say that physics education is in crisis in Hungary. Poor results of the PISA surveys and our teaching experiences made it clear to us that the majority of the students have serious problems in learning physics. We emphasize this fact not as a theoretical statement but rather as a practical consequence of the changes in physics teaching that have been made in the last decades. Another measureable fact is that students dislike physics and, as a consequence, there is a growing shortage of physics teachers in the secondary schools. One of the possible causes of this may lie within the inherent nature of the subject. Physics is a difficult subject to learn, requiring maximum effort, and the achieved grades may not always reflect the effort that students have paid [1]. For example, understanding modern physics needs strong abstraction far beyond everyday sensing. Further causes may arise from external circumstances. The time devoted to teaching physics in Hungarian schools has been reduced by approximately 50% during the last 25 years. In contrast to that, the content of the physics classes remained the same, or even increased. As a consequence, an average physics class today contains 40% of theory (definitions, laws, formulae), 40% of computational exercise and, only additionally, some practical knowledge about the applications and performing experiments. Young physics teachers often follow the way they where taught: standing in front of the board with a piece of chalk and explaining. This is the easiest way for the teacher, but not the best for the students.

PARADIGM SHIFT IN EDUCATION

The National Curriculum of Hungary and the curriculum frameworks for all subjects were renewed in 2012. Concerning physics, about 30% of new content appeared, in order to turn the subject into a more practical and useful one. Some examples from the new topics are: working principles of the radar and GPS, the way our cars get the energy to move (fuels), physical background of human live-functions and sensing, energy of the nutrition, physics of the weather and climate, global climate change, working principle of CCDs, and 3D displays, physical background of some medical therapies, etc.. These new topics give the teachers possibility and freedom to turn the traditional subject of physics into a more practical one.

The earlier paradigm for physics teaching was developed during the 1950s. According to this paradigm, the definitions of the physical quantities and the laws should be taught first, in their mathematical form. Every student should learn this scientific background and should be able to solve a set of basic computational exercises. The arrangement of the material, even the titles of the chapters, follow the order of the books used in universities. Applications are not in the focus of the teaching, or they have only supplementary role in the books and during assessment. From this point of view, following the logic of science, the material can be arranged only in a few ways: general mechanics is taught first, then the theory of heat, static electricity, electric current, electromagnetism, physical optics, atomic physics, nuclear physics, astrophysics.

At present there are two curriculum frameworks in Hungary. One of them, which denoted by the letter “B” follows this earlier paradigm of physics teaching. In curriculum framework “A” topics are not strictly arranged according to the logic of the science, but they try to follow the logic of everyday life instead.

Novel textbooks have been developed by our group and have been produced and published by the Hungarian Institute of Educational Research and Development (Fig.1.). At present at least fifty teachers have started to teach according to our textbook which follows more the logic of the appearance of the physical knowledge in everyday life than the logic of university books.

Fig.1. Cover of the new textbook for class 11 and an inner page, about the ways of transmitting television broadcast signals.

TOPICS OF THE TEXTBOOK

Let us provide a short list about the main topics of the textbook, following the order of their appearance:

class 9

Time scales and distances in the Universe, from the tiny up to the huge.

Physical background of transportation by vehicle. How are cars moving, how fast are they?

How to turn a car safely, what happens when we try to stop a car? How rockets work.

Movement of the objects of the Solar System: satellites, planets.

Energy, work and power: the main concepts.

Simple machines: torque and balance.

Waves and oscillations: La Ola wave, earthquake, resonance catastrophe.

Energy: The ways we consume energy, power stations, and many actual topics: calories, fuels, the Sun, passive houses, atomic energy, global challenges for mankind, energy crisis.

class 10

The water around us.

Motion of the air and water: winds, storms, oceanic streams, physics of flying and swimming.

Global environmental problems: ecological footstep and climate change.

How musical instruments work.

Sparkles and thunders.

Electric current: use of batteries

Safe usage of electric machines, domestic electric networks.

Creation and transportation of electric energy. Electric generators.

class 11

How do our eyes work? About eyeglasses, colours, the working principle of movies, imaging techniques in medical diagnosis (CT, MR, X-ray) and safety (X-ray at the airport).

Global communication: communicating via electromagnetic signals (television, mobile phone, digital coding of information).

What are things made of? Light sources, cameras, electrovoltaic cells, colours of different materials.

Radioactive radiation: medical applications, safety issues, nuclear power plants.

World of the stars: what does the star light tell us?

Universal questions: extraterrestrial life, “At the beginning…”, is it really written in the stars?

Physics of the Solar System.

Space exploration.

The topics mainly were selected because of their importance and strong presence in everyday life. We tried to cover almost each phenomenon which could be important for a kid to now. Despite of the fact that applications are in the focus, arrangement of the topics sometimes follows the traditional order of physics teaching. For example knowledge about mechanics can be found mainly in class 9 in the topic of the transportation, but the inner coherence of the topics are not as strong as usually, it is easier to change them or to omit some of them.

To summarize: according to this approach we should teach physics as it appears in our everyday life, in the streets, in the kitchen, in the household, during transportation, while using our mobile communication devices, when going to the cinema, etc.

Let's have an example about the waves. When we are teaching this topic according to the new book, the starting point of the teaching is not to give definitions of some quantities or draw up the definition of mechanical wave, transversal and longitudinal waves but to observe and examine the waves that are present around us. La Ola is similar to the shock wave, and a good example that a wave can transfer the energy in a certain direction without observable particle transfer. Students are interested in earthquakes, so it's a good chance to give them simple explanations of the surface and bulk waves produced by the earthquake (Fig.2.). At this point it's possible to speak about longitudinal and transversal waves as well, but the main aim is still not to define them very strictly, but to explain how the energy of the earthquake is dissipated and to expand the horizon of the students' mind.

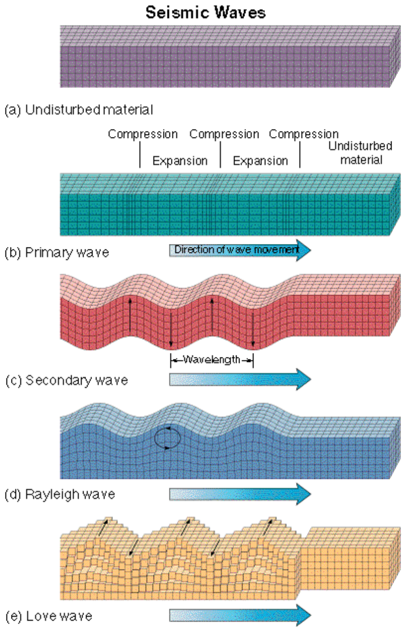

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Fig.2. Different types of waves produced by an earthquake [2]

Standing wave and its frequency are coming into the picture when we are explaining how the guitar is able to produce a sound. The main aim in a normal group (having 2 hours of physics per week or less) is not to teach the formula of the frequency of a standing wave on a string with fixed ends, but to develop the qualitative understanding about the working principle of the guitar – up to a certain extent.

There are many advantages and disadvantages of teaching in this way to consider thoroughly, but what is more, there is a possibility to observe the behaviour of the teachers and the progress of the students working with the new textbooks.

INNOVATIVE TEACHING METHODS

In order to understand the approach, it is important to keep in mind that the main aim is not to teach and make the kids memorize each and every useful fact found in the books. There are plenty of them and they can be found either in the book, or on the World Wide Web later. We neither aim at teaching more and more definitions and formulae, nor try to teach how to solve different types of computational problems. The aim is rather to give scientifically correct explanation of everyday issues up to a certain level of abstraction that is affordable for the pupils. This level depends on many factors and can be changed according to the prior/background knowledge of the children, and according to the aims of the school. It is good to use innovative methods that develop creativity, communication, cooperation and critical thinking of the students. These are accepted as the key competences for building a successful career in our quickly changing world.

Gamification is one of the promising innovative methods [3]. Look at the board (Table 1.) of the game with atomic energy levels. To start the game, our electron should stand in the ground state.

Table 1. Board of the physics game.

electron energy	-12 eV	-7eV	-4eV	-2eV	-1eV	0eV	1eV	2eV	3eV
electron state	ground	excited	excited	excited	excited	excited	free	free	free

After throwing the dice the electron can move from one energy state to another one. The rule is the same as in photon excitation: the electron can accept the energy (the number) only if it is equal to the energy difference between the present state and a possible excited state. A controlled trial experiment was performed at the University of Debrecen in 2014 to find out whether playing this game helps the students. There were two groups selected from first-year students with about 15 pupils in each. Both groups got the same lecture about photons, photoelectric effect, and energy levels of atomic electrons. Group B played the game as the application of the theory, while group A solved some computational exercises. After 3 weeks both groups wrote a test without previous announcement. Overall performance of the gamified group was slightly better than that of the other group.

Mobile phones are getting used widely in active learning because they can be used as measuring instruments [4]. Camera (CCD detector), microphone (sound detector for examining waves), three-axes accelerometer sensor can be found in every phone, ambient light sensor, magnetic field sensor are usually available. Popular applications (like compass, spectrum analyzer, metal detector) and applications for physical measurements (like Physics Toolbox) are quickly downloadable.

Using a frequency meter application, it is easy to tune empty bottles to create a musical sound with the desired tone [5] (Fig.3.).

Fig.3. Making music with bottles from [5]

In our experiment six groups were formed from the secondary school pupils, there were about three members in each groups. The task of each group was to tune their bottle into the desired note of the tonal scale (do, re, mi, fa, sol, la, ti, do). Members of one group calculated the frequency for each sound using the formula in the book; while others found a musical sheet for a simple song (see Fig.4.).

Formula for the simple major scale.

$$do\cdot\frac{9}{8}=re\,,\ re\cdot\frac{10}{9}=mi\,,\ mi\cdot\frac{16}{15}=fa\,,\ fa\cdot\frac{9}{8}=sol\,,\ sol\cdot\frac{10}{9}=la\,,\ la\cdot\frac{9}{8}=ti\,,\ ti\cdot\frac{16}{15}=do\,(1)$$
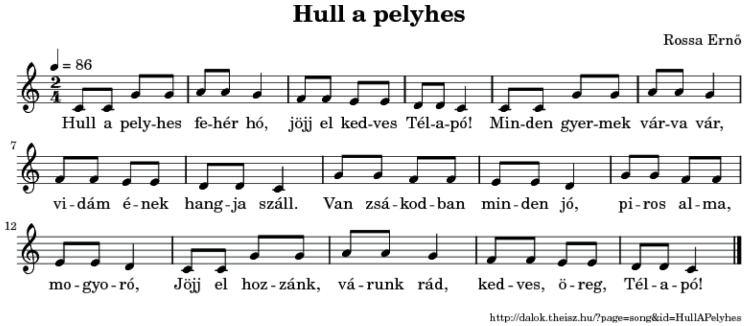
Fig.4. Sheet for a simple winter song starts with: do-do sol-sol la-la so, fa-fa mi-mi re-re do

At the end of the class it was possible to play a simple melody and that was a really good result of the cooperative effort.

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PUZZLING PROBLEMS ON GRAVITY

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ABSTRACT

Although Newton's gravitational law is simple to state, it leads to a rich diversity of motions ranging from parabolic projectile motion to chaotic dynamics. The tools applied in these problems are also versatile. Here a bunch of puzzling problems on gravity is presented with the basic ideas of their solutions. Each problem requires a kind of unique, individual method and each solution teaches us something new. Some of the results are surprising. Most of the presented problems are used in the preparation for the International Physics Olympiad, and their solutions are attainable by elementary, secondary school methods.

INTRODUCTION

Throughout the history of physics the understanding of gravity went through several metamorphoses. The law of gravitational attraction was discovered in the early 17th century by Sir Isaac Newton, who has also realized that the same law governs the motion of a falling apple and the motion of the planets around the Sun. Later, at the end of the 19th century Roland Eötvös experimentally proved with high accuracy the equivalence of gravitational and inertial mass. In the beginning of the 20th century this fact became a cornerstone of Albert Einstein's general theory of relativity, which interpreted the gravitational interaction as the curvature of spacetime. Today, in modern physics we know that gravity is one of the four basic interactions of Nature.

In this work we are going to study gravity at the secondary school level, based on Newton's law of gravity. Apart from the first problem we restrict attention to regular planetary motions. The basic tools used in the solutions of the problems are Newton's gravitational law, Kepler's laws, conservation laws (energy, angular momentum, momentum), the geometry of conic sections, and in the last problem the theory of non-inertial reference frames.

In the first chapter five simpler problems are discussed, which are important either because of their final result or because of the methods used in the solution. In the 2nd and 3rd chapters single, more difficult problems are addressed. They are slightly beyond the secondary school level because of the mathematics and the abstractions used there.

Variants of some of the problems discussed here and other similar problems can be found in [1]. These problems are used in the preparation of the Hungarian team [2] for the International Physics Olympiad [3].

BASIC INSTRUCTIVE PROBLEMS

In this section we review some simple and instructive problems.

Problem 1 (Long pendulum): Find the period T of a mathematical pendulum whose length L is comparable to the radius R of the Earth. Assume that the angular deviation is small and that the mass of the pendulum is close to the surface of the Earth.

Solution: Let *m* be the mass of the pendulum. There are two forces acting on this mass; the gravitational force and the tension of the rope, as indicated in Fig.1.

In case of small angular deviations the magnitude of both forces is constant *mg*. In terms of the small angles α and β indicated in Fig.1, the equation of motion (in horizontal direction) has the form:

$$mL\ddot{\alpha} = -mgL(\alpha + \beta), \quad \text{where} \qquad \alpha L = \beta R .$$

The solution of this equation is a simple harmonic motion with period $T = 2\pi\sqrt{\frac{LR}{g(R+L)}}$, which gives back the well-known formula for $L \ll R$.

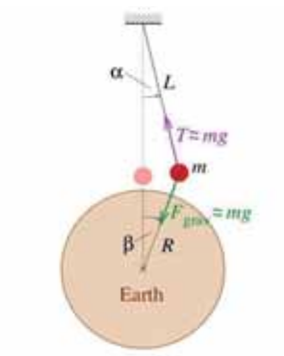

Fig.1. Forces acting on the long pendulum

Conclusion: The key point in the solution is that the magnitudes of the forces are constant (change only in second order of α) while their directions vary in first order of α. Generally, in the approximation of a vector field it is often useful to investigate separately the magnitude and direction of the vectors. This strategy is used also in the last problem.

The next problem is instructive for its own sake and it yields a result which can be used in other problems as well.

Problem 2 (Total energy of orbits): An object of mass *m* is orbiting another object of mass $M \ll m$. Express the total energy *E* in terms of the geometric parameters of the orbit. (These parameters are the semi-major axis *a*, the semi-minor axis *b* and the focal length *c*.)

Solution: First we assume that $E < 0$, so the orbit is an ellipse. Let r_P and r_A denote the distance of the perihelion *P* and aphelion *A* from the focal point at the central mass. The geometric relations between the distances indicated in Fig.2 are:

$$r_P = a - c , \qquad r_A = a + c , \qquad a^2 = b^2 + c^2 .$$

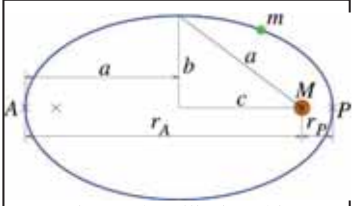

Fig.2. The elliptic orbit

The conservation of angular momentum and energy for the points *A* and *P* give the equations:

$$mv_A r_A = mv_P r_P , \qquad E_{ell} = \frac{mv_A^2}{2} - G\frac{mM}{r_A} = \frac{mv_P^2}{2} - G\frac{mM}{r_P} ,$$

where v_A and v_P are the speeds of the orbiting object at the points indicated in the subscripts. Eliminating the speeds and the focal length *c* from these equations, after a straightforward calculation the result

$$E_{ell} = -\frac{mMG}{2a} \tag{1}$$

is obtained. (The negative sign indicates that the elliptic orbit is bounded.)

If $E > 0$ then the orbits are hyperbolas. The geometry of the hyperbola is not so familiar to secondary school students as that of the ellipse, so it is worth discussing it in detail. Fig.3 shows the hyperbola with its asymptotes and the lengths *a*, *b*, *c*. The aphelion is at infinity, so:

$$r_A = r_\infty = \infty , \qquad r_P = |PF| = c - a , \qquad c^2 = a^2 + b^2 .$$

Again we have to use the conservation of angular momentum and mechanical energy between the point at infinity and the perihelion P:

$$mv_\infty p = mv_P r_P\,, \qquad E_{hyp} = \frac{mv_\infty^2}{2} = \frac{mv_P^2}{2} - G\frac{mM}{r_P}\,.$$

Calculations similar to the elliptic case give the result:

$$E_{hyp} = \frac{mMG}{2a}\,. \qquad (2)$$

Conclusion: The total energy of the elliptic or hyperbolic orbits depends only on the semi-major axis a, and it is independent of the other parameters (b, c) of the orbit.

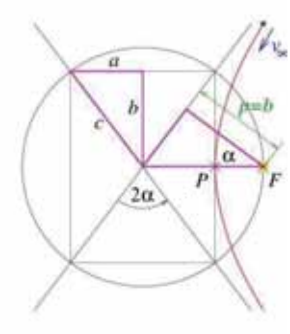

Fig.3. The hyperbolic orbit

Now we study in more detail another problem related to hyperbolic orbits.

Problem 3 (Deviation angle of hyperbolic orbits): A comet passes by the Sun. Determine its angle of deviation 2α in terms of the initial speed v_∞ (at infinity) and the impact parameter p (indicated in Fig.3).

Solution: With the use of the results of the previous problem the solution is simple. Using equation (2) and the formula $E_{hyp} = mv_\infty^2/2$, we get that $a = MG/v_\infty^2$. From Fig.3 it can be seen that $p = b$ and $\tan\alpha = a/b = \frac{MG}{pv_\infty^2}$.

Remark: Beside the conservation laws a key point of the solution is the relation $\tan\alpha = a/b$. This and the contents of Fig.3 should be discussed in more details in class [4].

Problem 4 (Racing satellites): Two satellites, A and B orbit the Earth on the same circular orbit, B lags behind A. How should B use its rocket in order to catch up with A? (Assume that the rocket can give only a quick impulse to the satellite.)

Solution: Our first, natural idea is to increase the velocity of B towards A. But this turns out to be wrong! Indeed, with this manoeuvre the total energy of the satellite is increased, so according to the result (1) of Problem 2, the semi-major axis a of the orbit increases. But due to Kepler's 3rd law, with increasing a the orbital period increases, too.

The above reasoning shows that paradoxically, the opposite manoeuvre has to be performed; the satellite should decrease its speed by giving an impulse opposite to its velocity. As a result of this, the satellite completes a faster cycle closer to the Earth, as indicated by the blue ellipse in Fig.4.

Fig.4. Satellite B decreases its speed

It is a nice exercise for practising first order approximations to find the relation between the change in the speed of the satellite Δv and the change in its period ΔT, provided that these quantities are small (relative to the total speed and total period, respectively). The result is:

$$\Delta T = \frac{6\pi R^2}{GM}\Delta v \qquad (3)$$

where M is the mass of the Earth and R is the radius of the circular orbit. The derivation of this formula is left to the interested students.

Problem 5 (Stopping the Moon): Imagine that the Moon's orbital motion around the Earth is suddenly stopped. How long would it take for the Moon to fall into the Earth? The orbital period of the Moon is T=28 days. (Assume that the Moon's orbit is a circle and neglect the Earth's motion around the Sun.)

Solution: The direct approach would be to solve the equation of motion but it is beyond the secondary school level.

A more tricky approach is to apply Kepler's 3rd law to compare the periods of the two different orbits of the Moon. The first orbit is the original circular orbit of radius R, period T=28 days and semi-major axis $a=R$. The second orbit is the degenerate ellipse corresponding to the motion of the Moon as it is falling into the Earth. The two foci of this ellipse are at the initial position of the Moon and at the Earth, so its semi-major axis is $a' = a/2$. Applying Kepler's 3rd law, the new period is $T' = T\sqrt{a'^3/a^3} = 2^{-\frac{3}{2}}T$. It means that the Moon would fall into the Earth in $T'/2 = 2^{-\frac{5}{2}}T = 4.95$ days.

ENVELOPING CURVE OF ORBITS

The problem discussed here is more difficult than the previous ones and it is for the best students.

Problem 6 (Enveloping curve of orbits): Let A be a fixed point in space at a distance d from a fixed sun S of mass M. Particles of mass m are shot from A in different directions at constant speed v. Which points can be reached by the particles? (Assume that v is small enough so the trajectories are ellipses.)

Solution: The arrangement has a rotational symmetry about the line AS, and all trajectories are planar curves, so it is enough to solve the problem in a single plane containing A and S. In this case our task is to determine the *enveloping curve* of a family of smooth curves.

Let us address this question generally. Let $\{C_\alpha\}_{\alpha\in I}$ be a family of smooth curves depending continuously on the real parameter α in the interval I, as shown in Fig.5. Pick two curves C_α and C_β corresponding to the parameter values α and β, and let K be their intersection point. It is heuristically clear from the figure that as $\beta \to \alpha$, the two curves come closer and closer to each other and their intersection K approaches a point of the enveloping curve, i.e.:

$$P_\alpha = \lim_{\beta\to\alpha} C_\alpha \cap C_\beta \ ,$$

where P_α is the point where C_α touches the enveloping curve. So a general point of the enveloping curve is the intersection of two curves lying very close to each other.

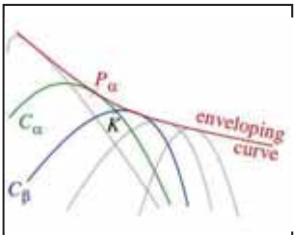

Fig.5. Enveloping curve of a family of curves

Now we return to the original problem. Since the speed v and thus the total energy E of the particles shot in different directions is the same, due to the result (1) of Problem 2, the semi-major axis

$$a = -\frac{mMG}{2E} = \frac{MG}{2MG - v^2 d}d$$

of the orbits is constant as well. Let us consider two elliptic orbits C_α and C_β lying close to each other, as indicated in

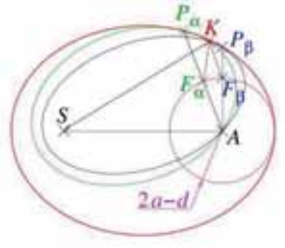

Fig.6. Two orbits (blue and green ellipses) touching the red enveloping curve

Fig.6. Let F_α, F_β denote their focal points (different from *S*), and let *K* be the intersection point of the two orbits (different from *A*). Since *A* is a point of both ellipses, $SA + AF_\alpha = SA + AF_\beta = 2a$, so $AF_\alpha = AF_\beta = 2a - d$. Thus the focal points F_α, F_β lie on a circle of centre *A*. Since *K* is also on both ellipses, $SK + KF_\alpha = SK + KF_\beta = 2a$, which means that $KF_\alpha = KF_\beta$. It means that in the limit $\beta \to \alpha$ the points *A*, $F_\alpha \approx F_\beta$ and $K \approx P_\alpha \approx P_\beta$ become collinear. Then for a general point P_α of the enveloping curve we have:

$$SP_\alpha + P_\alpha A = \underbrace{SP_\alpha + P_\alpha F_\alpha}_{2a} + \underbrace{F_\alpha A}_{2a-d} = 4a - d = \frac{2MG + v^2 d}{2MG - v^2 d} d,$$

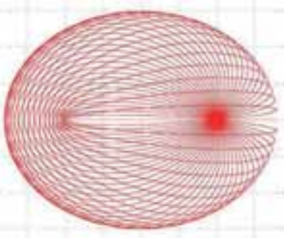

Fig.7. Many orbits fitting into the enveloping ellipse

so the enveloping curve is an ellipse of foci *A, S* and semi-major axis $2a - d/2$. Fig.7 shows a family of orbits which nicely fill out the enveloping ellipse.

Remark: Similar problems of finding the enveloping curves of certain trajectories can be formulated in optics (with light rays) and in hydrodynamics (with streams of fluids). The method discussed here helps in all cases.

MOTIONS OBSERVED FROM A SPACE STATION

In this section we discuss the motion of objects observed from a rotating reference frame. Non-inertial frames of reference and inertial forces are not involved in the Hungarian physics syllabus for secondary schools. The material of this section can be discussed in a special course for selected students after a systematic treatment of non-inertial reference frames and inertial forces [5].

Problem 7 (Motion around a space station): A space station is orbiting the Earth on a circular trajectory, facing always with the same side towards the Earth. A small object is thrown out of the space station with a small initial velocity **u**. How does the object move *relative to the space station*?

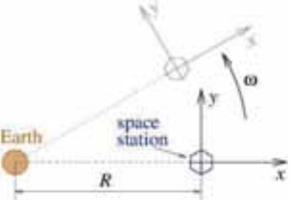

Fig.8. The reference frame of the space station

Solution: We solve the problem in the uniformly rotating reference frame of the space station. The axes are directed as indicated in Fig.8. The mass of the Earth and the small object are *M* and *m*, respectively. The radius of the orbit of the space station is denoted by *R*, and ω is the angular speed of the station. Furthermore, we shall use the constant $F_0 = GmM/R^2 = mR\omega^2$ to denote the magnitude of the centrifugal and the gravitational force acting on the small object in the space station.

We expand all forces acting on the object in first order of the position $\mathbf{r} = (x, y, z)$ and the velocity $\mathbf{v} = (\dot{x}, \dot{y}, \dot{z})$ components of the small object. As we have seen in Problem 1, it is advantageous to expand first the magnitude of the forces and then the direction.

In first order the magnitude and the components of the gravitational force are:

$$F_g = \frac{GmM}{(R+x)^2 + y^2 + z^2} \approx F_0\left(1 - \frac{2x}{R}\right), \qquad \mathbf{F}_g \approx F_g \begin{bmatrix} -1 \\ -y/R \\ -z/R \end{bmatrix} \approx F_0 \begin{bmatrix} -1 + 2x/R \\ -y/R \\ -z/R \end{bmatrix}.$$

(We have used the fact that $\sin(\varepsilon) \approx \tan(\varepsilon) \approx \varepsilon$ and $\cos(\varepsilon) \approx 1$ for small angles ε.)

Similar expansions for the centrifugal force are:

$$F_{cf} = m\sqrt{(R+x)^2 + y^2}\,\omega^2 \approx F_0\left(1+\frac{x}{R}\right), \qquad \mathbf{F}_{cf} \approx F_{cf}\begin{bmatrix}1\\ y/R\\ 0\end{bmatrix} \approx F_0\begin{bmatrix}1+x/R\\ y/R\\ 0\end{bmatrix}.$$

Finally the Coriolis force is:

$$\mathbf{F}_{Cor} = -2m\boldsymbol{\omega}\times\mathbf{v} = -2m\begin{bmatrix}0\\ 0\\ \omega\end{bmatrix}\times\begin{bmatrix}\dot{x}\\ \dot{y}\\ \dot{z}\end{bmatrix} = 2m\omega\begin{bmatrix}\dot{y}\\ -\dot{x}\\ 0\end{bmatrix}.$$

Substituting these expansions into the equation of motion $m\ddot{\mathbf{r}} = \mathbf{F}_g + \mathbf{F}_{cf} + \mathbf{F}_{Cor}$, after some simplification (cancellations) we get:

$$\ddot{x} = 2\omega\dot{y} + 3\omega^2 x, \qquad \ddot{y} = -2\omega\dot{x}, \qquad \ddot{z} = -\omega^2 z.$$

The last equation decouples from the other two and its solution is a harmonic motion with angular frequency ω in the z direction. Differentiating the first equation and using the second one, the equation $\ddot{v}_x = -\omega^2 v_x$ is obtained, whose solution is a similar harmonic motion. Taking into consideration the initial conditions $\mathbf{r}(0) = (0,0,0)$, $\mathbf{v}(0) = \mathbf{u} = (u_x, u_y, u_z)$, $\dot{\mathbf{v}}(0) = \mathbf{F}_{Cor}/m = 2\omega(u_y, -u_x, 0)$ we obtain the following solution:

$$\mathbf{r}(t) = \begin{bmatrix}x(t)\\ y(t)\\ z(t)\end{bmatrix} = \frac{1}{\omega}\begin{bmatrix}u_x\sin(\omega t) + 2u_y(1-\cos(\omega t))\\ 4u_y\sin(\omega t) + 2u_x(\cos(\omega t)-1) - 3u_y\omega t\\ u_z\sin(\omega t)\end{bmatrix}. \qquad (4)$$

Remark: It is worth discussing separately the special cases of the problem, when the initial velocity has only one non-zero component. It is also instructive to solve these special cases in the inertial reference frame of the Earth. The result (3) of Problem 4 can also be obtained from the general solution (4). We leave these investigations to the interested reader.

CONCLUSIONS

We have presented the solution of seven problems related to gravity, ranging from relatively simple ones to extremely difficult ones. Via these problems not only gravity, celestial mechanics can be taught to students, but many other things which are applicable in other branches of physics as well (e.g. approximation techniques, the geometry of conic sections, application of conservation laws, enveloping curves, non-inertial reference frames, differential equations, etc.). We hope that student readers enjoy learning physics from these nice problems and teacher readers think further some of the problems discussed here, and build into their own methodology some of the ideas presented here.

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FUNNY MOTIONS OF BILLIARD BALLS

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ABSTRACT

The rolling and slipping motions of billiard balls on a horizontal surface are extensively studied in the literature. Most of these phenomena can be understood in the framework of high school physics. The variety of the possible motions and the difficulty of the physical ideas behind them make this topic interesting for a wide range of students from classroom physics to the level of International Physics Olympiad (IPhO). In this paper we present some interesting problems and examples related to the motions of billiard balls, which can be used in the preparation of talented students for international physics competitions such as IPhO and APhO.

INTRODUCTION

The detailed description of the various types of motion of billiard balls can be found in the literature. Gustave-Gaspard Coriolis, the famous French physicist was the first theorist who wrote a book about the subject in the 19th century [1]. Although Coriolis's calculations are based on Newtonian mechanics, for a high school student it is hard to follow the tedious explanations due to the complicated geometry of the three dimensional motions. Even Arnold Sommerfeld mentioned this topic in his famous books on theoretical physics [2]. Without the details he sketches a proof based on the rotational and translational equations of motion about the parabolic trajectory of the center of a billiard ball after a Coriolis-massé shot (see Problem 2). In a more recent book written by Alciatore [3] the Coriolis-massé shot aiming method is analyzed in more detail. In addition to the proof of the parabolic trajectory Alciatore presents a calculation about the final direction of motion of the ball. Although this derivation is surprisingly short and elegant, the effect of friction between the ball and the table during cue stick impact is completely neglected. However, as Coriolis showed this friction has no effect on the final cue ball direction.

In the following discussion we want to show that the essence of these phenomena can be understood on a high school level. We discuss two different situations (Problem 1 and Problem 2) in which the application of the conservation of angular momentum provides a simple and elegant way of solution. We have used these problems in the last couple of years during the Hungarian preparation courses for the International Physics Olympiad. According to our experience, these kind of problems help the students deepen their knowledge and understanding about angular momentum and rotational motion. The problems presented here can be found in the problem collection written by the authors [4].

PROBLEM 1: MOTION ALONG A LINE

Problem 1. A ball, initially at rest on a billiard table, is struck by a cue tip at the point *T* shown in Fig.1. The cue lies in the vertical plane containing *T*, the centre of the ball *C*, and the ball's point of contact with the table *P*; consequently, so does the line of action of the resulting impulse. Construct the direction in which the cue should be aligned in order that after the shot, the ball's subsequent rotational and slipping motions terminate at the same instant and the ball comes to a halt. (As a result of chalking of the cue tip, the coefficient of friction between it and the ball is sufficiently large that there is no slippage between them during the cue stroke.)

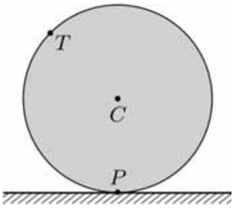

Fig.1. Position of the point of contact (P), the center of the ball (C) and the hitting point (T)

Solution 1. In general, after receiving an impulse from the cue, the billiard ball both rolls and slips and the instantaneous speed of its point of contact with the table is not zero. This 'grating' continues until, as a result of kinetic frictional forces, the velocity of that point relative to the table decreases to zero; after that, the ball continues to roll but without slipping.

Consider the point *P* at which the ball touches the table before the shot is taken. Note, that *P* denotes a *fixed* point *on the table*, and not the current contact point of the ball and table (which accelerates, or decelerates, during the stroke and the subsequent 'grating'). The total angular momentum of the ball about this point is zero before the shot, as well as at the simultaneous end of the rolling and slipping motions (when the ball again becomes stationary).

During the motion that follows the cue stroke, the net torque about *P* of the forces acting on the ball is zero, because the gravitational force and the normal reaction of the table cancel each other, and the line of action of the frictional force always passes through *P*. The angular momentum of the ball about *P* can only remain at zero throughout (from before the stroke until after the final halt) if it does not receive any during the stroke itself; this requires that the line of action of the impulse, and hence that of the cue, must be directed through point *P* (see Fig.2).

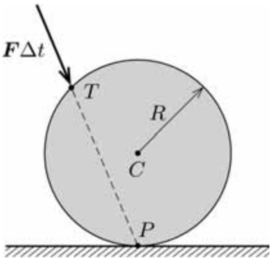

Fig.2. The direction of the cue must go through the point *P*

PROBLEM 2: MOTION IN 3D – THE 'CORIOLIS-MASSÉ' SHOT

Problem 2. If the line of action of the impulse in *Problem 1* does not lie in the vertical plane defined by the points *T*, *C* and *P*, then, just after the shot, the ball's angular velocity vector will not be perpendicular to the velocity of its centre of mass. Billiard players call this shot a *Coriolis-massé*.

Such a shot is shown in Fig.3, in which the line of action of the impulse meets the ball's surface (for a second time) at *T'* and the table at *A*.

a) What kind of trajectory does the ball's centre of mass follow from just after the shot until the point at which simultaneous rolling and slipping ceases?

b) In which direction, relative to the line *PA*, will the ball continue its path once it starts to roll without slipping?

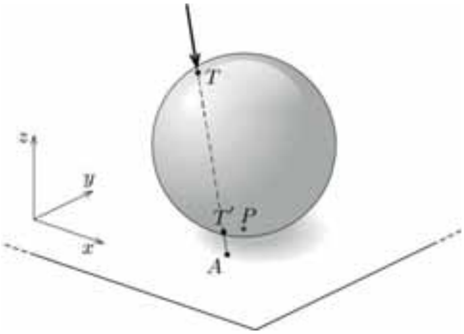

Fig.3. The direction of impulse in Problem 2.

(Assume that, whatever the downward force acting on it, the billiard cloth does not 'become squashed', and the ball's contact with it is always a point contact.)

Solution 2. Denote the vector pointing from the centre *C* of the billiard ball to its lowest point (where it touches the table) by $\boldsymbol{R}$, the mass of the ball by m, the velocity of its centre of mass by $\boldsymbol{v}$, and its angular velocity by $\boldsymbol{\omega}$.

As noted in the problem, for a general *Coriolis-massé* $\boldsymbol{\omega}$ will not be perpendicular to $\boldsymbol{v}$, and so the velocity of the lowest point of the ball,

$$\boldsymbol{v}_P = \boldsymbol{v} + \boldsymbol{\omega} \times \boldsymbol{R},$$

will not be parallel to the velocity of the centre of the ball, even at the start of the motion. A similar connection holds between the corresponding accelerations and the angular acceleration:

$$\dot{\boldsymbol{v}}_P = \dot{\boldsymbol{v}} + \dot{\boldsymbol{\omega}} \times \boldsymbol{R}. \qquad (1)$$

During the 'grating' motion, the horizontal acceleration of the ball and its angular acceleration are both caused by the frictional force $\boldsymbol{F}$, and so the dynamical equations for the translational and rotational motion can be written as follows:

$$\boldsymbol{F} = m\dot{\boldsymbol{v}},$$

$$\boldsymbol{R} \times \boldsymbol{F} = \frac{2}{5} m R^2 \dot{\boldsymbol{\omega}}.$$

Inserting expressions for $\dot{\boldsymbol{v}}$ and $\dot{\boldsymbol{\omega}}$, obtained from these two equations, into equation (1):

$$\dot{\boldsymbol{v}}_P = \frac{1}{m}\boldsymbol{F} + \frac{5}{2mR^2}(\boldsymbol{R} \times \boldsymbol{F}) \times \boldsymbol{R}.$$

Now $\boldsymbol{F}$ and $\boldsymbol{R}$ are necessarily mutually perpendicular, and so using either the right-hand rule or the vector triple product identity, it follows that

$$(\boldsymbol{R} \times \boldsymbol{F}) \times \boldsymbol{R} = R^2 \boldsymbol{F}.$$

So finally we have that

$$\dot{\boldsymbol{v}}_P = \frac{7}{2m}\boldsymbol{F}. \qquad (2)$$

The magnitude of the kinetic frictional force is μmg (where μ is the coefficient of friction), and its direction is opposed to that of the velocity of the lowest point of the ball:

$$\boldsymbol{F} = -\mu mg\frac{\boldsymbol{v}_P}{|\boldsymbol{v}_P|}. \qquad (3)$$

Combining this with equation (2), we have

$$\dot{\boldsymbol{v}}_P = -\frac{7}{2}\mu g\frac{\boldsymbol{v}_P}{|\boldsymbol{v}_P|}. \qquad (4)$$

Equation (4) shows that the velocity of the ball's lowest point has a constant direction throughout the simultaneous rolling and slipping motion, and that its magnitude decreases uniformly to zero at a rate of $-(7/2)\mu g$. It then follows from (3) that not only the magnitude of the frictional force, but also its direction, is constant. As this direction does not coincide with that of the initial velocity of its centre of mass, the billiard ball moves along a *parabolic* (rather than a straight) trajectory (see Fig.4).

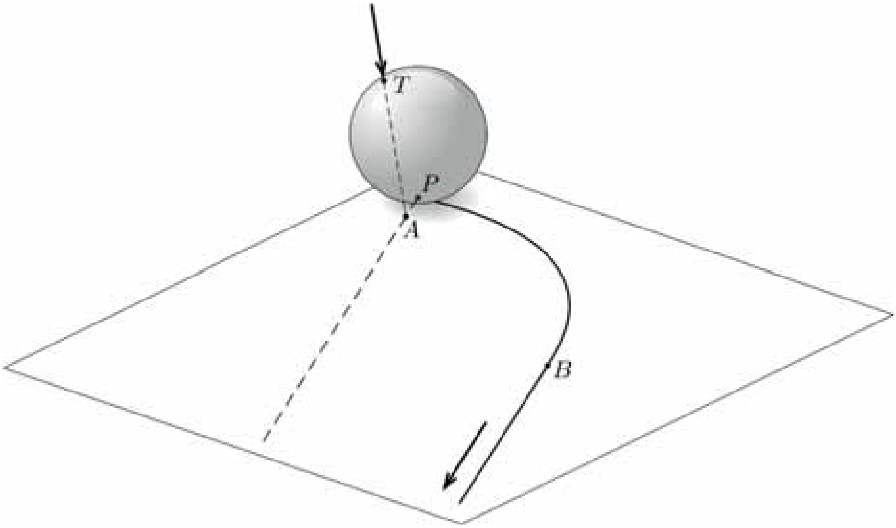

Fig.4. The parabolic trajectory of the center of the ball in the case of a Coriolis-massé shot

When the velocity of the lowest point of the ball becomes zero (this happens at *B* in Fig.4), the ball continues to roll, but without any slipping, until air drag and rolling friction bring it to a halt. Its straight-line path is along the tangent to the parabola at point *B*.

b) The final direction of the ball's motion can be found with the help of the law of conservation of angular momentum. We investigate the angular momentum of the ball about the line *PA*.

Angular momentum is a vector quantity, which is defined relative to a fixed (but arbitrarily chosen) *point* in space. But, it is also the case that a component of angular momentum in a given direction can be defined by an *axis* which lies in that direction. In this problem, for example - as will be shown later - the angular momentum of the ball relative to the *point P* is not conserved, but the component of angular momentum parallel to the line *PA* does remain constant.

Initially, the ball is at rest, so its angular momentum is zero. During the short time interval of the shot, the lines of action of the forces acting on the ball (the force of the shot exerted by the cue, the normal reaction force of the table, the frictional force, and the gravitational force) all pass through various points on the line *PA*. So, just after the shot, the angular momentum component defined by this line is also zero. This situation does not change as the ball moves along the parabolic arc *PB*, because the gravitational force and the normal reaction of the table cancel each other out, and the torque about this axis due to the frictional force is always zero (since the force and the axis lie in the same plane).

So, on the one hand, after finishing the 'grating' section of the motion the angular momentum vector of the ball remains constant -- it is horizontal, and perpendicular to the velocity of the centre of mass. But, on the other hand, as we have just shown, its component parallel to the line *PA* is zero. There is only one way to reconcile these two conclusions, and that is that the ball's path is *parallel* to the line *PA*.

CONCLUSIONS

In this paper we presented two sample problems which can be used to illustrate the usefulness of conservation of angular momentum when describing the quite complicated motion of billiard balls on a horizontal surface. Problems like these can be used for probing and improving the creative physical thinking of the gifted students, so such exercises could help the preparation of pupils for international physics competitions (such as APhO and IPhO) for high school students.

ACKNOWLEDGMENTS

We would like to thank Péter Vankó for his useful comments and remarks regarding the text of the problems and the solutions.

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BENEFITS OF IYPT IN PHYSICS EDUCATION

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ABSTRACT

The International Young Physicist´s Tournament (IYPT) is not a new thing in the world of physics education. Hungary has also been a successful participant of this competition since 1989. From the end of 2013 a new leader team helps the preparation of the Hungarian secondary school students. Since then we have been trying to invent and improve the teaching-learning process, which is based on the idea of IYPT and can help any participating Hungarian students to find their own way of getting better in physics. In this short article we would like to show how we are trying to improve the essential skills that are needed because of the special form of this competition – open ended problems, presentation, discussion etc.) - not only physics knowledge but much more!

INTRODUCTION / IYPT IN GENERAL

The International Young Physicist´s Tournament (IYPT, Fig.1.) is one of the most important worldwide physics competitions for secondary school students. It is also called the Physics World Cup [1], because it is not a competition for individuals but for teams. And this is not the only difference from the usual physics contests. Around 150 students of approx. 30 countries of the world are competing one another since 1988. This means as well that the official language of the tournament is English. Therefore, besides good physics knowledge students must have relatively high language and communication skills, too.

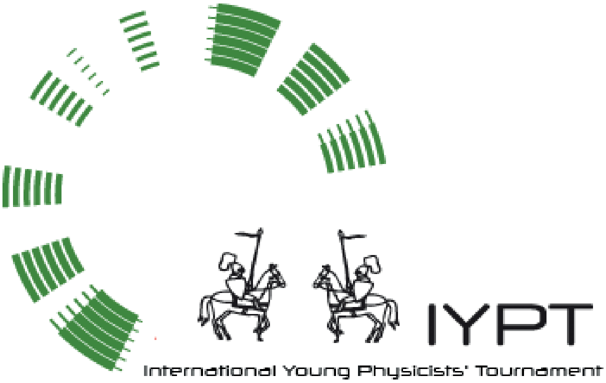

Fig.1. Logo of the IYPT [2]

The other very important specialty of IYPT is that the problems are 17 open-ended phenomena. This means that there are not any known solutions, for every precise result, the students have to work hard on their own. In the competition, students have to present their own results and defend it in a discussion with another opponent team. That needs obviously good presentation, discussion and communication skills. But to be honest, these skills are very important in the 21st century no matter if one is a physicist or not.

PROBLEMS IN IYPT

Every year after the actual competition, the International Organizing Committee (IOC) selects 17 open-ended problems. The problems are formulated in an easy and well-understandable short form. For such problems there are not any well-known solutions or even if there was a known physical background, the solutions of the different students would be very distinct from one another. Besides good knowledge of physics, creativity and preciseness in the measurements are essential to get a sufficient solution.

HOW TO SOLVE PROBLEMS?

Solving IYPT problems is a really hard task because of their complexity and not having an exact solution, but of course, it is not impossible. It takes significantly more time than finding a solution to a secondary school level theoretical exercise. The best way to describe the process is a year-long research (see Fig. 2.). To help students make the first steps, the IOC publishes a document called the Reference Kit, where some articles and webpages can be found which help getting the first ideas and objectives of a problem.

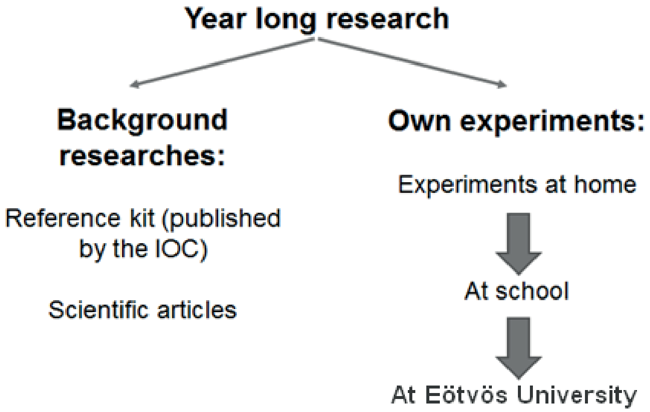

Fig.2. Structure of the preparation process

The Reference Kit is often not enough to set up the theoretical model, thus further investigation is needed from other scientific articles. Sometimes even physicists do not know what the exact explanation of the given phenomenon is, so students need to find out a simple theoretical model.

Since IYPT is about research, besides theory, conducting experiments has a major role in solving a problem. Choosing the right experiments and the right method is one of the hardest part in the process. Measurements are done at home firstly but usually the results are not precise and accurate enough, therefore a more sophisticated experimental method and apparatus is needed which can be found in secondary schools. After getting into the Hungarian team, students work in the laboratories of the Eötvös University where the required accuracy and precision can be obtained because of the better equipment, set-up and the help of the academic staff.

THE PHYSICS FIGHT

The main scene of the IYPT is called the Physics Fight (PF). During the tournament, each team has 5 PFs in which they compete against 2 or 3 teams from other countries depending on the number of participants. There are 3 main roles (see Table 1.), each team takes a role (in the case of 4-team fights, one team is just an observer), then they switch roles.

Table 1. Subjects of the three roles in a physics fight

Reporter	**Opponent**	**Reviewer**
- Presents own solution. - Defends it in a discussion.	- Gives an overview of the report. - Challenges the reporter in the discussion.	- Tests the knowledge of the reporter and the opponent. - Gives a review of the report and the discussion.

The structure may be complicated at the first sight but it is very logical (see Fig.3.) The first role is the reporter, who presents own solutions and defends it in a scientific discussion with the opponent. The opponent's job is to give an overview of the report and to challenge the reporter's understanding of the presented concepts; theories and principles in a discussion (see Fig.4.). The third role is the reviewer, who tests the knowledge of both the reporter and the opponent, and gives an objective summary of the report and the discussion. The performances of the reporter, opponent and the reviewer are graded by an international jury, whose members can test the knowledge of any of the 3 teams by questions. (see Fig.5.)

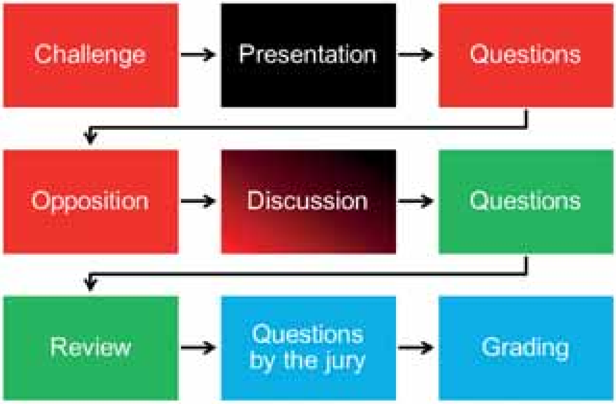

Fig.3. Structure of a physics fight

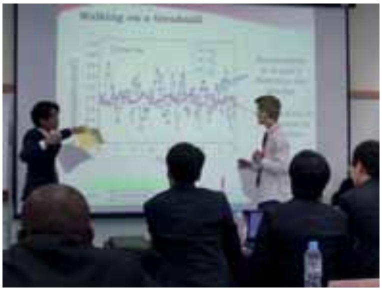

Fig.4. Discussion

Fig.5. Scores of the jury

BENEFITS FOR STUDENTS

Preparing for IYPT takes a lot of free time from students but it has numerous advantages. It is a significant opportunity for one to learn about some really interesting topics in physics which are not covered by secondary school curriculum. Also, they learn how to plan and conduct experiments, which is an essential skill for a physicist. Furthermore, they learn how to evaluate experimental data using basic and more advanced computer methods. After the national selection tournament, students work in pairs, this way teamwork can be learnt.

Fig.6. Hungarian team in an ancient Thai temple

They also spend significant time on meetings with the team leaders so they can get an insight into the work of a physicist. At the university high-class equipment is available which was never used by an average secondary school student. For those who get into the team, the IYPT is also a great opportunity to get to know different countries and cultures. (see Fig.6.) Above all, a really good community is built between the students and the team leaders.

DIDACTICAL ASPECTS

It is very important for us that every Hungarian high school student gets the chance to participate in the Hungarian selection process. To reach this aim, we publish a call to participate in the KöMaL (Mathematical and Physical Journal for Secondary Schools) every year in September. Furthermore, we send posters and calls for many Hungarian high schools directly and we are using the internet as well as possible. The selection process has three rounds. Each round is a bit different so we can improve a wide spectrum of skills [3].

The 1st round: writing a scientific essay. Till the end of November students have to investigate a self-selected problem and write a scientific essay in the limit of 8 pages in Hungarian language. The improved skills and capabilities in the 1st round are:

- reading scientific papers (English comprehension, finding the main points),
- doing own research (logical structure, precision),
- improving creativity (using physics in practice),
- cooperating with the teacher as a workmate (a new role for teachers and students, too),
- writing a scientific report (how to explain findings to others).

The 2nd round: Hungarian Young Physicist´s Tournament. This round is for the best 15 students based on the written essay mentioned above. In the middle of December students present their results in 10 minutes using English as the language of presentation. The jury is made up of professors of the Eötvös University. Beside the presentations the participants have to oppose an old IYPT presentation to show how good they are in finding the errors and shortcomings in someone's presentation. The best eight students can work further at the Eötvös University. The improved skills and capabilities in the 2nd round are:

- using criticism in a positive way (evaluation of the 1st round can help to improve the first results),
- creating appropriate presentation (logical structure, easy to follow and to understand),
- English language and presentation skills,
- getting deeper and more detailed physics knowledge in the selected problem.

3rd round: Selection of 5 team members for the team Hungary in IYPT. The selected 8 students work in pairs after the 2nd round. This is the first step of the team building. Since IYPT is a team competition, working together and team building are essential, just as they are in the real life. The team members can learn presentation and communication and IT skills from experts in the Hungarian IYPT committee.

To be a member of the 8 students' team is a great feeling for our students because they can work together with professors of the ELTE University. A laboratory is available for the IYPT students where they can conduct experiments in pairs under the supervision of the university professors. In the middle of March the best 5 students are selected after another presentation of their problems. The three students who do not make it into the team can participate in an international preparation contest, the Austrian Young Physicists' Tournament. Improved skills and capabilities in the 3rd round are:

- working in pairs and smaller teams,
- using lab equipment (mostly at Eötvös University but sometimes at the Technical University of Budapest and at Szent István University)
- presentation and communication skills.

NO FUTURE WITHOUT TRADITIONS

Whatever we have done in the last few years for the preparation of the Hungarian IYPT team, it was obviously not without antecedents. As it was mentioned at beginning of the article, Hungary has participated in the IYPT since 1989 with numerous [2] [4] medallions. The team leaders Zsuzsanna Rajkovits, Lajos Skrapits, Judit Illy, and Péter Kenesei between 1989 and 2012 were not only preparing the students for the competition, but also built the most important communication channels to students and teachers. Without their work and help it would have been impossible to reach a wider range of Hungarian students. Beside all of this they could evenorganize the IYPT in Budapest in 2000. Their work made an excellent basement for the cooperation with many physicists of the Eötvös University [4], which is essential for the future teams, too.

As a proof of the success of the former leaders we could mention many names of the former Hungarian teams who have become great engineers and physicists in many countries of the world. Some of these former participants help the further work of the Hungarian team. What could prove the success of the pioneer team leaders and the IYPT itself more than the ex-team members who join the Hungarian team of future physicists?!

CONCLUSIONS

The benefits of the IYPT, such as the preparation itself, are based on the modernity of this physics competition. The Hungarian education system actually raises mostly students who have a relatively huge amount of lexical knowledge but they are not practiced in working in teams. We have to face that the keys of success in the future are creativity, good practical sense and capability for teamwork. With this competition we can reach students who may not be the best in theoretical physics but are capable of learning by doing. Meanwhile our students improve their communication, presentation and language and team-working skills which help them to be successful in their entire life!

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MIKOLA COMPETITION

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ABSTRACT

Back in 1981 it was realized that there is no nation-wide competition in physics for the ninth and tenth grade high school students. To be able to recognize students talented in physics as early as possible, a new competition named after a famous Hungarian physics teacher Mikola was organized for them. The competition consists of three rounds. The first and second rounds mainly focus on theory and problem solving. The final round consists of both theoretical questions and experiments. The usual venues of the finals are the Berze High School in Gyöngyös (ninth grade) and Leőwey High School in Pécs (tenth grade). This year (2015) the 34th Mikola competition was held.

INTRODUCTION

Between 1978 and 1980 a new curriculum was introduced in Hungary. According to this curriculum physics began in the high schools at the ninth grade. In 1981 it was realized that there is no nation-wide competition in physics for the ninth and tenth grade students. To be able to identify students talented in physics as early as possible, it was desirable to organize one. In the following a short history of the competition and, to illustrate the spirit of the competition, an example from the problems of it will be shown.

SHORT HISTORY

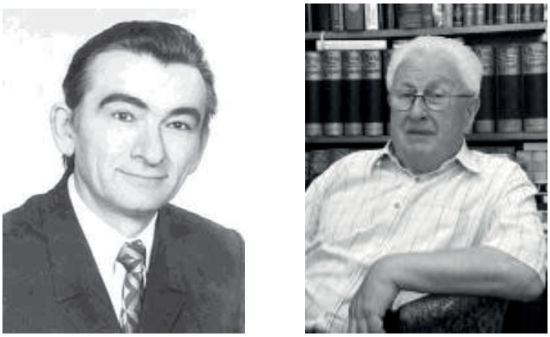

Fig.1. Left panel: Lajos Kiss (1939-1995). Right panel: Márton Nagy [1]

International Physics Olympiad (IPhO) was established in 1967 by Czechoslovakia (Rostislav Kostial), Poland (Czesław Ścisłowski) and Hungary (Rezső Kunfalvy and Géza Tichy). When the Hungarian organizers were looking for new members for the students' Olympic team, they recognized that there is a need for a nation-wide competition in physics for the 9/10th graders. With the help of György Marx a new competition was founded for them. The two organizers of the finals were Lajos Kiss (Berze High School, Gyöngyös) and Márton Nagy (Berzsenyi Dániel Gimnázium, Sopron) Fig.1.

1981/82: The first competition was held with two rounds (regional and national). In the first round only two students per school could participate. The final was held with 40-40 participants. 1982-84: The competition was adopted by the Ministry of Culture as a nationwide physics contest for talent scouting. (Its Hungarian name was: Országos Középiskolai Tehetségkutató Tanulmányi Verseny, OKTTV). In the next academic year (1985/86) the competition had already got three rounds. In its first round the number of participants was not limited, and separate categories were introduced for high school and vocational school students. 1986/87: The competition got its present name after Sándor Mikola, the famous Hungarian physics teacher. The homepage of the competition (edited by Miklós Kiss) started in 1998. From 2001 it was edited by Gergely Kiss. In 2008 the four-day finals were changed to a three-day one.

ROUNDS OF THE COMPETITION

In the first and second rounds of the contest students should solve theoretical problems. Participants reaching a 50% result in the first round can enter into the second round where the best 40 or 50 students are selected for the finals of both grades. Finals are in 2 parts. The theoretical competition consists of some theoretical questions (problems). In the practical exam the competitors complete one or two experimental problems in a laboratory. Initially the number of first-round participants was a few thousand but unfortunately this number is decreasing continuously. The venues of the finals (Figs.2. and 4.) are the Berze High School in Gyöngyös (nine graders) and Leőwey High School in Pécs (ten graders), the latter was held earlier in Sopron.

Fig.2. Left panel: 1999 (Zoltánné Bóna, Dr. László Zsúdel, Béláné Farkas, Miklós Kiss). Right panel: 2000 (Miklós Kiss, Andrea Gyebnárné Nagy, András Mester, Dr. József Kopcsa, János Suhajda, Dr. László Zsúdel, Dr. Péter Czinder)

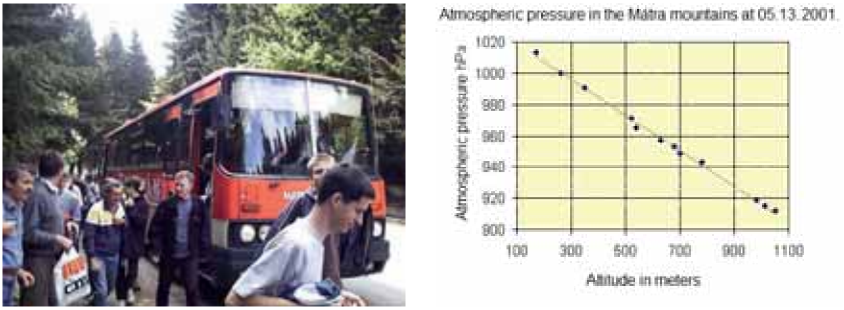

Fig.3. Left panel: 2001 A trip to Kékestető. Right panel: Air pressure in the Mátra Mountains

Fig.4. Left panel: Péter Simon, president of the jury and Ádám Varga, the winner in 2008. Right panel: 2014 Measuring in the BERZELAB

The program of the competition often included a short excursion to the countryside where the participants performed physical experiments, too. Fig.3. shows the result of the atmospheric pressure measurement performed during a trip to the highest mountain of Hungary. The competition is closed with a ceremony of the announcement of the results. The ceremony begins with a scientific presentation which is delivered by a well-known Hungarian physicist. (You can see more pictures at the homepage [2]. A complete report about the 27th final is in [3]. Results, problems, measurements and solutions are in the references [2-10]).

EXAMPLE: THE MEASUREMENT TASK IN THE 33RD FINALS

Investigation of non-central collision of coins

Devices:

-1 pc 50 HUF coin

-1 pc 5 HUF coin

-2 pcs template to mark the centre of the coins

-1 pc short ruler

-1 pc long ruler

-1 pc triangle ruler

-1 pair of compasses

-2 pcs A3 measuring sheets of paper

-Blu-tack (glue)

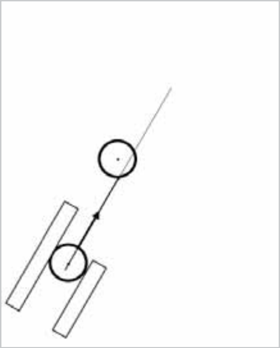

Fig.5. The arrangement of the coins and rulers

The measurement

Investigate the non-head on collisions of coins. The target coin is at rest, while the velocity of the other coin (the projectile coin) can be varied. Let the angle between the velocity vector of the projectile body and the line going through the centres of the coins be 45°. The figure (Fig.5.) and the measuring sheet prepared in advance help to set up. The initial and final position of the coins can be marked on the measuring sheet. It is advisable to fix the rulers with the blue-tech. Templates may help to mark the centre of the coins.

It can be assumed that the coefficient of kinetic friction is the same for every coin.

Make a plan for the evaluation of the measurement!

Tasks:

1. Verify that the velocity of coins is proportional with the square root of the covered distance.

2.

a) Collide the fifty-forint coin with the five-forint coin, which is at rest. Mark the positions of the coins at the moment of the collision and where they stopped.

b) Measure the displacement of the coins. (The direction of the motion of the projectile coin will also be required.)

c) Determine the velocities of the coins after collision. The velocities can be given in convenient arbitrary (freely chosen) unit.

d) Measure the angle of velocities after collision.

e) Construct the velocity of the five-forint coin. Determine the mass ratio of the fifty-forint and five-forint coins.

f) From the measured data determine the collision number (coefficient of restitution) and the energy ratio. (The latter is the ratio of the whole energy of the two coins after collision, divided by the energy of the projectile coin.)

3. How does the measurement verify the assumption concerning the coefficient of kinetic friction?

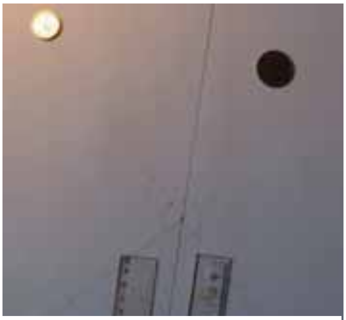

Fig.6. The initial and final position of the coins

The initial positions of the coins should be indicated in advance (Fig.6.). Draw the coins around and mark the centre of the coins with the template. Care should be taken to ensure that the displacement of the coins is determined relative to their own initial position.

Fig.6. shows the result of a collision. After the collision the coins are at rest. The position of the coins at the moment of the collision and the line of the projectile velocity inclining 45° to the line through the centres of the coins are also denoted in the figure. From the magnitudes of the displacements after collision, the velocities can be gained in arbitrary units:

$$v_1 \sim \sqrt{s_1} \text{ and } v_2 \sim \sqrt{s_2} \tag{1}$$

Using the momentum conservation law for the collision we get:

$$M\mathbf{v} = m\mathbf{v}_1 + M\mathbf{v}_2 \tag{2}$$

where M and m are the mass of the fiftyforint and that of the five-forint coin, respectively. In the equation $\mathbf{v}$ and $\mathbf{v}_1$ are the velocities of the fifty-forint coin before and after the collision and $\mathbf{v}_2$ is the velocity of the five-forint coin. The momentum equation can be transformed to a velocity addition rule, where $\frac{m}{M}\mathbf{v}_1$ is called the modified velocity of the projectile coin:

$$\mathbf{v} = \frac{m}{M}\mathbf{v}_1 + \mathbf{v}_2 . \tag{3}$$

This provides a way of construction. Having known $\mathbf{v}_2$ (direction and magnitude), and the direction of $\mathbf{v}$ a parallelogram can be constructed and the value of $\frac{m}{M}\mathbf{v}_1$ can be determined. Comparing this with the magnitude of $\mathbf{v}_1$ the mass ratio can be obtained:

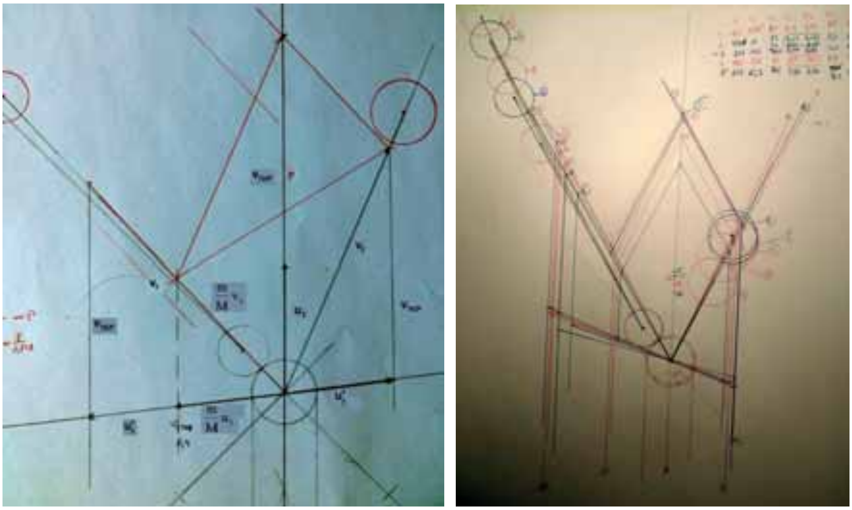

Fig.7. Left panel: Construction of the parallelogram from a measurement, Right panel: Construction of the parallelograms from many measurements

$$\frac{m}{M} = \frac{\frac{m}{M} v_1}{v_1}. \tag{4}$$

By the use of the mass ratio the velocity of the centre of mass can be determined.

$$(m+M)\mathbf{v}_{TKP} = m\mathbf{v}_1 + M\mathbf{v}_2 = M\mathbf{v} \tag{5}$$

$$(m+M)\mathbf{v}_{TKP} = M\mathbf{v} \text{ hence } \mathbf{v}_{TKP} = \frac{M\mathbf{v}}{m+M} = \frac{\mathbf{v}}{\frac{m}{M}+1} \tag{6}$$

Subtracting this from the velocities (cf. Fig.7.) we get the velocities in the system of the center of mass: $\mathbf{u}$, $\mathbf{u}_1'$ and $\mathbf{u}_2'$, $\mathbf{u} = \mathbf{u}_2 = \mathbf{v} - \mathbf{v}_{TKP}$. In this system the whole momentum of the colliding bodies both before and after the collision is zero. Therefore $\mathrm{mu}_1 + \mathrm{Mu}_2 = \mathrm{mu}_1' + \mathrm{Mu}_2' = 0$. Hence:

$$\frac{m}{M} u_1 + u = \frac{m}{M} u_1' + u_2' = 0. \tag{7}$$

It shows that the vectors which are on the same side of the equation are opposite ones.

Now we can calculate the collision number as well:

$$k = \frac{p_{2TKP}'}{p_{2TKP}} = \frac{u_2'}{u_2} = \frac{u_1'}{u_1} \tag{8}$$

The energy ratio is:

$$\varepsilon = \frac{\frac{1}{2}mv_1^2 + \frac{1}{2}Mv_2^2}{\frac{1}{2}Mv^2} = \frac{\frac{m}{M}v_1^2 + v_2^2}{v^2} = \frac{\frac{m}{M}s_1 + s_2}{s} \qquad (9)$$

where s is given from the square of the initial arriving velocity.

Table 1. Measurement data

	s1	v1	s2	v2	p2	p1	p	m	v_{TKP}	p_{2TKP}	$p_{2'TKP}$	k	s	ε	α
1.	149	12,21	131	11,45	11,45	6,7	15,3	0,55	9,88	55	46	0,836	234,1	0,91	66
2.	165	12,85	67	8,19	8,19	6,5	13	0,51	8,63	44,5	35,4	0,796	169,0	0,89	54
3.	121	11,00	51	7,14	7,14	5,9	11,5	0,54	7,49	40	32,5	0,813	132,3	0,88	58
4.	201	14,18	78,5	8,86	8,86	7,3	14,4	0,51	9,51	49	39	0,796	207,4	0,88	58
5.	186	13,64	81	9,00	9,00	6,8	13,9	0,50	9,28	42	36,5	0,869	193,2	0,90	56
6.	151	12,29	78,5	8,86	8,86	7,1	14,1	0,58	8,94	51,5	38,5	0,748	198,8	0,83	58
							average:	0,53				0,809		0,88	58,33
							deviation:	0,03				0,041		0,03	4,08

The actual mass ratio is $\frac{m}{M} = 0.555$. The calculated result agrees well with the real mass ratio of the coins.

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ON THE FIRST YEAR STUDENTS OF THE PHYSICS TEACHER TRAINING PROGRAMME AT EÖTVÖS UNIVERSITY

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ABSTRACT

Eötvös Loránd University (ELTE) is the most prestigious university in Hungary in the field of teacher training. However, since there is no entrance exam, many physics students lack even an average level knowledge of high school physics. To overcome this problem new courses were introduced to the physics teacher training program, where high school physics is taught. Still, experience has shown that these courses are efficient only for approximately 40% of the students. The reason is that besides the absence of physics knowledge, students also have problems with mathematical knowledge, formal thinking and some basic skills, like reading comprehension, study skills, and note-taking skills.

INTRODUCTION

Most of the papers concerning physics teaching deal with teaching in high school or secondary grammar school. Since the introduction of the new university admission system in Hungary, questions of high school level teaching also appear on the undergraduate level.

One of the reasons is that physics students are admitted to the universities primarily based on the results of their high school final exams of two subjects of their choice from the following list: biology, chemistry, geography, informatics, mathematics, and physics. That is, students can be accepted at universities (including the most prestigious universities) without a significant background in physics. Moreover, the minimum score for admission is rather low for the physics-related courses, especially for the teacher training programme. In order to handle the situation, extra physics courses were introduced for students with incomplete high school physics knowledge. These extra courses were mandatory for approximately 70-80% of the admitted students.

In this paper some typical (high school level) problems are studied that were found hard-to-understand for at least 30 % of the students taking the extra physics courses. The observations are based on the monitoring of individual problem solution and midterm exams of approximately 20-40 students per semester for 6 semesters. Notice that the difficulties of the students arose not just when they first met the problems, but also when the problem types were already discussed in detail in class.

EXAMPLE 1. GRAPH-DRAWING, INTERPRETATION OF GRAPHS

Problem 1. A car is moving along the x-axis according to the graph of velocity versus time (Fig.1., left panel). Determine the position of the car as a function of time. The starting position is $x=0$ m.

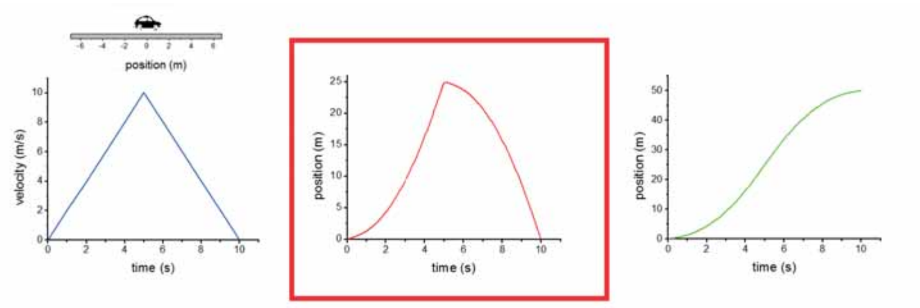

Fig.1. Motion in one dimension. Left panel: the velocity-time function given in Problem 1, middle panel: the typical incorrect answer, right panel: the correct solution

The middle panel of Fig.1. shows the typical incorrect answer. According to the (wrong) solution, after reaching the maximum velocity, the direction of the motion changes. The wrong answer originates from correlating the slope of the velocity-time function to the direction of the motion, i.e. if the slope of the function $v(t)$ is positive, the car goes in the positive direction, and in case of negative slope the direction of the motion is negative. However, it is obvious that the direction of the motion does not change, since the velocity is still positive.

In order to change this concept it is effective to link the negative velocity to an “activity-image”, e. g. to back up. The discussion of problems of the following kind is also useful.

Problem 2. Draw the velocity-time function of the following stories. Kati would like to go shopping. The shop is along a long and straight road.

a) First she rides on a bicycle. For 30 *s* she accelerates to 5 *m/s*, then rides at constant velocity for 15 minutes and when she notices the shop, she starts to decelerate for 20 *s*, then she stops.

b) Second she goes by car. It takes 2 minutes to accelerate to 20 *m/s*, then travels with constant velocity. Unfortunately she notices the shop too late, so after deceleration for 20 *s* she has to back up: she accelerates to 5 *m/s* for 1 s, then decelerates to zero to stop at the shop.

EXAMPLE 2. NEWTON’S LAW.

Problem 3. A hockey puck struck by a hockey stick is given an initial speed of 20 *m/s*. The puck slides 120 *m* on the ice, slowing down steadily until it comes to rest. Determine the coefficient of kinetic friction between the puck and the ice.

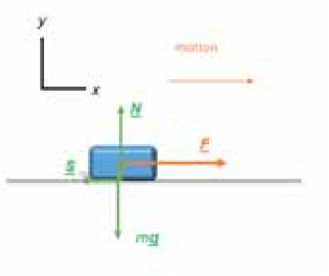

Fig.2. The free-body diagram of the motion of a hockey puck. The introduced force ***F*** indicates that the student uses Aristotle's concept of physics. (The vectors on the figure are a bit shifted for the sake of clarity.)

Since the puck moves to the right, many students think that there must be a force ***F***, which acts on the puck in the direction of the motion, and therefore they write Newton's law in the x direction in the following form:

$$F - S = ma, \tag{1}$$

where S is the friction force. This means that these students think the force is related to the velocity of the object, i.e. they use Aristotle's concept of physics.

One possibility to avoid the introduction of non-existing forces is to emphasize that force is the consequence of interaction. Here the puck interacts only with the ice (the origin of forces ***S*** and ***N***) and with the Earth (***mg***). Therefore force ***F*** is not a consequence of interaction (in an inertial frame), thus it does not exist, so Newton's second law gives

$$-S = ma. \tag{2}$$

EXAMPLE 3. VECTORS, ABSTRACTION

Problem 4. A man pulls a 2 *kg* box on a frictionless incline with a horizontal force ***F*** ($F=20\ N$) upward. The acceleration of the box is 3.66 m/s^2. Determine the angle of the ramp with the horizontal.

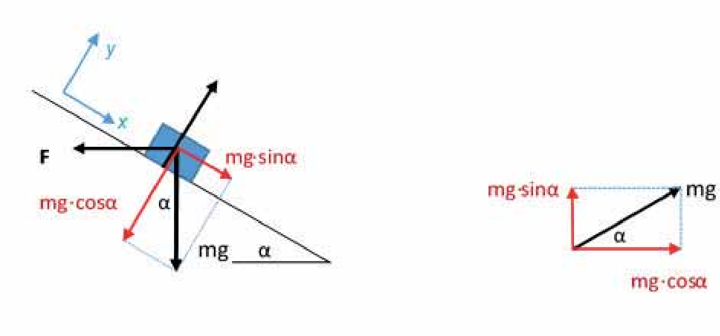

Fig.3. Left panel: The free-body diagram of a box pulled with horizontal force. Right panel: computing the components of the gravitational force in the "usual" coordinate system

The strategy to solve this problem is to compute the x- and y-components of the forces using trigonometry. (The x-axis is parallel and the y-axis is perpendicular to the slope.) By taking the sum of the x-components one can obtain the x-component of the resultant force, which is *ma*, according to Newton's second law. (Here *m* and *a* are the mass and the acceleration of the box, respectively.)

Approximately 35% of the students cannot determine the components of the forces in the tilted coordinates in Problem 4, though they can determine the components in the "usual" coordinate system (with horizontal and vertical axes) (Fig.3., right panel). Many students just memorize the x- and y-components of *mg* exerted on the object on a slope inclined at an angle α. These students typically lack the mathematical skills needed to solve an equation or an equation system, where the coefficients are not given constants, therefore missing the chance to understand how the result depends on the coefficients.

EXAMPLE 4. FRICTION FORCE

Problem 5. A block of mass $m=3\ kg$ is pulled by a string with a force $F=10\ N$ at angle α above the horizontal. Determine the coefficient of kinetic friction (μ), if the block/sled moves with constant velocity.

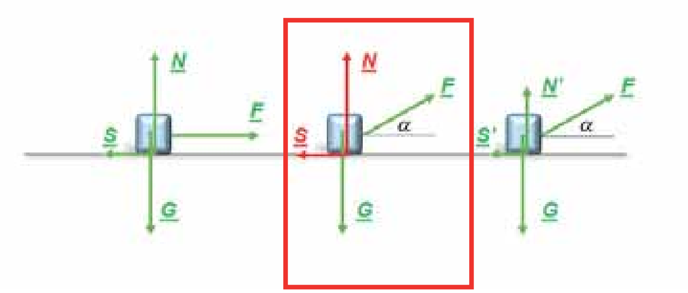

Fig.4. Changes in friction force and normal force as the angle of the pulling force is changing from zero (left panel) to *α* (right panel) and the typical incorrect answer (middle panel)

In the case of $\alpha = 0°$ almost everyone finds the correct solution. The two components (horizontal and vertical) of Newton's second law for the block/sled are:

$$F - \mu \cdot mg = m \cdot a = 0 \tag{3}$$

and

$$N - mg = 0. \tag{4}$$

However, many students use the same equations also in case of $\alpha > 0°$: $F \cdot \cos\alpha - \mu \cdot mg = m \cdot a = 0$ and $N - mg = 0$. These students think that changing the angle of the string does not have an effect on the friction force (and the normal force). As it is well known, the vertical component of the pulling force reduces the normal force to

$$N = mg - F \cdot \sin\alpha, \tag{5}$$

and therefore the friction force is

$$S = \mu \cdot (mg - F \cdot \sin\alpha). \tag{6}$$

Thus Eq. (3) must be changed to

$$F \cdot \cos\alpha - \mu \cdot (mg - F \cdot \sin\alpha) = m \cdot a = 0. \tag{7}$$

EXAMPLE 5.

Problem 6. A uniform horizontal beam of length 2 *m* and weight 300 *N* is attached to a wall by a pin connection that allows the beam to rotate. Its far end is supported by a cable that makes an angle of 30° with the horizontal. Find the magnitude of the tension in the cable. Indicate the forces acting on the beam.

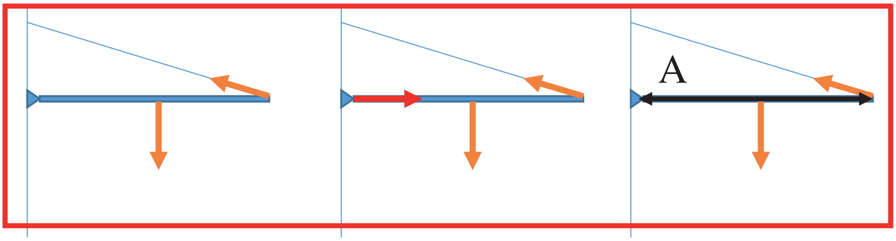

Fig.5. Problems emerging during the solution of Problem 5. Left panel: missing force, middle panel: misdirected force, right panel: wrong determination of the lever arm

More than 50 % of the students commit (at least) one of the following mistakes:

1) They forget about the force on the beam exerted by the wall, therefore on the free-body diagram only the gravitational force and the tension in the cable are identified. (Fig. 5, left panel).

2) They notice the force exerted by the wall, but they think its direction is the same as the direction of the beam (horizontal, in this case) (Fig. 5, middle panel).

3) During the calculation of the torque, the lever arm is taken as the distance between A and the point of application of the force, where A corresponds to the axis of rotation, perpendicular to the plane.

The first five examples suggest that the introduction of extra courses for approximately 70-80% of the students is unavoidable, since without these courses students cannot make up for their shortage in high school physics and mathematics. However, there are other types of problems as well. The average result of a test concerning definitions and formulae is about 60% if the test was announced before and 10% if it was not. It appears likely that this is caused by (besides the ever-present laziness and disinterest) the lack of studying skills. It is worth noticing that these results were obtained by students who chose to study physics. Solutions of midterm tests suggest that several students misinterpret or do not understand the problems, which may be caused by the low level of reading comprehension.

EXAMPLE 6. ABSTRACTION

Problem 7. An object weighing 100 *N* hangs tied to two cables that are fastened to the ceiling, as in Fig. 6, left panel. The cables make angles of 37° and 53° with the horizontal. Find the tension in the cables.

Problem 8. Four charges ($Q_1=Q_2=Q_3=-1\ C,\ Q=1C$) are placed according to Fig. 6, right panel. The distances from charge Q is 1 *m*, 2 *m* and 1.5 *m*, respectively. Is charge Q in equilibrium?

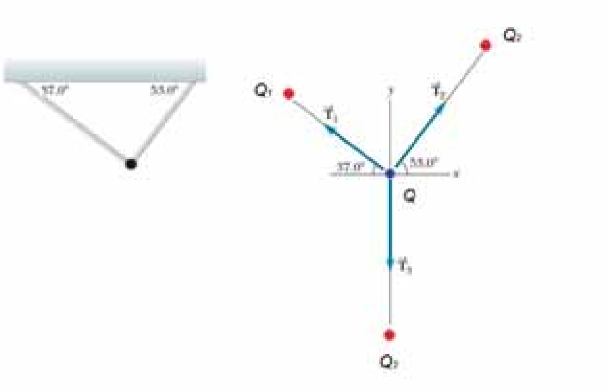

Fig.6. Left panel: object suspended by cables (Problem 7). Right panel: arrangement of charges (Problem 8)

The solution of equilibrium problems in mechanics is usually easy for the students if they do not have to use the concept of torque. But this is not the case if the topic is no longer mechanics. While 80% of the students solve Problem 7, only 20% of the students can solve Problem 8, though the two problems have the same free-body diagram. Most students can calculate the forces between the charges, but they think that the Coulomb's force is a force only in its name, so they do not use the strategies they used to solve Problem 7. Even after a detailed discussion of the problem still 40 % of the students are incapable of solving a problem of this kind.

Problems 3 and 6 suggest that capability of solving problems does not depend on just the physics and mathematics knowledge, but also on the cognitive structures of the students. It seems likely that a high percentage of the students are not operating in the domain of formal thinking, as was found in [1]. For students whose cognitive structures have not reached the formal thinking stage the extra courses are not sufficient, individual methods are needed.

CONCLUSIONS

Physics students are accepted at Hungarian universities without a significant background in physics. To handle this situation, high school level physics courses were introduced that are mandatory for approximately 70-80% of the students. We have shown several examples for problems arising in these courses that are caused by various reasons besides the lack of physics knowledge, such as problems in mathematics, reading comprehension, study skills. It also seems likely that the cognitive structures of many students have not reached the appropriate level.

ACKNOWLEDGMENTS

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VIII. CONTEMPORARY PHYSICS

RESEARCH BASED PROPOSALS TO BUILD MODERN PHYSICS WAY OF THINKING IN SECONDARY STUDENTS

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ABSTRACT

Conceptual knots in classical physics are often cited as motivation for the exclusion of modern physics from secondary school, but the physics of the last century is now part of the secondary school curricula in many EU countries and in the last 10 years appear in secondary textbooks, even if not in an organic way and with a prevalent narrative approach. Therefore, a wide discussion is now growing on goals, rationale, contents, instruments and methods for its introduction in secondary school. Modern physics in secondary school is a challenge which involves the possibility to transfer to the future generations a culture in which physics is an integrated part, not a marginal one, involving curricula innovation, teacher education and physics education research in a way that allows the students to manage them in moments of organized analysis, in everyday life, in social decisions. In the theoretical framework of the Model of Educational Reconstruction, we developed a research-based educational proposal organized in five perspective directions: 1) the analysis of some fundamental concepts in different theories, i.e. state, measure, cross section; 2) problem solving by means of a semi-classical interpretation of some physics research experimental analysis techniques; 3) the study of phenomena bridging different theories in physics interpretation, i.e. diffraction; 4) phenomenological exploration of new phenomena, i.e. superconductivity, 5) approaching the basic concepts in quantum mechanics to develop formal thinking starting from phenomenal exploration of simple experiments of light polarization. Research is focused on contributions to the practice of developing coherent learning proposals in vertical perspective related to content by means of Design Based Research, to produce learning progression and to find ways to offer opportunities for understanding and experiencing what physics is, what it deals with and how it works in an operative way. Empirical data analysis of student reasoning in intervention modules supports proposed strategies.

1. THE PROBLEM OF MODERN PHYSICS IN SECONDARY SCHOOL

The upper secondary school curricula of a large part of countries of the European Union include contents of the physics of the last century, here named briefly Modern Physics (MP hereafter) [1]. The most recent texts devote chapters to MP topics, even if not in an organic way [2-5]. Although conceptual knots in classical physics are quoted often to argue the exclusion of modern physics from secondary school, the international literature shows a rich debate on how to introduce MP, concerning: goals/rationale (to create a culture of citizens? For guidance? For popularization of recent research results? For education?); contents (what is useful to treat? Fundaments, Technologies, Applications?); teaching strategy: How? (Story telling of the main results? Argumentation of crucial problems? Integrated in Classical Physics? At the end of curriculum as an additional/complementary part?) [4-6]; to whom? (All citizens? Talented students? Lyceum/Gymnasium students?) [2-6]. MP in secondary school is a challenge which involves the possibility to transfer to the future generations the cultural value of physics, building a cultural heritage where physics is an integrated, not a marginal part, in a way that allows the students to manage themselves in moments of organized analysis, in everyday life and social decisions.

Three planes are involved: curriculum innovation, teacher education, physics education research [4, 7]. Here we present our research approach on modern physics in upper secondary school, exemplifying main contributions, presenting more extensively the path on superconductivity and some general results of research on students learning in that field.

2. OUR RESEARCH-BASED APPROACH FOR MODERN PHYSICS (MP)

Our research-based proposals on MP aim to offer a cultural perspective, focusing on the foundation of basic concepts as well as methods and applications in physics research, integrating them into the physics curriculum and not as a final appendix, offering experience of what MP is in active research. Vertical paths are identified as a learning corridor [8-10] for individual learning trajectories and step-by-step concept appropriation modalities [11-13].

Attention is paid to identify strategic angles of attack and critical details used by common knowledge to interpret phenomenology [14, 15], to study a spontaneous dynamical path of reasoning [7], to find new approaches to physics knowledge [14-18]. We avoid the reductionism in favor of offering opportunities of learning and not only understanding of information, interpreting solutions and results (to become able to manage fundamental concepts), competences of instruments and methods [7].

The Model of Educational Reconstruction (MER) is our theoretical reference for the design of research-based educational proposals [8]. According to the MER model the first step in research task is to rethink scientific content as a problematic issue and to rebuild it with an educative perspective. This task is integrated with empirical research on student reasoning and learning progress [7, 16-18], Design-Based Research (DBR) in planning intervention modules [19-22]; action–research [7] in a collaborative dialectic between school and university to contribute to classroom practice and to develop vertical T/L path proposals experimented by means of different interventions in classes [10]. The approaches in our work are therefore not purely based upon disciplinary content [23] in order to identify strategies for conceptual change [24].

The research approach on learning processes focuses on the obstacles that must be overcome to reach a scientific level of understanding and the construction of formal thinking, rather than to find general results or catalogues of difficulties. We are interested in the internal logic of reasoning, spontaneous mental models, their dynamic evolution following problematic stimuli (inquiry learning) in proposed paths, the ways for building formal thinking.

Empirical data analysis is carried out in four main research directions:

1) individual common sense perspective with which different phenomena are viewed and idea organization, in order to activate modeling perspective in the interpretation of phenomena;

2) the exploration of spontaneous reasoning and its evolution in relationship with a series of problematic stimuli in specific situations, in order to formulate activity proposals;

3) finding the modalities to overcome conceptual knots in the learning environment;

4) learning progression from defined low anchor to specific learning outcomes by means of detailed paths.

To monitor the learning progress, data collection is carried out by means of pre/post test, to obtain an overview on the student conceptions and the learning impact of the proposal experienced, IBL tutorials monitoring the students' learning process, often integrated with Interviews carried out according semi-structured protocol and the mirroring Rogersian method and usually also Audio/Video-recording of small or large group discussions and interactions.

The different proposals for MP cover mutually inclusive perspectives, for a global vision on MR: 1) Phenomena bridging theories, as for instance diffraction and specifically light diffraction; 2) The physics in modern research analysis technics, as for instance the Rutherford Backscattering (RBS), Time Resolved Reflectivity (TRR), electrical transport properties of material analysis with resistivity versus temperature and Hall coefficient measurements (R&H) [25]; 3) Explorative phenomenological approach to superconductivity (a coherent path) [26]; 4) Discussion of some crucial / transversal concepts both in CP and MP, for instance the concept of state, the measure process, the cross section concept [27], mass and energy [28]; 5) Foundation of theoretical thinking in an educational path on the fundamental concepts of quantum mechanics and is basic formalism [29-30].

3. EXAMPLES OF MODEL OF EDUCATIONAL RECONSTRUCTION (MER) PROPOSALS

3.1 Phenomena bridging theories: optical diffraction

Optical diffraction is an important context in many perspectives: it is a common phenomenon around us; it has a large use in research analysis, as well as in technological applications useful in everyday life; its interpretation bridges geometric and physical optics, classical physics and quantum physics.

The proposal on optical diffraction is based on the educational opportunities offered by the new technologies. It was designed, set up and experimented parallel to a research and development project aimed to realize the LUCEGRAFO system [31], a patented device connected to the computer USB-port in a R&D research [19-21], which is an evolution of a previous prototype [32]. Through this system, students acquire in real time and then analyse qualitatively and quantitatively the light diffraction pattern produced by a laser beam crossing a single slit, a single hair, a double slit, a grating (Fig.1). The features of light diffraction pattern cannot be framed in the rectilinear behaviour model and motivate students to look for an interpretative hypothesis on the wave nature of light, activated by recognition of similarities that characterize the different diffraction phenomena (the sea waves rather than sound waves). In our approach, students construct a model based on the Huygens-Fresnel principle reproducing the experimental light distribution and fitting the experimental data. A software environment of modelling, now realized also on an electronic worksheet, permits students to implement that model (Fig.1.C), focusing on the physical meaning of the model rather than on the mathematical calculations to obtain an analytical expression for this model [33]. The theoretical model based on the Huygens-Fresnel principle could be interpreted in a classical physics frame as well in a quantum mechanical one, analysing the consequence of the interference of point sources on the wave front.

3.2 The physics in modern research analysis techniques

We developed three proposals concerning the research techniques involved in the analysis and characterization of materials in modern physics and regarding: the optical physics (here exemplified by concerning light diffraction [32]); the Rutherford Backscattering Spectroscopy (RBS) analysis technique [34]; The Time Resolved Reflectivity (TRR) [35]; Measurement of Hall coefficient and resistivity versus temperature of metals (R&H), semiconductors and superconductors to characterize electrical transport properties of solid materials [36].

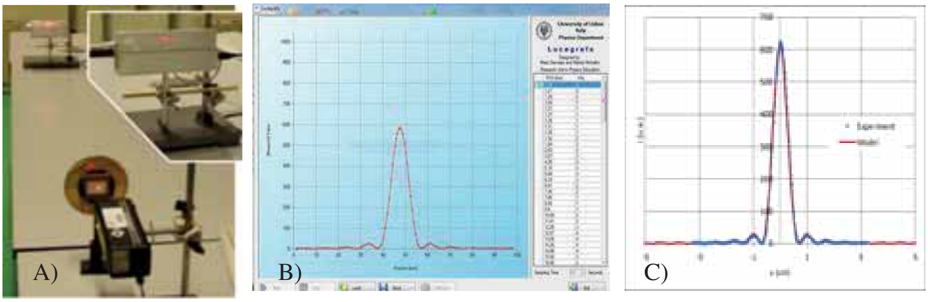

Fig.1. A) Apparatus LUCEGRAFO B) Diffraction patterns from single slit (width 0.12 mm) C) Fit of the experimental distribution with a Huygens-Fresnel based model

3.2.1 Rutherford Backscattering Spectrometry (RBS)

The Rutherford Backscattering Spectroscopy (RBS) measurement consists of collecting the energy spectra of ions (He^{++} of 2 MeV from a linear accelerator) backscattered along a certain direction, after a collision with the atoms of a target. RBS provides information about the depth distribution of the constituent elements of the first 500 nm of the surface of a sample (Fig.2). The principles of the measurement and semi-classical data treatment are discussed with students and real and simulated spectra are analyzed and interpreted as a problem solving activity [34].

Students construct the concepts used for the RBS spectra analysis as the cross-section and the stopping power. They are involved in simple experiments realized with poor materials studying the interaction of spherical projectiles and different shape targets to have an operative experience of the meaning of the cross section concept.

The RBS proposal offers the students the opportunity to: explore the Rutherford-Geiger-Marsden experiment; understand the role of energy and momentum conservation principles in the context of research analysis; understand how microscopic structures can be studied through indirect information and measurements; interpret RBS spectra; have a look of scientific material characterization research methodologies [37-39].

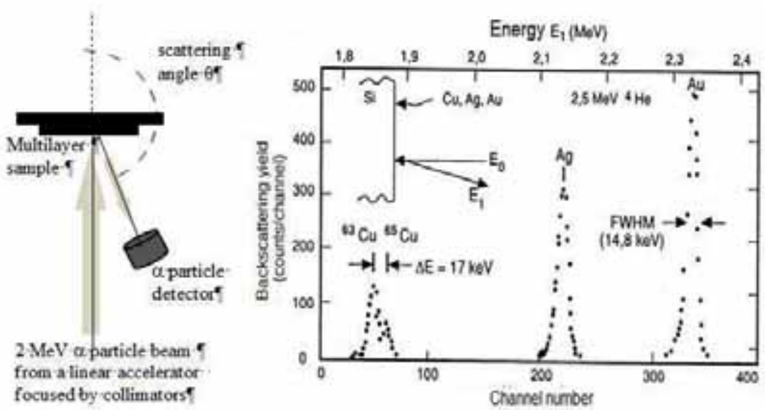

Fig.2. RBS experimental apparatus schema and RBS spectrum (from [39]): the target is a monoatomic layer of Cu, Ag and Au in equal concentration on a silicon layer. The incident beam is composed of 2.5 MeV α-particles, scattered at θ=170°

3.2.2 The Time Resolved Reflectivity (TRR)

The Time Resolved Reflectivity (TRR) technique exploits the interference produced by the light reflected by a double layer, using two visible light or microwave monochromatic sources (Fig.3.) [35]. The TRR techniques can be used to study the epitaxial growth of a sample, analysing the changes in the interference pattern of the two laser beams reflected by changes of the two interfaces, produced by changing one of the two sources. Students carry out measurements with microwaves and laser light, measuring thickness of various thin films of materials, analysing the interference fringes.

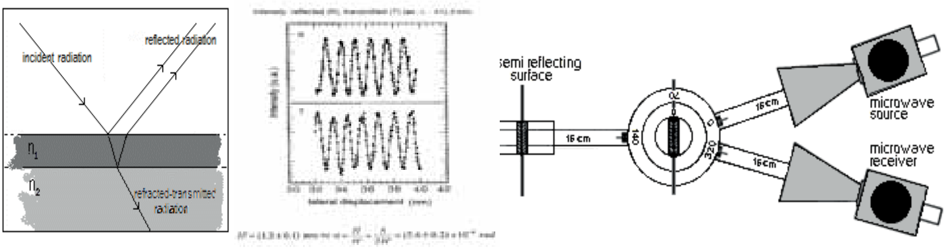

Fig.3. TRR for visible light (left) and relative fringe pattern (data from [35]); setting in the case of microwaves (right)

3.2.3 Electrical transport properties of solids

In the science of materials, the analysis of the electrical transport properties of materials is based on the measurement of the resistivity as a function of temperature, combined with that of the Hall coefficient (R&H) [36] (Fig.4.). That allows to identify sign, number, mobility and

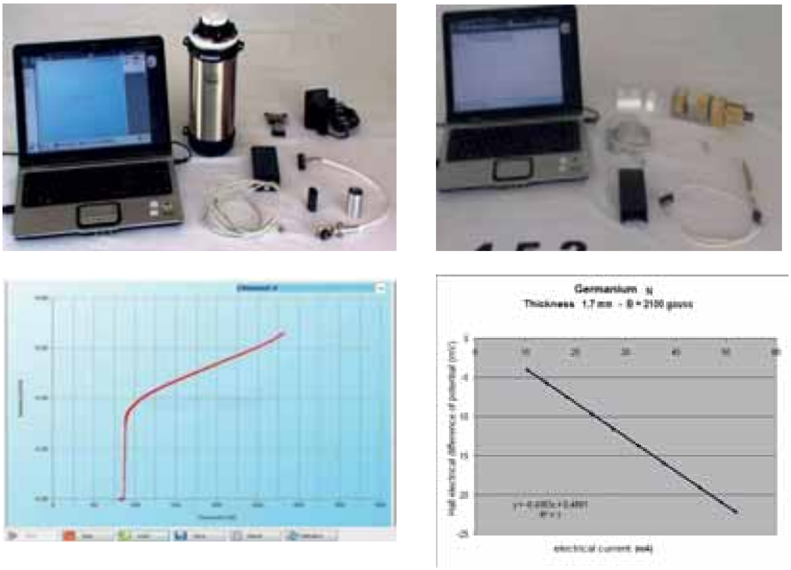

Fig.4. Left: The USB interface developed for the resistivity versus temperature (example of R-T graph for an YBCO sample). Right: Hall coefficient measurements (example of graph for Germanium N)

energy level of the electrical carriers on the basis of microscopic models for metals, semiconductors, and materials such as silicides [25, 39]. The research on superconductors is based on measurements of resistivity as a function of temperature, without or in the presence of a magnetic field [38]. We developed an approach to the matter physics by developing a patented USB probe for the measurement of the resistivity as a function of temperature of metals, superconductors and semiconductors at four points, and one for the measurement of the Hall coefficient of metals and semiconductors (Fig.4.) [36]. That system was designed and developed for a high school didactic laboratory but the constructive characteristics and the reliability of the measurements allow its use even in an advanced laboratory [40].

4. CRUCIAL/TRANSVERSAL CONCEPTS IN CLASSICAL PHYSICS AND IN MODERN PHYSICS (MP)

Some concepts, for instance the concept of system, state, properties are quite general and not related specifically to classical physics or modern one, although the basic theories of the '900s gave a new look to all these concepts. In our perspective these concepts could be developed across all the physics curriculum in school offering also insights on how these concepts acquire new meanings in the MP, as presented for instance in the section devoted to MQ. In that perspective, we developed innovative approaches on mass and energy, considered starting with a re-analysis of their classical meaning and then considering the new vision of these concepts given by the theory of relativity [28]. Here we focus on the cross-section, a transverse concept quite important in physics, crucial in the actual research in many fields of physics, but completely neglected in the secondary school.

The concept of cross section is important both in classical physics and in MP, for instance in studying the interactions between elementary particles in nuclear physics at both low and high energies, in atomic collisions, in structure of matter studies (as seen in the brief description of the RBS proposal). It becomes essential in the case of quantum mechanics, because it is impossible to attribute a trajectory to a quantum system. Approaching the construction of the concept of cross-section allows us to move from classical physics to wider and more complex fields using a powerful research tool.

A reductionist approach based on a geometrical interpretation of the concept of cross section might seem to be the easiest approach, but this is not the case. In fact, this interpretation is adequate only in the case of classical rigid spheres. The general concept of cross section is characterized by a probabilistic meaning, and this is what needs to be highlighted in an educational approach.

In the educational approach, students analyze some typical although simple cases of collisions, highlighting the general aspects of the phenomena and showing how to relate measurements and interpretations in a way completely different from the traditional force/equation model of motion/trajectory scheme. The line of the conceptual development of the educational path on cross section is reported in Appendix 1.

5. QUANTUM PHYSICS (QP) IN SECONDARY SCHOOL. FOUNDATION OF THEORETICAL THINKING.

In literature, there are quite different educational proposals [41-44], and a preliminary clarification is necessary to distinguish between physics of quanta, quantum physics and quantum mechanics. In the description of the birth of the theory of quanta the narrative treatment of the discussions on the hypothesis (proposed and not innate to students' reasoning) usually prevails in the educational approaches over aspects relating to the subject itself. The descriptive dimension if acceptable in a popularization plan does not appear to be satisfactory in an educational plan. There is the need to produce the awareness of the reference assumptions of the new mechanics [45-47] and to offer some indications on the formalism that is adopted, the formalism, in fact, assumes a conceptual role in QM [44-45].

The formal approaches, based usually on the wave formulation of quantum mechanics, are rigorous, but demand strong competencies both in physics and in mathematics [48]. Computer simulation to 'visualize' quantum situations helps to overcome the formal obstacles [49-50], leaving the knots open for interpretation.

In our perspective, there is the need to produce the awareness of the reference assumptions of the quantum mechanics theory and to offer a look on the conceptual role of its formalism rather than to stress on the way to use that formalism in problems and applications. Two lines of intervention were developed. The first constitutes a contribution to the traditional approach to quantum phenomena: experiments that are critical for the classical physics interpretation, to focus on the problems (Photoelectric effect; Compton effect; Frank & Hertz experiment; Millikan experiment; normal and anomalous Zeeman effect; emission and absorption spectra; diffraction of light and particles; Ramsauer effect) [51]. The second line, constituting the core of our proposal, is for quantum mechanics (not quantum physics or physics of quanta) in secondary school following a Dirac approach. We chose to approach: the theory of quantum mechanics; the first step toward a coherent interpretation with a supporting formalism; an introduction to the ideas of the theory, through the treatment of crucial aspects, fundamental concepts, peculiar elements to QM [29-30, 52]. Our core proposal for QM may be divided into two levels: on the disciplinary level we have chosen to begin with and focus on the principle of superposition and its implications; on the educational level we have chosen an in-depth discussion of specific situations in a context that allows for the polarization as a quantum property of photons.

Three are the basic elements of the proposal: to explore light polarization on experimental, conceptual and formal levels [53-55]; to discuss ideal simple experiments involving interactions of single photons with polaroids and birefringent materials (calcite crystals) [51]; to describe in quantum terms by two-dimensional vector spaces the states of polarization of light (or spin) [30, 53-54].

The first part is focused on the superposition principle, discussing a series of experiments with polaroids and calcite crystals, and its consequences as the uncertainty principle, the non-epistemic indeterminism, the description of macro-objects and the problem of measuring, the non-local nature of quantum processes, renouncing the classical way of thinking, including trajectory [29-30]. In the second part, each of the conceptual aspects discussed in the first part is formalized with an appropriate mathematical structure, starting from the vectorial representation of the quantum state and the representation of observables with linear operators [30, 52].

The rationale of the educational path includes: the operative introduction of the phenomenology of light polarization, using polaroids on an overhead projector and organizing conceptually through the Malus law, that students can "discover" in a real lab using on-line light sensors; the recognition of the validity of the Malus law in reducing light intensity, polarization is identified as a property of a single photon; exploring the interaction of polarized photons with polaroid, they identify mutually exclusive properties, incompatible properties and the uncertainty principle; the identification of the state of the polarized photon by a vector and the superposition principle can be written as: $\mathbf{w}=\mathbf{u}+\mathbf{v}$; distinction between state (vector) and polarization property, identified by icons living in different spaces; identification of the QM measurement as a transition of the polarized photon to a new state (the precipitation of the system in those measured and its genuine stochastic nature; interaction of polarized photons with birefringent crystals to understand entangled state, impossibility to attribute a trajectory, non-locality of the quantum processes; introduction of basic formalism starting from the transition probability from state u to state w as a projector, expressing the probability of transition with a scalar product:

$$P_t = N_t/N = \cos^2\theta = (\mathbf{u}\cdot\ \mathbf{w})^2.$$

These aspects can be discussed also in a very similar way considering the more usual case of the two-slit interference, where it can also be discussed what kind of picture emerges from the quantum behaviour when a hidden variable framework is assumed.

All the steps of the proposal are implemented in stimuli worksheet tutorials, aiming to monitor the students' learning paths and to involve them in an inquiry-based educational environment [55]. The different situations proposed in the educational path as well as allowing the pupils to explore their own hypotheses can be realized virtually in a gym of simulated ideal experiments using the applet JQM [51] (free access at: http://www.fisica.uniud.it/URDF/secif/mec_q/percorso/avv_11.htm). Fig.5. shows an example of JQM experiments and tools available.

All the proposals, discussed in a research perspective in different papers [29-30, 52], are also available on the web to be used and adapted by teachers in schools (http://www.fisica.uniud.it/URDF/secif/mec_q/percorso/teoria.htm).

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Fig.5. The tools and the environments used by students to explore the phenomenology in single photon of light interaction with polaroid and birefringent crystals

Extensive research experimentations were carried out with more than 300 students [56-59]. From these it emerged that students profit from the iconographic representation and discussion in a proper way on mutually exclusive properties (80%) and incompatible properties (55%). The employment of the iconographic representation (85%) and formalism (60%) facilitate reasoning in the framework of QM. The rigorous reasoning proposed promotes the spontaneity used in new contexts (50%), the construction of a coherent framework (80%), even if in a different conceptual perspective. In fact the students' learning paths show evolution toward quantum concepts, where some typical hidden variables assumptions often bridge them from classical to quantum way of thinking [57].

6. FROM ELECTROMAGNETISM TO SUPERCONDUCTIVITY

The explorative approach to superconductivity is integrated in a vertical path on electromagnetism [26, 60]. It uses the experimental kits developed in the European projects SUPERCOMET and MOSEM [61], including more than 100 simple low-tech experimental activities on electromagnetism and electrodynamics and 8 high-tech apparatus on superconductivity, computer modelling proposals, 20 simulations. In our approach, secondary school students explore and explain superconductivity first in classical physics and then they have a look at the quantum mechanism that can take into account the transition from normal conductor to a superconductor. The research-based path includes an inquiry-based learning (hands/minds-on) approach to SC using the theoretical framework of classical electromagnetism; ICT learning-based, integrated measurements carried out by sensors, modelling, simulations. The focus is on reasoning for the interpretation of the phenomena [26].

In developing vertical paths on electromagnetism and superconductivity from primary to upper secondary school, our research involved: T/L proposals development by means of DBR [19-22]; Learning process analysis by means of Empirical Research [7, 14-18] and in the perspective of Conceptual Change [24]; R&D of new ICT system [20-21]; Teachers' professional development; Micro-steps of Conceptual Lab of Operative Exploration (CLOE) are carried out to build the formal quantities characterizing the magnetic field B [13].

In experimenting with the same explorative path in secondary school (l8 schools, N=160 students, 17 years hold), magnetic field lines assume the roles of a conceptual tool: to interpret magnetic interactions (65%); to distinguish between magnetic field (direction of orientation) and force (direction of starting motion) (55%); to produce reasoning in terms of flux, individuating that it is a constant quantity in field line system (80%); with related consequences, such as that magnetic field lines are closed (68%), the non-separability of poles (50%) or div=0, interpretation electromagnetic induction (76%), identification of the related applications (56%) [60].

The rationale of the path on superconductivity and the results of the school experimentation are reported in Appendix 2 and 3.

7. CONCLUDING REMARKS

From our research in physics education we developed five different perspectives of proposals mutually inclusive for the Modern Physics to build in young people:

- physics identity
- physics as a cultural issue
- the idea of physical epistemic nature

Avoiding the reductionism our aim is to offer opportunities to:

• Experience the quantitative exploration of crucial phenomena (diffraction), individuating laws, fitting data and testing basic principal ideas and results with experimental data

• Understand the crucial role of classical physics in modern research techniques (RBS, TRR, R&H) manipulating data and interpretation like in a research laboratory

• Focusing on reasoning to conduct the exploration of a phenomenon (superconductivity) understanding the role of analogies for finding explanations

• Reflect on the physical meaning of basic concepts in different theories (state, measure, cross section) revising meanings in classical physics and understanding the different perspectives of new theories

• Approach to the new ideas of QM theory: the first step toward a coherent interpretation with a supporting formalism experiencing aspects, cardinal concepts, elements peculiar to QM

One of the main follow-ups at national level of our expertise in teaching-learning modern physics was the IDIFO Projects (2006-2016), a PER contribution for Innovation in Physics Education and Guidance. That project involves 20 Italian universities cooperating in: Master for teacher formation on modern physics (162 cts articulated in clusters of 3cts courses on the following area for (60cts) on: Modern Physics; Physics in contexts (in art, sport...); Real time Labs and modelling; OR- Formative guidance; SPER – School experimentation); Summer school for talented students; Educational Labs, co-planned with teachers, to experiment with innovation in the school [62].

APPENDIX 1. THE OUTLINE OF THE EDUCATIONAL PATH ON CROSS SECTION.

To approach the concept of cross section, students compare first the quite simple case of the collision of two spheres (or two circular disks) and the case where the target sphere is substituted by an object with an irregular shape, measuring the dependence of the scattering angle θ from the impact parameter *b*. In the first case it is simple to reconstruct the analytical relation between b and θ, including the radius *R1* and *R2* of the two spheres [$b = (R1+R2) \cos(\theta/2)$], in the second case the work becomes harder immediately by considering an ellipsoidal shape of the target system, both in the mathematical perspective and, much more important, in the physics perspective, because the dynamics of the collision becomes immediately strongly dependent on the initial condition: a very small variation in *b* can cause variations of any order of magnitude in the scattering angle. A consequence of this is that by driving the two bodies against each other a number of times with a poor control of initial conditions, the individual results (final states) obtained are significantly different. Does this mean that such an experiment does not give any kind of information about the collision or the geometry of the two bodies?

Students can recognize, using both experiments and simulations when a beam of symmetrical projectiles impact on a target system of arbitrary shape, that the asymmetry in the target shape can be associated to the specific asymmetry in the distribution of the scattered projectiles [27, 37]. The relation between *distribution asymmetry* and *asymmetrical shape* shows to students that it is possible to extract information on the collision phenomenon trough a statistical analysis of the distribution of scattering angle. In general, a complete characterization of the collision requires the knowledge of the probability P_i for any given measurement outcome S_i; these probabilities can be obtained from the average $P_i = \langle N_i / N_{tot} \rangle$, where N_i is the number of outcomes S_i for N_{tot} observations carried out. That probability still depends on the details of the measuring procedure. For instance, increasing the width of the distribution of the impact parameter of projectiles, there will be a greater number of cases in which the projectiles will not interact with body 2 at all. In order to avoid this, it is necessary to consider more in detail a general situation like that represented in Fig.6. A uniform beam of (identical) particles colliding with a target of evenly distributed (identical) particles. So an incoming particle, wherever it crosses the panel (a), meets, on average, the same target distribution. Therefore the total number N_i of scattering events having a certain final state S_i will be proportional to the number of incident particles (there are no border effects due to the 'width' of the beam).

On the other hand, given the limited range of the scattering phenomenon, a certain incident particle will only interact with the particles of the target within the range of action of the force (represented in Fig.6. by the small rectangle of area *A* on the surface of the target (panel (b)).

The probability that any incident particle of the beam interacts with a target particle within area *A*, creating a certain result S_i, will be: $P = P_1 \cdot P_2 \cdot P_{int}$, where P_1 is the probability that the incident particle will cross *A*, P_2 is the probability that there will be a target particle in that area and P_{int} the probability for that type of interaction. With two sufficiently sparse distributions, P_1 and P_2 will be given by: $P_1 = \langle N_1 \rangle = n_1 \cdot A$, $P_2 = \langle N_2 \rangle = n_2 \cdot A$, where n_1 and n_2 represent the surface densities in a projection transversal to the axis of the beam. The average (total) number of interactions with outcome S_i will be obtained by summing up all the small rectangles, of number N_A, into which the section A_{tot} effectively crossed by the beam can be divided:

$$\langle N_i \rangle = N_A P_1 P_2 P_{int} = (A_{tot}/A)(n_1 A)(n_2 A) P_{int} = A_{tot} n_1 n_2 (A P_{int}) \quad .$$

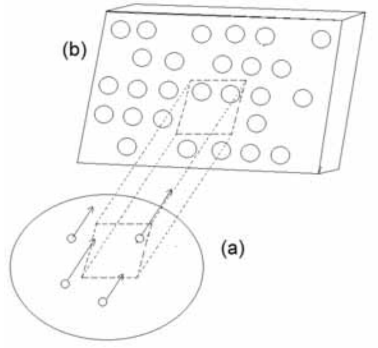

Fig.6. A beam of particles (panel (a)) colliding with a target (panel (b)).
The dotted lines represent the active volume of a beam particle (that is, the region in which it can interact with a target particle)

The factor $s_i = (A \cdot P_{int})$ is related to the characteristics of the observed interaction. The factor has the physical dimensions of an area and for this reason it is called cross section (for the reaction channel considered). The geometrical meaning of the cross section could be easily recognized by applying the previous results to the case of rigid spheres. The information given by s_i is on the intensity of the interaction (or, alternatively, on its range), due to its nature of integral quantity.

To obtain a similar quantity able to offer a deeper insight into the interaction phenomenon considered, it is necessary to consider explicitly each possible result S_i of the collision. If N_i is the number of the outcomes for which the scattering angle is in the interval $(\theta, \theta + \Delta\theta)$, the cross section σ for the collisions with a scattering angle in such an interval is:

$$\sigma = AP_i \approx AN_i/(n_i A) = N_i/n_i$$

where n_i is the number of incident particles per unit area.

This value depends on $\Delta\theta$ and therefore it is better to introduce the so-called differential cross section:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\theta} = \lim_{\Delta\theta \to 0} \frac{\sigma}{\Delta\theta} = \lim_{\Delta\theta \to 0} \frac{<N_i>}{n_i} \frac{1}{\Delta\theta}$$

That concept could be easily generalized to a solid angle.

The expression of the differential cross section can be applied to the important case of the scattering of two pointlike bodies with charge *Ze* , *Z'e* charge, which interact according to a repulsive Coulomb potential. The dynamics of that interaction is governed by the conservation principles of angular momentum and energy (E) and the following relation between b and θ can be easily obtained

$$b = \frac{ZZ' e^2}{2E} \operatorname{cotg} \frac{\vartheta}{2} .$$

The differential cross section is immediately obtained:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \left(\frac{ZZ' e^2}{4E} \right)^2 \sin^{-4}\left(\frac{\theta}{2} \right)$$

That important result could be used to discuss in detail the historical study of Rutherford and the related Geiger and Marsden experiments as well as we have shown in the section of RBS, or to have a look on nuclear interactions [27].

APPENDIX 2. A COHERENT EDUCATIONAL PATH TO SUPERCONDUCTIVITY

The path on SC is structured into two parts: 1) Magnetic properties of a superconductor, Meissner effect, electromagnetic induction and eddy currents for interpretative analogy, the pinning effect [26, 38]; 2) Resistivity vs temperature using the R&H USB system (described in section 3.2.3) to find the critical temperature for a superconductor at the breakdown of resistivity [25, 36,39]. We use different perspectives: Historical, Phenomenal exploration, Applications [60, 63-64].

Let us follow the reasoning path proposed, starting from the Meissner effect, focused on understanding correctly the effect in the framework of the magnetic interactions, and focusing on how students face the main interpretative knots. The educational path [26] approaches the Meissner effect through an experimental exploration of the magnetic properties of a superconductor sample (a disc of YBCO with very weak pinning effect). Students analyse the diamagnetic nature of a superconductor constructing step by step a phenomenological interpretation based on production of persistent supercurrents produced by electromagnetic induction that are at the base of the levitation phenomenon due to the Meissner effect.

The first step of the educational path aims to individuate the change in the magnetic properties of an YBCO disc at room temperature and then at the temperature of the liquid nitrogen (LN hereafter). It could be inspired by an exploration of the magnetic properties of a set of different objects of different shapes, weights and materials (aluminium, copper, water, wood, graphite) by means of a home-made simple torsion balance, by hanging these and see if they are attracted, repelled or not affected by a “strong” magnet. A phenomenological classification of magnetic properties of material can show three main types of properties: ferromagnetic materials (that are strongly attracted, almost in any condition, by a magnet and present often that property also after the interaction with a magnet), paramagnetic materials (that are very weakly attracted by a magnet); diamagnetic materials (they show “magnetic repulsive properties” only in the presence of a magnet). Also the paramagnetic properties of the YBCO at room temperature are analysed by putting two discs of YBCO at the ends of a homemade torsion balance. At T_{LN} temperature, when the YBCO is at thermal equilibrium in a bath of LN (77K), a levitation phenomenon appears due to a strongly repulsive interaction between the YBCO disc and the magnet, or, in other words, the YBCO disc shows strong diamagnetic properties.

The change in the magnetic properties of YBCO (quite evident) happens so suddenly when the temperature reaches T_{LN}, that is we are in the presence of a phase transition. This will be confirmed in the educational path analyzing the breakdown of resistivity.

Before proceeding, it must be emphasized here that the levitation stability of the magnet on the YBCO disc is guaranteed by a residual of pinning effect, which is always partially present in this type of superconductors. However, this does not affect decisively the conclusions that will be gradually drawn.

The diamagnetic properties of the YBCO can be explored by moving the magnet, rotating the magnet or going close to the YBCO from different directions (from lateral side for instance). It is clear that the levitation phenomena is not a suspension of two repelling magnets, constrained for instance in a tube, for two reasons: the magnet on the YBCO levitates without any constrains; by changing the pole of the magnet closer to the YBCO, the repulsion appears anyway. Moreover, if an iron clip is put on the cooled YBCO, no interaction is observed, showing that the diamagnetic behavior is induced only by the presence of the magnet, or in other word the magnetization of the YBCO is not permanent. This aspect is similar to that of other diamagnetic materials, in the case of the superconductor the diamagnetic effects are very intense (comparable to that of ferromagnetic systems) contrary to the ordinary diamagnetic phenomena, which are usually very weak. To understand something more on the diamagnetic properties of the YBCO, it is possible to perform a simple exploration of the magnetic field inside the disc of YBCO, analysing whether the external field of the magnet penetrates the YBCO. This test can be performed using a sandwich of a YBCO putted between a magnet and an iron slab. At room temperature you can't lift the sandwich pulling the magnet, it remains a compact structure. At T_{LN} this effect disappears, that is, the magnet is unable to lift the YBCO and the iron ring (Note: this is not completely true if there is some pinning effect). At room temperature: the YBCO is transparent for the action of the magnet on the iron, the B field of the magnet "arrives" on the iron passing through the YBCO, a magnetic field can exist in YBCO. At T_{LN}, the B field of the magnet does not reach the iron clip, evidencing that it is really small or negligible through the YBCO.

To appreciate the Meissner effect, producing the repulsive effect between the magnet and YBCO and at the base of the levitation of the magnet over the YBCO disc, the levitation of the YBCO can be observed, when it is cooled in presence of a magnet. When the temperature of the YBCO goes below the critical values, the magnet lifts levitating over the YBCO.

The phenomenology described shows that the magnetic behaviour of YBCO appears to be induced by the presence of the magnet, or better by the magnetic field produced by the magnet. An analogy can give the instrument to interpret the phenomena.

A falling magnet on a copper bar decrease its velocity gradually. A magnet falling inside a copper tube falls at constant velocity. In that phenomenon, the electromagnetic induction and the eddy currents have a crucial role. The interpretation of the falling magnet in a copper tube requires as conceptual tools: the field lines (in our perspective an operative definition of that lines); the flux of B ($\Phi(B)$), defined operatively); The Faraday-Newman-Lenz law. To interpret how the eddy currents arise in the tube, we can ideally slice the tube in rings standing one over the other. The eddy currents arise because the change in the flux of B when the magnet passes from a ring to the ring below: in the first ring that current produces a B field in the same direction of the magnetic field of the falling magnet; in the second ring that current produces a B field in the opposite direction of the magnetic field of the falling magnet. Applying the Lorentz force law, it can be seen that a net force emerges, directed vertically opposite to the direction of the weight of the magnet and producing the braking effect on the magnet. Repeating the experiment with geometrically equal tubes of different materials (bronze, aluminium, copper…) it is possible to correlate the falling velocity and the resistivity of the material of the tube. The analogy between the "braking" of the magnet in the presence of a "real" conductor and the levitation of the magnet over the YBCO disc appear to work if the conductor is "perfect" ($R=0$). The currents initially induced by the magnet never stop, because the Joule effect is not present in the case of a $R=0$ conductor even when the electromagnetic induction ends ($v=0$).

Effectively a superconductor, such as the YBCO at T_{LN}, shows this property. Students can explore that effectively in a lab analysing the behaviour of the resistivity as a function of the temperature, characterizing a superconductor as a system with $B=0$ and $R=0$

The interpretation of the perfect diamagnetism of a superconductor as an electromagnetic induction effect in the case of an ideal conductor (that is $R=0$) can be extended to also include the situation when YBCO becomes superconductor in the presence of an external field.

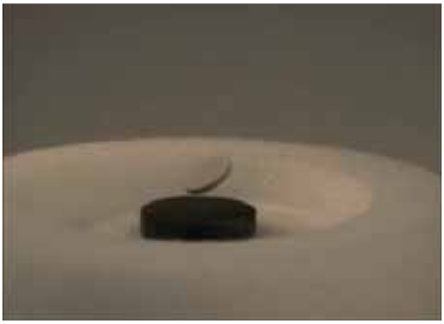

Fig.7. The Meissner effect

Fig.8. The pinning “train” on the magnetic track

The explorative part of the educational path of superconductivity includes also the analysis of the pinning effect, characterizing the superconductor of type II and at the base of the functioning of the MAGLEV train. This effect manifests itself in the fact that the magnet remains anchored to the superconductor at the distance at which it was when it made the phase transition. The pinning effect is due to the penetration of the magnetic field inside the SC sample inside the vortexes created by supercurrents and at the same time the repulsive effect due to the Meissner effect (Fig.7). The analysis of the stability of the train on the magnetic track (Fig.8) offers the opportunity to discuss the conditions needed to obtain a stable levitation.

To interpret how the phase transition occurs in a superconductor it is necessary to consider a quantum approach to solid state physics. We set up a minimal treatment based on energy levels. We usually start discussing the (discrete) equilibrium energy levels of a chair, to give an analogy for the atom levels. When isolated atoms are combined to build a crystal, the energy levels of electrons change dramatically. Using simulations as that of Visual Quantum Mechanics [49] students can understand how the level of one atom splits (http://phys.educ.ksu.edu/vqm/html/eband.html) into 2….n levels close to the other forming bands when 2…n equal atoms go close to one another as it occurs in a crystal lattice.

Electrical transport properties of a solid, and in particular its nature of insulator or conductor, depend on the band structure and on electron states. These states and their occupation are determined by the Pauli exclusion principle. When the superconductive state is created a great change occurs. Due to an effective attractive interaction between electrons, mediated by the lattice vibrations (phonons), the formation of the so called Cooper pairs is favoured because of energy reasons. The Cooper pairs are particles of spin 0 and therefore they can all occupy the same state, that is, the fundamental state that is separated by an energy gap. The existence of that gap assures the stability of the superconductive state and the vanishing of the resistivity of a superconductor [26].

APPENDIX 3. EXPERIMENTS WITH STUDENTS

Experiments in school were performed in 44 Italian sites involving students of different age (29 K13; 6 K12-13; 1 K12; 6 K11), for a total of 1315 students of 292 classes of about 150 schools. 5/44 experiments were performed in informal educational contexts organized in the limit of university-school projects involving 275 students. From these experiments it emerged that students are strongly involved and motivated in the exploration of phenomena such as superconductivity because: it is very surprising and engaging (95%), of the great interest in the technological application of the superconductors (75%), of the general interest in the construction of an explanation of that phenomenon (83%) [60]. These results were confirmed also by the other experiments done in very much different contexts and in formal setting. The majority (20/44) of these experiments were performed by service teachers and in two cases by prospective teachers involved as experimenter of the material of the European projects of the Supercomet family [63-64]. These experiments constitute positive feasibility tests of the introduction of superconductivity in different contexts and types of school, gives as outcomes that teachers individuated four different educational paths to introduce superconductivity in school: Introduction to superconductivity - approach through the magnetic properties; Approach to superconductivity through the exploration of the resistivity of materials. The energy transformations and superconductivity, Approach to superconductivity starting from the exploration of its technological applications. From that experimentation emerged also the positive evaluation of students' learning performed in standard ways by teachers and as unresolved educational problem as treated in school the Cooper pair formation, an aspect remaining open also in their formation [60, 63]. 5/44 experiments were performed by PhD students as part of their research project with 125 students [60, 65]. From these works it emerges that prevalently (81%) students characterize the superconductive levitation as a repulsion consequence of the diamagnetic properties acquired by the YBCO, characterizing that with a magnetization vector (57%), or using a global representation using field lines (24%) explaining also in some cases (22%) that the sample becomes a superconductor or that its resistance falls down to zero. In a few cases (19%), students just describe the system of forces acting. (YBCO repels the magnet with a force that is equal to the weight force). Students were able to distinguish the features of Meissner effect from that of the pinning effect (87%), but without developing different models for the two effects [66].

Nine of these research experiments (9/44) in school were research-based activities conducted with 287 students (66 students were 17 and 261 students were 18) to understand how students learn superconductivity and to validate the didactic material prepared to monitor students' learning paths and were performed in curricular activities, with entire school classes, or in summer schools organized at the University for selected students from all Italy [66]. The models of students are mainly centered on the concept of the magnetic field and the magnetic properties of the systems involved (68%). The static models underlying how students initially describe the superconductive levitation, was substituted at the end of the educational path in the majority of cases (84%) with models describing the condition B=0 inside the superconductor: 63% that the YBCO at $T=T_{amb}$ was passed by field lines (was paramagnetic) and at $T=T_{NL}$ it expels the field lines, in 1/3 of cases adding that this is due to surface currents; 25% the field lines do not cross the YBCO, the YBCO screens the field lines; 12% field lines are trapped. That models are supported by causal explanations based on an intuitive magnet image model (38%) [67] or on the induction electromagnetic role in the superconductive levitation (62%).

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ALL-PERVADING LIGHT – OR HOW THE KINEMATICS OF MODERN PHYSICS IS BASED ON LIGHT

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ABSTRACT

The space-time of modern physics is tailored on light. We rigorously construct the basic entities needed by kinematics: geometry of the physical space and time, using as tool electromagnetic waves, and particularly light-rays. After such a mathematically orthodox construction, the special theory of relativity will result naturally. One will clearly understand and easily accept all those puzzling consequences that makes presently the special theory of relativity hard to digest. Such an approach is extremely rewarding in teaching the main ideas of Einstein's relativity theory for high-school and/or university students. Interesting speculations regarding the fundaments and future of physics are made.

ON PHYSICS AND POSTULATES

Physics is undoubtedly an experimental science [1]. It's laws are derived from experiments and it's theories are confirmed through experiments. It is considered to be exact science, but many scientist consider it less rigorous than mathematics is. The main reason behind this fact is that mathematics is built on clear postulate systems, while in physics it is not allways obvious what our postulates are. This is also the way how we teach physics: it is not straightforward for students (and sometimes also for the teacher) what we postulate and what results from these postulates. From time to time we use phrases like “it is evident”, “it is not unrealistic to assume”, or simply “let us assume”. In such cases students might get confused whether we state a new postulate or affirm something realy obvious resulting logically from the already accepted postulates.

Any logically consistent theory must be based on postulates. It is not possible to prove everything, and there is thus no ultimate true [2]. Any statement or law in science is true or false in the framework of a postulate system. In physics we also have thus postulates. Postulates can change as physics progress, and our goal to reduce the number of postulates and/or to postulate more simple things is slowly, but advancing. The physical description of nature is however always bonded to a postulate framework. We might or might not realize these postulates, but they are silently there.

The less rigourous manner in which physics handles it's postulates was however not an impediment for its development. Being non-rigorous in the pure mathematical sense has also advantages and allows for describing more easily the complexity of nature using just our intuition. This is one reason why physics became so successful and advanced quickly in describing many complex phenomena. Not realizing however the postulates on which our reasoning in physics is built and relaying to much on intuition can seriously fool us and obvious facts might appear as paradoxes. There are times thus in physics when we have to stop, look back and review the postulate system on which our current understanding is built.

In this work I plan to do this, by building the basic elements of modern kinematics in a rigorous and logically consistent manner. I will argue that the tool we use nowadays to define the geometry of the physical space and time is light, or electromagnetic waves in general. After taking the effort of doing a solid grounding by postulates for our main tools: space and time, we then collect the benefits. The special theory of relativity, Lorentz transformations and all "strange" consequences of these will become crystal clear. We will be surprised how simple and logical and self-consistent this theory is. We will also realize some common misconceptions that are still sorounding us in many textbooks and science popularization books or movies.

LIGHT AND ITS' SPEED OF PROPAGATION

Light and electromagnetic waves in general are our primary source for getting information about the surrounding world [3]. Light is however a tricky entity. Light rays propagate in straight line, and it shows both wave and particle properties. In some experiments light behaves as a classical wave (diffraction, interference) and yet in other experiments exhibits particle properties (photoelectric effect, Compton scattering). There are also properties of light that can be understood both by it's particle and it's wave-like nature (refraction, reflection). Nowadays we know that light is an electromagnetic wave, which transports energy in quanta, named as photons. Electromagnetic waves and therefore the propagation of light are described by the celebrated Maxwell's equations [4] which predicts that the propagation speed of electromagnetic waves in vaccum, and light in particular, is very big (~300 000 km/s). Experimentally it was quite a hassle to determine its value and a lot of debates were on this subject during the history of science (see Appendix 1.).

Getting the value for the speed of light is however only half way the problem done! Whenever we speak about speed we do need to specify the reference frame relative to which this is measured. Sound and acoustic waves propagate relative to a medium with mechano-elastic properties. In air for example, when we admit that the speed of sound is 340m/s this is understood as being the value measured relative to air. We are used to the fact, that each wave-like phenomenon propagate relative to some medium, and when we speak about the velocity of the wave, we usually do refer to its velocity relative to this medium. We know now that light is an electromagnetic wave, and the natural question we can pose is to find the medium in which electromagnetic waves are propagating, or the medium in which Maxwell equations are valid. The medium was hypothetically named *aether* and the hunt for its discovery began. The method to reveal the existence of eather was based on the detection of the eather wind. The effect of the eather wind on the propagation of light would be something similar like the effect of the wind on the propagation of sound. For sound waves in air we know that an observer that travels with a speed of 10 m/s relative to the air, would measure a speed of 350 m/s for the sound waves coming in his/her direction and a speed of 330 m/s for the sound waves travelling in the same direction as his/her motion relative to air.

Carefully designed experiments were however unable to detect such eather wind [5]. Eather proved to be either inexistent or hard to be observable due to some unknown reasons. As we will detail in the following, physics got in an unpleasant situation, which drove physicist to rethink the very basic foundation of our basic notions in physics: space and time and the postulates on which the modern apparatus of physics is build.

SPACE AND TIME IN PHYSICS

Space is the most fundamental entity of physics, the ground and background of matter, our models' natural environment [6]. Its existence can be stated as a postulate: it is something that exists. Physical space does not have however an inbuilt, intrinsic geometry. Geometry is our attempt to describe the form of the objects and their relative positions in space, following the idealisation we have achieved in mathematics. Physics relies on geometry, since one of our aims is to account for the relative position of objects and to describe their changes. In physics we have to distinguish clearly between the mathematically defined abstract spaces and the space we deal with, when the description of the spatiality of the matter is our focus.

The **ideal mathematical space** is defined by postulating all its *metrical* properties. Metrical, in this case means that we have a distance unit and we can construct a 'geodesic' line between any two points. This geodesic line is the shortest distance between two points in our ideal space. It is the generalisation of the concept of 'straight line' encountered in simple Euclidean geometry. Once we have the geodesic lines and postulated the distance unit, we are able to measure distances between any two points. The distance between two points will be obtained by measuring the length of the geodesic line drawn between them. We also have the possibility of defining objects with spatial extension in the space: spheres, cubes, etc. Objects placed in such a space will not alter the postulated geometry.

For example, Euclidean geometry in plane defines its metric by the five postulates we all learned in elementary or high school [7]. Euclidean space is the simplest mathematical space. Geodesic lines are the "classical straight lines" we all have imprinted in our minds since our middle school years. For any triangle we have that the sum of its interior angles is 180 degree. In the Euclidean space one can also state that for any elementary triangle built on two infinitesimally small segments perpendicular on each other: *dx* and *dy*, the third segment (*ds*) can be calculated as: $ds^2 = dx^2 + dy^2$.

Our **physical space** is not an idealized mathematical space, and metrics is not an a priori given; rather, it is determined by the matter spread throughout the Universe. In order to construct any geometry in this space, the first task is to reveal the geodesic lines and have a well defined concept of distance. One possibility would of course be to postulate an a priori metrics for space, and the handiest would naturally be a three dimensional Euclidean space. In such an approach distances between objects would be measured using a hypothetical infinitely extensible ruler (which is postulated to be the straight line) and a postulated unit of length. This is what Newtonian physics does. Distances between the bodies around us are measured using such an ideal ruler together with a postulated unit of length, which is the International Prototype Metre kept at the International Bureau of Weights and Measures in Paris. Apart from the logical inconsistency of the a priori postulated metrics (straight line concept), the drawback of this approach is that it makes impossible to measure distances on a cosmological or micro scale. Using a ruler you cannot measure large distances on Earth, and you definitely cannot extend investigation to the cosmological or microscopic scale. A viable alternative to this approach is to use light rays to reveal the geodesic lines in the physical space. Light rays in vacuum have always been thought to move in a 'straight line', or at least this was considered to be true on the terrestrial scale in an optically homogeneous medium such as air or a vacuum. After the development of Euclidean geometry, measurement of large distances and methods of mapmaking, such as the classical triangulation method, employed this idea extensively. The solution seems simple. Then, why not turn the problem around, and postulate the path of light rays between any two given points as a geodesic line? The idea could work on both the cosmological, terrestrial and micro-scale and would define a usable geometry for physics.

Nowadays, we need to be careful when speaking about the geometry of physical space, since we inevitably mix up two different metrics… *In our everyday life* we use the Newtonian paradigm of ideal space alongside Euclidean metrics, which we find convenient. The optically different materials around us and, as a result, the light refractions at the boundaries of different media make complicated the use of geodesic lines defined by light. This is why we tend to say that light rays bend and we accept that sometimes they do not move in a ‘straight line’. Practical problems relating to tracking the path of light rays and handling such rays also suggest that it is easier to use a traditional ruler. But we should add here, that given the rapid advances in laser technology this picture is quickly changing; even on a small scale we nowadays use light to measure distances and trace straight lines. *On a cosmological or microscopic scale*, however, the concept of the straight line is inextricably linked to the path of a light ray. The metric is defined by the propagation path of light, which is influenced by the matter spread throughout the Universe. Luckily, in our everyday life the two different metrics are not at odds, since light rays do not bend in any detectable way in a homogeneous medium and the gravitational field around us is rather homogeneous over small distances. However, if light interacted more strongly with the Earth’s gravitational field and this gravitational field were not homogeneous, the situation would have been more complicated. We would immediately sense there was problem, since our ruler would no longer look ‘straight’ to us, even if the medium around us were a vacuum.

Light therefore defines the geometry of the physical space. Such geometry may not be simple, since the metrics is influenced by the interaction between matter and light. The properties of light are inevitably mapped onto the geometry of space. We might well discover that in such space the sum of the interior angle of the triangles is not 180 degree and for the diagonal ds of the elementary triangle constructed on the two perpendicular segments dx and dy we find that $ds^2 \neq dx^2 + dy^2$. Instead of this relation, we might find in a plane a more complicated formula of the type: $ds^2 = a(x,y)\cdot dx^2 + b(x,y)\cdot dy^2 + c(x,y)\cdot dx\cdot dy$. In such cases the geometry of the physical space is a non-Euclidean type. The abstract mathematics of non-Euclidean ideal spaces developed by Bolyai, Gauss, Lobachevski and Riemann therefore acquired a major application in dealing with the geometry of the physical spaces [8].

Time in the physical space. In order to approach the concept of time we should first think about what gives physical meaning to it. We use the concept of time, in order to describe changes [5]. In a completely static Universe, time would have no role. More precisely, we need time so that we can order the events or changes that happen in the physical space, to detect and describe their possible *causality*. The existence of causality is a basic postulate in science. Causality implies that the cause must always precede the effect in time, and the same causes always produce the same effects. Time is a creation of our mind and makes sense only in connection with changes and movement. It is derived from two basic quantities that do exist in the Universe: space and changes. Time is therefore not an a-priori given quantity and similarly with the geometry of the physical space, the Universe does not naturally come with time embedded in it, and it is something that we have to construct it.

Clocks are devices that are used to measure time [9]. In order to make time measurable we need an etalon clock that gives periodic signals. Once we have defined this etalon clock, the unit of time will have been properly fixed, and we will be able to time events taking place in the physical space. However, an etalon clock is just halfway in timing events. Physical events take place at different points in space and in order to describe them properly, we need synchronised ‘clones’ of this ideal etalon clock placed at each point in physical space, so that we can time events at their own spatial location. Synchronisation of clocks and thus measurement of the local time of events was—and still is—a difficult task. Let us merely scratch the surface of the problem’s complexity. In order to have reliable local clocks, ideally you first have to produce clones of the original master clock, and than from time to time you have to synchronise them with the master clock. In order to achieve synchronisation an ideal information carrier is needed. For this information carrier you need to know exactly the speed of propagation along the geodesic line between any two clocks, since only in this way can you account for the time lapse in the propagation of the information. We therefore also have to locate the geodesic line between the clocks and calculate precisely the distance along this line. All these are of course needed if we have an information carrier that propagates at finite speed. On the other hand however, if we had an ideal information carrier that propagated at infinite speed, the problem would be much simpler, and synchronisation of local clocks using such a signal would be trivial. Alternatively, timing of events occurring at different points in space can be hypothetically achieved using only one master clock. To proceed in this way, we again need some universally available information carrier and we have to know the length of the geodesic line between the master clock and the event. When the event occurs, we transmit a signal through the information carrier to the master clock. When the master clock receives the signal, we record that time and subtract from it the time needed to travel the distance between the event and clock. This procedure requires also the knowledge of the geodesic line and the speed at which the signal is propagated along it. Timing is again simple if we use an information carrier that travels at infinite speed.

It was only natural that in the beginning physics considered the simplest alternative: definition of an ideal time. This was defined at each point in space by hypothetically similar and ideal clocks, based on the assumption that they were synchronised with an ideal information carrier that travelled at infinite speed. Alternatively, this was equivalent to time events with a master clock, assuming no time lapse between the occurrence of any event and its detection at the location of the master clock. The simplicity of Newtonian mechanics resides in the fact that we assume the existence of an ideal information carrier that moves at infinite speed. Unfortunately, however, our Universe is more complicated than that. The fastest and the only universally available information carrier we are nowadays aware of is the electromagnetic wave, and we do know that its propagation speed is finite. In such case there is a serious catch, however: we do not know the medium through which light is propagated, since we were unable to detect aether. Whether it exists and we are just unable to find it or whether it does not exist, there is still a problem. In order to be capable of timing events at different spatial locations and to have a well-defined space time in physics we have to know the propagation speed of light along the correct geodesic line in any reference frame. The aether wind would influence this propagation speed, and the timing of events would then depend upon the frame of reference where the master clock is positioned. Now imagine for a moment that we know where the aether is. Theoretically, we would then be able to make a correct timing, but in practice it would be an arduous task. However, the advantage would be that by this method we would have an absolute frame of reference related to aether, and the timing of events relative to this would preserve a time concept that would also be absolute in nature. At the beginning of the twentieth century, however, aether was undetectable, and in order to progress, physics keenly needed a properly defined concept of time in physical space, if it was to tackle cosmological and electromagnetic phenomena.

Einstein gave in 1905 the only feasible outcome from this paradoxical situation by postulating that the speed of light in vacuum is a universal constant independent of the direction of propagation or frame of reference [10]. In the context of how we constructed and introduced the logic of time, this step now seems quite obvious and it is easy to conclude that physics had no other alternative. Thitherto space-time had not been properly defined, it did not make sense to speak about speed, and so the speed of light too had no physical meaning without a properly defined time. Einstein's postulate, as well as fixing the value of the speed of light, allowed local times to be properly defined at each point in physical space and the "catch 22" type paradox was elegantly solved. In the beginning, the value of the speed of light was set at the best available experimental data, and it was proposed that this value should be constantly revised according to new experiments.

The story of grounding the physical space-time by means of light rays does not end here, however. For a consistent definition of space-time one immediately realises that it is problematic that geodesic lines and time are defined by means of light propagation, whereas the unit of length is still defined by the traditional ruler. In addition, if we know exactly the speed of light (since in Einstein's paradigm it is a universal constant), then the unit of length should result automatically after the time unit has been set. The time unit of the master clock has to be set in any case, both in the Newtonian and in the Einsteinian paradigm in order to have a working master clock. By setting the time unit [11], and by knowing exactly the speed of light we could measure any distance in space using light rays and an etalon clock. Instead of postulating the unit length, it is much more convenient for modern physics to postulate the value of the speed of light. It was not until 1983 that physics, accepting the proposal of the Hungarian physicist Zoltan Bay, decided to postulate this value in consensus with the best experimental results at that time [12]. Today this value is set at c=299,792,458 m/s. This was the last crucial step in defining a logically consistent space-time for physics.

However, this last step closes the circle and makes it impossible henceforth to detect aether by the eather wind, should it exist. In our new measurement paradigm, both the physical definition of distances and the construction of space-time are linked to the fact that light travels at a constant speed in every direction through space, independently of the chosen frames of reference. Any self-consistent eather wind experiment should give thus negative results. We do have thus a usable and well-defined space-time entity, but we have lost the aether-wind in the presently postulated physical space-time.

THE PRINCIPLE OF RELATIVITY

In physics we may use several frames of reference for describing the same phenomenon. For example, the collision of two cars on a road can be described within the frame of reference of the road, within the frames of reference of the two colliding cars, or within the frame of reference of any other car driving past on the road. It can be even described within the frame of reference of a light ray passing at the speed of light, or infinitely many other imaginable reference frames. These frames of reference are in motion relative to each other. When describing events from different frames of reference we intend first to locate the event within the particular frame of reference (giving the spatial and time-like coordinates) and then we try to understand it in a causal way according to previous events, applying the laws of physics. Each frame of reference comes with it's own space-time entity, so we are interested to get also the relations (transformations) that connect the spatial or time-like coordinates of any event as measured from different reference frames.

Mechanics is founded on the experimental observation, which holds that there are special frames of reference within which the law of inertia is valid. These reference frames are called *inertial frames of reference* and these are those special reference frames where the geometry is Euclidean. If one frame of reference is inertial, any other frame of reference that is moving at a constant speed relative to it is again an inertial frame of reference (according to our postulates defining the geodesic lines their geometry is also Euclidean).

For the inertial frames of reference physics accepted the *principle of relativity*. According to this principle all inertial frames of reference are equivalent when describing physical phenomena, meaning that the laws of physics are the same in all inertial frames of reference. Mathematically this implies that the basic equations describing physical phenomena should have the same form in all of them. Taking into account their Euclidean nature (similar metric properties) this seems to be a logically consistent statement. According to the principle of relativity there is also no distinguished inertial frame of reference, or in other words there is no *absolute frame of reference*. Motion is always relative, and whenever we speak about motion we mean it only in a relative manner. On the contrary, if we had an absolute frame of reference the notion of motion and rest would also be absolute. In Newtonian space-time the absence of an absolute frame of reference is due to the fact that the information carrier travels at the same infinite speed relative to all inertial frames of reference. In Einsteinian space-time the absence of an absolute frame of reference is a direct consequence of the fact that we have postulated the constancy of speed of light independently of the frames of reference. In such a way, we postulated that there is no aether, which would have been the absolute frame of reference for physics. Our postulate about the uniform propagation speed of light, independently of the frames of reference, is thus consistent with the principle of relativity, which holds that there is no absolute frame of reference in physics.

COORDINATE TRANSFORMATIONS

Both Newton's ideal space-time and Einstein's tangible space-time ought to be consistent with the principle of relativity. In both cases the spatiality and temporality of events are completely measurable and we can construct a well-defined system of coordinates to characterize this. However, the principle of relativity does not affirm that the temporal or spatial coordinates of events measured from different inertial frames of reference are the same. In Newtonian space-time, all the local clocks of the inertial frame of reference are naturally synchronised and time is absolute, but spatial coordinates are not. In Einstein's Universe the concept of the synchronisation of clocks in different inertial frames of reference is more complicated and consequently time is not absolute. In both cases, however, if we know the spatial and temporal coordinates in one inertial frame of reference, we can calculate these coordinates in any other inertial frame of reference that is in motion relative to the original one at a given velocity. We call this *coordinate transformation* between two frames of reference [13] (for deriving the coordinate-transformations see Appendix 2.).

For the Newtonian space-time the coordinate transformations are given by the simple Galilean transformations we all learned in high school. Within the framework of Galilean transformations time coordinates are invariable. The coordinate transformations for Einsteinian space-time are given by the more complicated *Lorentz transformations*. In this case, time coordinates are not invariable, and they are transformed as a whole along with spatial coordinates. This is why we say space and time forms a 'space-time continuum'. The consistency of the space-time defined by Einstein is demonstrated by the fact that the basic equations of electrodynamics, the Maxwell's equations [4], are fully covariant with Lorentz transformations. From this viewpoint, the electromagnetic theory of light becomes a logically consistent and closed system. Lorentz transformations were derived by assuming there is no absolute medium through which light is propagated (no aether), and the equations that describe light lead us to the same conclusion: within each reference frame light travels at the same universal speed.

THE AFTERMATH

If one uses the space-time entity tailored on the finite propagation speed of light (and implicitly the Lorentz coordinate transformations), several fascinating consequences arises. First, one can easily realize that the simultaneity of events is not an absolute concept anymore. Events that are simultaneous in one frame of reference will not necessarily be simultaneous as viewed from other reference frames. The time-length of an event, or the spatial length of an object becomes also a relative concept. An observer moving with respect of a purely time-like event (an event happening at the same spatial coordinate in a reference frame that is in rest relative to the event) will measure a longer time-length for the event than the observer in rest relative to that event, a phenomenon called *time-dilation*. The spatial length of an object measured by an observer in rest relative to that object is longer than the one measured by an observer moving in the direction of the measured length. This phenomenon is known as *length-contraction* (Appendix 2.). Composition of velocities is also more complicated than in the Galilei-Newtonian kinematics. The interested reader can learn more about these fascinating effects from many excellent textbooks (see for example Einstein's original text [13]), here we will not elaborate more on them. All these effects that seemingly contradicts our common sense are simply the direct consequences of the method by which our actual space-time entity is tailored on light.

As we have argued in the previous chapters, the story and the logic of the construction for the physical space-time is quite complicated, and even physicists sometimes forget this. Once it has been properly understood, however, special relativity becomes crystal clear and one can also realize that the presently used space-time paradigm might not be the ultimate solution for grounding physics. In the followings I will allow myself to be less rigorous and finish with some speculative thoughts.

An important, and sometimes misunderstood issue that we have to discuss here is the existence of a signal other than electromagnetic waves for allowing information to travel on cosmological scales of length. As our detection methods improve thanks to rapid advances in technology, a channel via such a non-conventional information carrier might become more appropriate for communication and measurement. At present, nothing guarantees that such an information carrier, if it exists, would travel at a lower speed than light. Contrary with what it is falsely believed, a speed bigger than the speed of light wouldn't be a disaster for modern physics. The problem that might arise in such a case, would be that the space-time we built in the context of the theory of special relativity would not be self-consistent and we would violate the principle of relativity. It would be inertial reference frames in which one would detect the cause preceding the effect, contradicting the principle of causality (see Appendix 3.). In order to make the theory consistent, instead of light we would now use the new information transmitter signal to synchronise clocks. Postulates regarding this new signal would replace those made for light. The advantages from such a new space-time paradigm would be that we would be able to answer some of the questions we have previously labelled 'unanswerable'. Detection of the aether wind, the universal nature of the speed of light, and straight-line propagation of light rays would become questions that once more made sense.

Escaping the bonds of Einstein's space-time and using some other logically consistent definition of space-time is an interesting challenge even if we cannot find any new information carrier. A new method of synchronising clocks or a new procedure for measuring time, along with the traditional ruler for measuring distance, might also help to bring the aether wind to light. Such experiments would not use interference or other wave-like properties implicitly based on Lorentz covariant electrodynamics. Instead, direct time of flight measurements of the propagation of light-rays, performed on laboratory scales of length, would be the most appropriate for us. As optoelectronics is making rapid progress, this does not seem to be unrealisable in the near future.

Previously we argued that our physics is based on the presumption that we have no absolute frame of reference, and all inertial reference frames are equivalent regarding the laws of physics. This also means that there is no special frame of reference known to us, relative to which electromagnetic waves are propagated. Modern cosmology is cautious enough to teach us that this might not be true, however. Apparently, there is a special, absolute frame of reference, relative to which the Cosmic Microwave Background Radiation (CMBR) is isotropic, and this could be regarded as an absolute frame of reference for the electromagnetic waves originating from the birth of the Universe [14] (more information on CMBR is given in Appendix 4.). The special frame of reference defined by the CMBR naturally raises several questions and thoughts about the present foundation of physics. Firstly, it would be important to know whether the CMBR's frame of reference generally defines the aether we were looking for. Will light rays travelling through the Universe always move with constant speed only relative to this frame of reference? When investigating such questions, we have to be quite cautious, however, since our present working paradigm, built on the constancy of the speed of light, would inevitably distort the measurements and their interpretations. Nonetheless, the proven existence of a special frame of reference for the CMBR is a serious argument pointing to the need to overhaul the present foundation of our basic concepts of space and time.

Another important issue we might discuss here in connection with space-time based on light is the microcosm. At the level of elementary particles, quantum mechanics seems to work when describing the microcosm. The image currently provided by physics, which states that elementary particles are wave-like in character and at the same time behave like classic particles is merely a desperate attempt to create a visual picture. Let us make a less desperate attempt and provide an alternative understanding of elementary particles' strange dual nature starting from the obvious fact that the tools for investigating the microcosm are also electromagnetic waves. All physical information is collected via this channel, thus the geometry of the microcosm is shaped by light. Distances are measured via electromagnetic interactions and electromagnetic waves. We do know, however, that light has an experimentally proven dual nature. Apart from being a particle, its propagation is also wave-like. On the microscopic scale (the scale of length comparable with wavelength of light) this wave-like behaviour dominates, with the result that photons (energy carriers of the light) can be propagated in a strange manner along non-deterministically defined paths between two points of the space. The straight-line concept based on light yields a fuzzy, non-deterministic trajectory. If we do extrapolate our accepted definition of geodesic lines on microscopic scales, this thinking leads us to a non-deterministic, random metrics on the microscopic scale. The movement of microscopic objects would automatically obtain a probabilistic character, something similar to what we see in quantum mechanics. From this viewpoint, geometric spaces with random metrics might be than the tool to provide the particle-wave duality with an alternative description.

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APPENDIX 1. MEASUREMENT OF THE SPEED OF LIGHT

Ancient Greek philosophers were much more interested about vision, and light was only their second concern. Empedocles for example presumed that light travels with finite speed, while Aristotle assumed an infinite propagation speed for light. The first scientifically grounded thinking about the finite light propagation speed was formulated by the Arab scientist Ibn al-Haytham in the eleven century, and the first documented attempt to measure its value was by Galileo Galilei around the year 1600. Galileo designed a very basic experiment with too lamps placed on the top of two hills sufficiently far away from each other, but still in sight. His method was the following: let in the beginning both lamps be covered. Then, he would uncover his lamp, having instructed his apprentice to uncover his lamp as soon as the light from Galileo's lamp become visible. By this experiment Galileo planned to measure the time-gap between uncovering his lamp and the receiving signal from the other lamp. Due to the extremely high propagation speed of light, this method of course couldn't work, even if the two hills are tens of kilometers apart from each other. Galileo finally concluded that if the speed of light is finite, then it is too high to be measurable in such experiments. He also concluded that the speed of light must be at least 10 times bigger than the speed of sound, and we know nowadays that this is a strongly underestimated limit. Danish astronomer Olaf Roemer gave the first scientific proof that light travels with a finite speed. He made this conclusion by studying the observed eclipse times of the Jupiter's moon: Io. Astonishingly based on his results a good estimate can be obtained on the propagation speed of light. The first successful experiment for measuring the propagation speed of light in terrestrial experiments was made by the French physicist Armand Fizau in the mid-nineteenth century, obtaining a result that differs with less than 1% from the value accepted nowadays. Many later, carefully designed experiments confirmed these estimates and improved its accuracy. Nowadays our International System of Units is built in such manner (and we will understand later why this is a natural choice!) that the propagation speed of light is postulated. Following the proposal of the Hungarian physicist Zoltan Bay, in 1983 the propagation speed of light in vacuum was postulated as: 299 792.458 km/s.

APPENDIX 2. DERIVING THE COORDINATE TRANSFORMATIONS

We consider two inertial reference frames, K and K'. The geometry in both reference frames is Euclidean and we construct the usual Ox, Oy and Oz coordinate axes in K and the O'x',O'y' and O'z' axes in K', so that the corresponding axes are parallel with each other. Let us assume that K is moving with a uniform speed *u* relative to K' in the direction of the common Ox -- O'x' axis so that at time *t=0* we synchronize the etalon clocks in K and K' (*t'=0*) and at this time moment the centre O is coinciding with O'. Let an event P happen on the Ox -- O'x' axis. Assuming that the time and length units used in both reference frames are the same, we are interested in the relation between the coordinates of the event measured in K (x_1, y_1, z_1, t) and K' (x_1', y_1', z_1', t_1') (see Fig. 1). In our geometry for the P event $y_1 = y_1' = 0$ and $z_1 = z_1' = 0$, so we are looking for the relation between x and t coordinates measured in K and K'. Assuming a general functional relationship between the (x_1, t_1) and (x_1', t_1')coordinates we can write:

$$x_1' = F(x_1, t_1, u)$$
$$t_1' = G(x_1, t_1, u) \tag{1}$$

Using the principle of relativity, the same functional relationship should be true inversely, if we replace *u* by –*u*:

$$\begin{aligned} x_1 &= F(x_1',t_1',-u) \\ t_1 &= G(x_1',t_1',-u) \end{aligned} \tag{2}$$

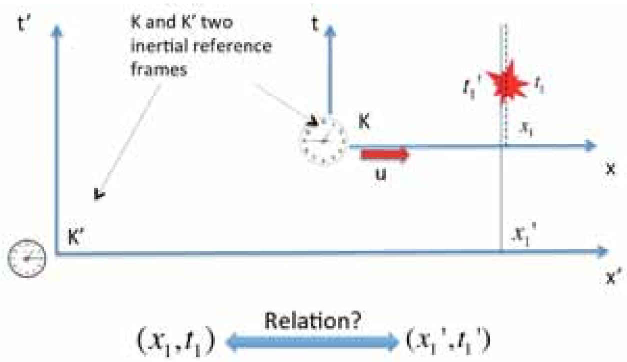

Fig.1. Coordinate transformation between the inertial reference frames K and K'.

One can get the inverse transformations however also from (1). In order that these should have the same functional form it is necessary that the transformations should be linear in the *x* and *t* coordinates, otherwise the functional form would change, and we would contradict equation (2) and implicitly the principle of relativity. The most general linear transformation we can write is:

$$\begin{aligned} x_1' &= a(u)x_1 + b(u)t_1 + d \\ t_1' &= g(u)x_1 + f(u)t_1 + k \end{aligned}$$

Considering the initial condition $x_1 = x_1' = 0$ at $t_1 = t_1' = 0$ we get *d=k=0*, leading to:

$$\left.\begin{aligned} x_1' &= a(u)x_1 + b(u)t_1 \\ t_1' &= g(u)x_1 + f(u)t_1 \end{aligned}\right\} \rightarrow \frac{dx_1'}{dt_1'} = v_1' = \frac{a(u)\dfrac{dx_1}{dt_1} + b(u)}{g(u)\dfrac{dx_1}{dt_1} + f(u)} = \frac{a(u)v_1 + b(u)}{g(u)v_1 + f(u)} \tag{3}$$

Here v_1 denotes the velocity for the movement of a body as measured in K and v_1' the same velocity measured from K'. According to the principle of relativity the inverse transformations should be:

$$\left.\begin{aligned} x_1 &= a(-u)x_1' + b(-u)t_1' \\ t_1 &= g(-u)x_1' + f(-u)t_1' \end{aligned}\right\} \rightarrow \frac{dx_1}{dt_1} = v_1 \frac{a(-u)\dfrac{dx_1'}{dt_1'} + b(-u)}{g(-u)\dfrac{dx_1'}{dt_1'} + f(-u)} = \frac{a(-u)v_1' + b(-u)}{g(-u)v_1' + f(-u)} \tag{4}$$

If we study the relative motion for the origins of the two coordinate system K and K' we get that in case $x_1 = 0 \rightarrow dx_1/dt_1 = v_1 = u$ and for $x_1' = 0 \rightarrow dx_1/dt_1 = v_1 = -u$. These conditions in (3) yields: $b(u) = u \cdot f(u)$ and $a(u) = f(u)$.

Galilei-Newton transformations. If one assumes that the speed of light is infinite, synchronization of clocks is trivial since there is an absolute time, and in such manner for any event one should have: $t_1' = t_1$ leading to: $g(u) = 0$ and $f(u) = 1$. The coordinate-transformations write thus as:

$$x_1' = x_1 + ut_1$$
$$t_1' = t_1 \tag{5}$$

As an immediate consequence we have than, that for any event, it's time-length is the same from any reference frame ($dt_1' = dt_1$) and the length of any object is the same from any reference frame. The length of an object from reference frame K is measured by determining it's coordinates at the same time moment, so that $dt_1 = dt_1' = 0$. As a result we get $l_1' = dx_1' = dx_1 = l_1$. The velocity transformations result automatically from eq. (3)-(5): $v_1' = v_1 + u$

Lorentz-Einstein transformations. In case the speed of light is finite, synchronization of clocks can be made only by assuming that the speed of light is the same, from any reference frame. This means that a light beam that travels along the Ox axis in K should have the same *c* finite value measured both from K and K'. Equation (3) and the relations established before yield thus: $c = \frac{f(u)(c+u)}{g(u)c + f(u)} \rightarrow g(u) = f(u)\frac{u}{c^2}$

According to this we can write:

$$x_1' = f(u)(x_1 + u \cdot t_1)$$
$$t_1' = f(u)\left(x_1 \frac{u}{c^2} + t_1\right) \tag{6}$$

Deriving from here the inverse transformations one gets:

$$x_1 = \frac{x_1' + ut_1'}{f(u)\left(1 - \frac{u^2}{c^2}\right)} \quad ; \quad t_1 = \frac{x_1' \frac{u}{c^2} + t_1'}{f(u)\left(1 - \frac{u^2}{c^2}\right)} \tag{7}$$

In order to satisfy the principle of relativity (and the inverse transformations should be of the form one must have: $f(u) \cdot f(-u) = \left(1 - \frac{u^2}{c^2}\right)^{-1}$, leading in our geometry to the Lorentz transformations:

$$x_1' = \frac{x_1 + ut_1}{\sqrt{1 - \frac{u^2}{c^2}}} \quad ; \quad t_1' = \frac{x_1 \frac{u}{c^2} + t_1}{\sqrt{1 - \frac{u^2}{c^2}}} . \tag{8}$$

One realizes now that quite differently form the Galilei-Newton kinematics, simultaneity of events becomes a relative concept. In case of a purely time-like event taking place in K (the spatial coordinates in K are the same, $dx_1 = 0$), we get:

$$dt_1' = \frac{dt_1}{\sqrt{1 - \frac{u^2}{c^2}}} \geq dt_1 . \tag{9}$$

According to this, the time-length measured by an observer who moves relative to the event that is purely time-like in K is always bigger, a phenomenon known as *time-dilation.* In the direction of the movement the lengths of the objects are measured shorter. This phenomenon is known as *length-contraction*, and can be derived immediately from equations

(6). When measuring the length of an object from reference frame K’ we need to determine the end-points coordinates in the same time moment, so $dt_1'=0$. For deriving the magnitude of the length-contraction we have to use thus the inverse transformations of (6). We get:

$$dx_1 = \frac{dx_1'}{\sqrt{1-\frac{u^2}{c^2}}} \rightarrow dx_1' \leq dx_1 \tag{11}$$

The velocity transformations result simply from equations (3),(4) and (8):

$$v_1' = \frac{v_1 + u}{1+\frac{v_1 u}{c^2}} \quad ; \quad v_1 = \frac{v_1' - u}{1-\frac{v_1' u}{c^2}} \tag{12}$$

APPENDIX 3. CAUSALITY PRESERVED

From the Lorentz transformations we already foresee that we have problems if we have reference frames that move relative to each other with a higher velocity than the velocity *c* of light, since negative numbers under the square root appear. This does not forbid however, to have a special signal that travels with a higher velocity than *c*.

Let us now recall that our belief in the principle of causality was the main reason for which we needed time. It is imperative then that causality should be preserved by the space-time entity we have constructed. The question that makes sense from such a viewpoint is whether causality is preserved within any frame of reference. Let us assume that we have two events *a* and *b*, which are causal: *a* causes *b*. Let us assume that event *a* happens within frame of reference K at spatial location x_a and time t_a, and event *b* happens at spatial location x_b at the time moment t_b. Let us assume $x_a < x_b$ and causality in frame of reference K means that $t_a < t_b$. This order must be preserved in any inertial frame of reference. If we had an inertial frame of reference where this order is inverted, the principle of relativity would be violated, since the event does not make scientifically sense within this frame of reference. Causality in the frame of reference K means that there should be some signal starting from space point x_a at time moment t_a and arriving at space point x_b in time moment t_b. We will consider that this signal is the one that creates a causal connection between the two events, i.e. event *b* is triggered through this channel. From the $x_a < x_b$ spatial location of the events and from their time moments $t_a < t_b$, one can calculate the propagation speed of this signal. In principle any positive velocity value $v = (x_b - x_a)/(t_b - t_a) > 0$ is acceptable. Let us now use a second K’ frame of reference travelling in the direction of the line from point x_a to x_b at a velocity of u (note that this is quite the opposite direction as the one sketched in Figure 1). We learn from the Lorentz transformations, (use of eq. (12) with $u \rightarrow -u$) that within this frame of reference:

$$t_b' - t_a' = \frac{t_b - t_a}{\sqrt{1-\frac{u^2}{c^2}}}\left(1 - \frac{vu}{c^2}\right) \tag{13}$$

In order to preserve causality ($t_b' > t_a'$) we need thus $uv<c^2$ be satisfied for any $u<c$ value! Since the speed of reference frame K’ and the signal from *a* to *b* are not connected, their values can vary independently. We thereby arrive at the conclusion that the value of *v* is also bound by the value of *c*. In other words, in order to preserve the principle of relativity (i.e. to hold causality within any frame of reference) we put forward that there is a speed limit in our Universe, and this is the speed of light! It is not allowable for any signal to be propagated

faster than the speed of light, and no frame of reference (i.e. object) can have a speed relative to the other one bigger than the speed of light. These statements must be true in order to preserve the logical consistency of the special theory of relativity.

APPENDIX 4. THE COSMIC MICROWAVE BACKGROUND RADIATION

The CMBR is an electromagnetic radiation detectable throughout Universe, and thus measurable on the Earth, too. Arno Penzias and Robert Wilson discovered it by accident in 1964 during radio astronomy and satellite communications experiments. In the signal captured by their specially built horn antenna, the CMBR appeared as a continuously present electromagnetic noise coming from every direction in the Universe. The spectrum of this electromagnetic radiation peaks in the microwave region, and it was found to be characteristic of very low-temperature (around 3K) thermal (or black-body) radiation. This electromagnetic radiation is assumed to be a leftover from the "Big Bang" that created our Universe. Nowadays, using modern apparatus, we are able to map this radiation with great precision at micro Kelvin resolution, and anisotropies from different directions of space are precisely measurable. It was found that apart from randomly distributed, tiny anisotropies, the CMBR measured from Earth has also a prominent "dipole-anisotropy" on milli Kelvin resolution, which results from the motion of Earth (and our group of galaxies) relative to the CMBR's frame of reference [1]. In this way, we have a detectable, special frame of reference, relative to which the dipole anisotropy of the CMBR would vanish. Interestingly, we know this special frame of reference, and it appears to be moving at a speed of around 600 km/s relative to the Milky Way.

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SIMPLE EXPERIMENTS WITH SEMICONDUCTORS AND LEDS

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ABSTRACT

In contrast to classical chapters of physics, only a few simple experiments are available for discussing semiconductors in the schools. This paper describes some simple experiments tested several times. By examining the electrical resistance of a Ge slice, some basic properties of semiconductors are illustrated like changes in resistance under the influence of heating or illumination. The possible application of semiconductor devices in further demonstrated by experimenting with light-emitting diodes (LEDs), known from everyday practice. The focus is on the description of experiments, and explanations are given only in terms of basic physics.

INTRODUCTION

As in the science of physics, experiments play a vital role also in physics teaching. The discussion of each topic in physics should ideally start with the presentation of a related experiment. The primary task with the experiments presented here, which do not need too many devices and can be carried out quickly, is to grab the attention of pupils and to motivate them to understand the explanation of the phenomenon.

Semiconductors play an important role electronic equipment used in modern everyday life. Young people are eager to learn how the devices they use work and it should be kept in mind that almost all the main features of those devices rely on semiconductors. It is important to realise that the introduction of semiconductors in secondary schools physics is unavoidable since they have become an inevitable part of the preparation for any engineering profession. In teacher training at universities the discussion of semiconductors takes place only after thorough quantum mechanical and material science courses. This may be the reason why so many teachers don't even think of dealing with semiconductors. In fact, students are lacking the necessary knowledge of material structure required for a deeper understanding of the related phenomena. Here we show that a different approach might be more efficient: experimental investigation of some phenomena is also a valuable, especially when experiments are carried out by the students themselves.

The topic of semiconductors is also cross-curricular, bridging the gap between different science subjects, i.e., chemistry and physics. The efficiency of learning is higher for students if they recognise that the knowledge they have acquired in chemistry can be essential for their further comprehension of physics.

EXPERIMENTAL INVESTIGATION OF THE CONDUCTIVITY OF GERMANIUM

In our first experiment we measure the resistance of a germanium slice. To this end we need a multimeter, a slice of germanium, an insulating support, and electrical wires (Fig.1). We place the germanium crystal carefully on the insulating support and fix it. (We have to be careful because a thin layer of Ge crystal is very fragile.)

The multimeter is used in the "resistance measurement" mode and is connected to two edges of the germanium slice. The multimeter contains a built-in power supply, and the circuit is closed through the germanium. The multimeter displays the resistance of the germanium at room temperature. The resistance of a thin layer of germanium, as can be seen in Fig.2, is of the order of MΩ-s. This value is very high compared to the values measured on metals of similar geometry, but it is much smaller than the resistance of electrically insulating materials.

Spray on the Ge slice some kind of freezer spray, available in medication. The instrument indicates that the electrical resistance of the cooled germanium increases dramatically. Heat the germanium slice with a hairdryer above room temperature. The electrical resistance of the material decreases with increasing temperature (Fig.3). If the germanium sheet is illuminated with a table lamp its resistance decreases again (Fig.4).

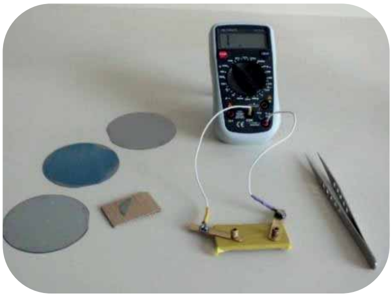

Fig.1. The tools needed

Fig.2. The multimeter shows us the resistance of the germanium at room temperature

Fig.3. When warming up the Ge crystal, its electrical resistance decreases

Fig.4. When illuminate the Ge crystal, its electrical resistance also decreases

The decrease in resistance under the influence of illumination is easily measurable. This change is interesting especially in comparison with that in metals. In the case of metals the electrical resistance increases parallel to the increase in temperature, and illumination does not cause any measurable change in resistance.

For an elementary explanation of the conductivity of metals, we introduce the free electron model, the classical Drude model [1]. The structural foundation of this is already known for students from chemistry. In physics, we augment this picture with a more microscopic interpretation of currents by mentioning that the oscillating movement of the metal atoms around their equilibrium positions in the crystal hinders the free movement of electrons. This is considered to be the cause of electrical resistance of pure metals. The interpretation of conductivity of semiconducting materials is based on the knowledge of their chemical structure. In chemistry the elements of Group 4 and 5 are called metalloids, and it is noted that in these groups the metallic character increases from top to bottom. Take, e.g. diamond carbon, silicon and germanium. The crystal structure of each of these materials is tetrahedral, based on covalent bonds, a so-called diamond lattice. In the case of diamond, electrons in covalent bonding are strongly bound and there are, therefore, no free charge carriers in the crystal, diamond is thus electrically insulating. In the case of Si, and Ge, that are below the carbon in the periodic table, electrons can be more easily released from the bonds (for example by heating or illumination). In Si, more energy input is needed, which demands, e.g., more intensive heating. In the case of Ge, a significant increase in the number of free electrons is experienced already at moderate temperature rise or illumination.

The electrons set free by the methods described above conduct electricity just like the free electrons in metals. The increase of current due to the electrons set free by heat or illumination is much stronger than the decrease due to the enhanced thermal oscillation around the equilibrium atomic positions.

In addition to the abovementioned electron conductivity mechanism an electron-hole mechanism gives a further contribution to electric conduction. At medium level it is sufficient to add a remark on this. At advanced level we can elaborate more on the passive movement of the holes. Our experience is that at secondary school the concept of the “energy-band structure” [2] is unnecessary since a quantum mechanical foundation is hopeless to be given at this level.

SIMPLE EXPERIMENTS WITH LIGHT EMITTING DIODES (LEDS)

In many appliances and instruments semiconductors are the basic components, of which the most commonly used are LEDs [3]. LEDs are well known as energy-saving light sources which directly convert electrical into light energy.

The LED light output as a pole-dependent device

In terms of physics, a LED is a special semiconductor diode. Simple experiments illustrate that LED conducts electricity in one direction only. If we join the anode of LED to the positive pole of a battery, and the cathode to the negative pole, the LED conducts electricity, and lights up (Fig.5). This connection is in the forward direction (Fig.6). (For protecting the LED we apply a 100-ohm resistor.) Using reverse polarity, the LED does not light up.

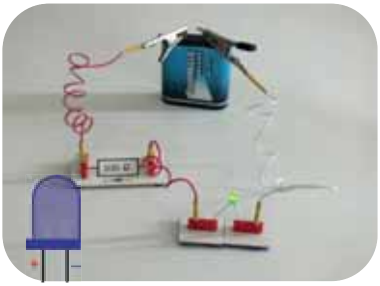

Fig.5. The LED lights up in the forward direction

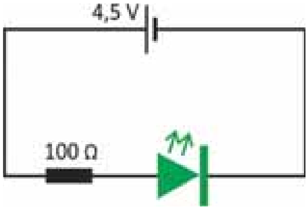

Fig.6. Schematics of an electrical circuit in the forward direction

LED is a special semiconductor diode

The fact that LEDs conduct electricity exclusively in one direction can be illustrated with another spectacular experiment. Take an approximately half meter double-stranded electric wire and a battery. If a LED is connected between the ends of the wires, the LED lights well (for protection we apply again a 100 ohm resistor in series). When rotating the light emitting diode at the end of the connecting wires, while holding the other end of it in our hand, the LED traces out a continuous circle of light (Fig.7).

Fig.7. With direct current we see a continuously lighting circle

Fig.8. With alternating current we see an interruptedly lighting circle

In the second experiment we use alternating current with a frequency of 50 Hz. Apparently, the LED lights well again. However, when spinning the wire with the LED, we see an interruptedly lighting circuit (Fig.8). The reason is that the LED lights up in the forward direction and goes out in the reverse direction. This alternation is so fast that without the rotation it cannot be observed by naked eye.

LED WORKS BEYOND A THRESHOLD ONLY

We can illustrate with a very impressive and interesting experiment that a LED – as any other diode – works only above a certain opening threshold voltage. We need some moderately wet earth, two electrical wires, and direct current from an electric power supply, two electrodes made by metal plates, a voltmeter, a ruler, and a LED. The electrical circuit needed can be seen in Fig.9.

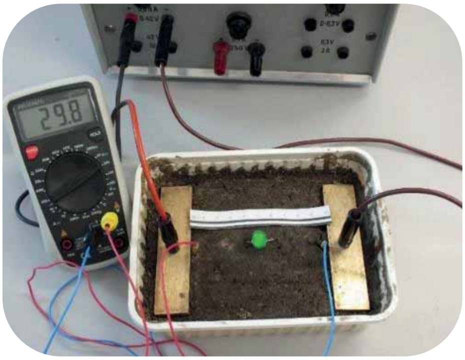

Fig.9. The electrical circuit used for the illustration of the existence of a potential threshold. The white ruler marks the direction of the electric field in the system

The distance between the two electrodes is about 10 centimetres. On the surface layer of the wet earth a nearly uniform electric field is formed. The voltmeter in Fig.9. shows about 30 Volts. We insert a LED into the wet earth. Make sure that the LED is to be inserted in forward direction. If the legs of the LED are far enough from each other, and are parallel to the ruler, the LED lights up, because the potential difference between the legs is higher than the threshold voltage. (In our experiment the distance between the legs of the LED was 2 centimetres. The maximum potential difference between the legs is thus about 6 Volts.) If we rotate the LED step by step, the potential difference between the legs decreases, the LED will provide dimmer light (Fig.10).

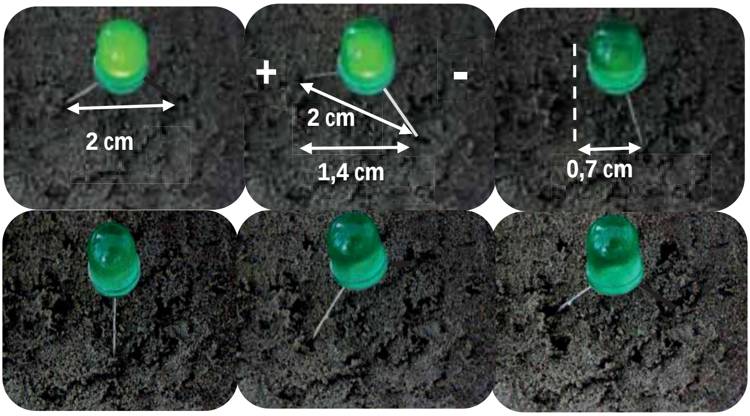

Fig.10. When slowly rotating the LED the light become dimmer, and at a threshold angle it goes off

Measuring the distance x between the legs parallel to the ruler when the LED goes off (in our experiment $x \approx 1.4$ cm, see the second panel of Fig.10), we can determine an approximate value of the threshold voltage as:

$$U_{th} \approx \frac{30\ \mathrm{V}}{10\ \mathrm{cm}} \cdot 1.4\ \mathrm{cm} \approx 4.2\ \mathrm{V}\,.$$

The LED does not light up, of course, if its legs are on an equipotential line (perpendicular to the ruler). In this case the potential difference between the legs is zero. If the LED is rotated further, the potential difference between the legs becomes negative, so it does not light up because the LED conducts electricity only in one direction.

LED as a photovoltaic cell

A voltage can make a semiconductor light up, the reverse phenomenon is that light can generate voltage in a semiconductor. It can be shown by a simple experiment that LEDs can work as power supplies. In our experiment a LED is illuminated by another one from above (Figs.11, 12). Between the electrodes of the illuminated LED we measure voltage. By varying the intensity of illumination (e.g. by increasing and decreasing the distance between the LEDs) the measured voltage changes.

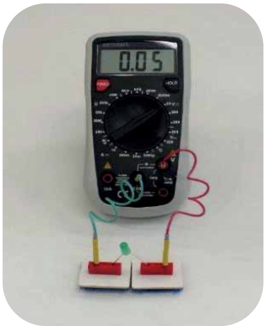

Fig.11. The LED's voltage is rather low in room light

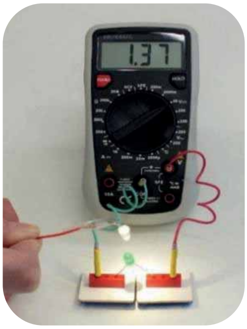

Fig.12. By illuminating the LED with another one, the voltage goes up

This experiment illustrates that LEDs and solar cells work in a similar way.

CONCLUSIONS

Based on the students' previous knowledge on semiconductors, teachers may explain why metals conduct electricity and insulators don't; how the conductive and semiconductive features of materials depend on the temperature and light intensity.

The experiments shown here are suitable to illustrate semiconductor properties, and the functioning of some devices made from semiconductors. To give deeper explanations was not our goal, since for these the students' deeper previous knowledge would be necessary, such explanations could be provided e.g. in special mentor classes, if we can awake our students' interest.

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COORDINATE TRANSFORMATION IN THE DESCRIPTION OF PHYSICAL PHENOMENA

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ABSTRACT

The treatment of the collisions at secondary school level is a nice application of the general principles of mechanics, namely the conservation of the energy and the conservation of the momentum. By transforming the coordinates into a system moving with the centre of mass of the colliding bodies the use of quadratic equations can be avoided. Another interesting use of the coordinate transformations can be found in the theory of relativity. By the use of Lorentz-transformation between inertial frames it can be demonstrated that the quantum mechanical wave function is a result of the transformation of standing waves into the frame which is moving relative to the first one.

ELASTIC COLLISION

It is well known, that solving physical problems is simpler when an appropriate reference frame is used. It is suitable even in case of colliding bodies. Considering the elastic head-on collision of two discs of different masses we can use the laws of conservation of energy and momentum:

$$m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2', \tag{1}$$

$$\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1v_1'^2 + \frac{1}{2}m_2v_2'^2 \,. \tag{2}$$

In these equations the masses m_i and the velocities v_i on the left side are known, and the value of velocities v_1' and v_2' after the collision are to be determined. Let the mass of the first and second discs be m_1 = 3kg and m_2 = 2kg, respectively. The first disc is moving to the right at velocity v_1 = 4m/s, while the second to the left at velocity v_2 = – 9m/s in the laboratory system which is attached to the table where the discs are moving. Substituting these values into the equations above, we get:

$$-6 = 3v_1' + 2v_2', \tag{3}$$

$$210 = 3v_1'^2 + 2v_2'^2 \tag{4}$$

Solving the equations, we get the velocities: v_1' = – 6,4m/s and v_2' = 6,6m/s after collision. But the calculation needs the solution of a quadratic equation which is beyond the curriculum of the 9th grade students.

However, the results can be obtained with simpler mathematical manipulations if the collision is described in the frame attached to the centre of mass of the system [1]. In this frame the centre of mass remains at rest during the collision and the sum of the momentums of the two bodies is zero all the time. It means that the momentum of the bodies is equal in magnitude but their direction is opposite. Since the kinetic energy of the system is also conserved, therefore only the direction of the momentums could be changed, the magnitudes of the momentums must remain the same during the collision.

The change between the frames happens on the basis of Galilean transformation, which leads to the classical addition formula of the velocities. In the laboratory frame of reference the centre of mass of the system is moving to the left with velocity $V = -1{,}2$m/s according to the formula

$$V = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \quad . \tag{5}$$

Now, let us calculate the momentums in the frame of reference which is moving at this velocity. It is the reference frame of the centre of mass. In this frame the velocity and momentum of the first body are 5,2m/s and 15,6kgm/s, respectively, while those of the second body are –7,8m/s, and –15,6kgm/s. As the reasoning given above shows, the direction of the momentums become opposite during the collision. From this the velocities of the first and second bodies can be calculated: – 5,2m/s and 7,8m/s, respectively. Transforming these velocities back to the laboratory system we get velocities v_1’= – 6,4m/s and v_2’ = 6,6m/s. The result agrees with those gained previously.

Thanks to the appropriate choice of the frame the quadratic equations could be avoided. The train of thoughts based on the coordinate transformation is not an easy one, but according to my experiences it is comprehensible for 9th grade students.

THE DE BROGLIE WAVES

Derivation provided in this section helps in understanding the essence of the quantum mechanical wave function. Nowadays this procedure can be used probably only at a more advanced level of physics teaching (e.g. at introductory courses of universities.) However, my previous experiences obtained in teaching the elements of the theory of relativity at secondary school level indicate that in special secondary school classes the presented train of thought can be understandable.

In 1924, one of the keynotes of de Broglie’s theses was that a frequency can be assigned to the rest energy of micro-objects according to the relation

$$\upsilon_0 = \frac{m_0 c^2}{h} \tag{6}$$

(m_0 is the rest mass of a particle, c is the speed of light, h is the Planck constant) – see e.g. [2], [3]. At that time the idea was wondrous as this kind of frequency had come up before only in connection with differences of energy levels, and never in relation to the energy of a given state – see e.g. [4]. Nowadays, this relation is taken conventionally, since it is an organic part of quantum theory. In the abovementioned articles we can read about the relationship of the de Broglie waves and the theory of relativity in connection with de Broglie’s thesis. The question of de Broglie waves is also examined in [5]. Article [3] comes out from assuming that in the quantum’s rest frame a standing wave is present and the quantum is not point-like.

In the following the formula $\lambda = h/p$ will be derived from (6) with a self-constructed train of thought of the author of the present paper. It will be shown that if in the quantum's rest frame K a standing wave of *infinite* wavelength and rest-frequency m_0c^2/h is present, then using the Lorentz transformation we get in the frame K' a travelling wave with wavelength $\lambda' = h/(mV)$. This is the de Broglie wavelength. V is the relative velocity of frames K and K', m is the relativistic mass of quantum.

It is known that the quantum in the rest frame has infinite de Broglie wavelength. Starting from this, the standing wave in the rest frame K can be represented with a function

$$y(x, t) = A \cdot \sin(\omega t) , \qquad (7)$$

where the value of y does not depend on x – see Fig.1. The dependent variable y can be an arbitrary scalar physical quantity. The angular frequency in the phase is $\omega = 2\pi / T$.

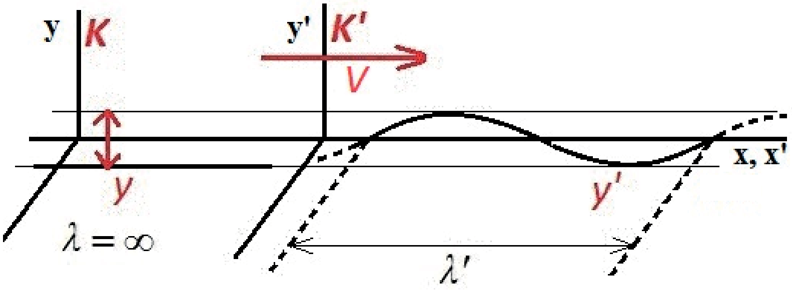

Fig.1. Function y(x, t) in the frame K and K'

The function takes a maximum value simultaneously at each point of frame K. Let us look at what we get if we consider the values of function in a system K' which moves parallel to the x-axis at a constant speed V. At this point, for describing the transformation of x and t, we have to use the formulas

$$x' = \frac{x - V \cdot t}{\sqrt{1 - \frac{V^2}{c^2}}}$$

$$t' = \frac{t - \frac{V \cdot x}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}} \qquad (8)$$

of the Lorentz transformation.

Because of the relativity of simultaneity, we could also expect that while the maximum values of the function occur at each point of frame K at the same time, this will not be the same in frame K'. In a fixed moment t', the value of the function is determined among others by coordinate x'.

In frame K' we have to work with a chosen coordinate t'. It results from the formula of time transformation that if we want to get the same coordinate t' at each point of the frame K', we have to increase the x coordinate along with the coordinate t. More precisely, the increase of coordinate t with Δt can be compensated by increasing coordinate x with the suitable value of Δx. It is clear that in case of a fixed x, if Δt takes the time period from zero to T, then with a fixed t, the suitable Δx runs an interval related to a whole spatial period. Therefore, in frame K', the state frozen at moment t' will be a harmonic function which is equal to such a 'crease' of the standing wave where the creases are characterized by wavelength λ', measured along the axis *x'*. We wish to determine this wavelength.

We transform the pair of events by data (x, t) and $(x + \Delta x, t + T)$ into frame *K'*. The aim is to have a simultaneous pair of events in frame *K'*. According to the formula for time transformation, it is evident that the requirement $t' = const$ refers to the relation

$$t - \frac{V\cdot x}{c^2} = const \quad . \tag{9}$$

Therefore, the relation $T = V \cdot \Delta x/c^2$, otherwise $\Delta x = T\, c^2 / V$ must be valid. If this condition is valid, we will get a simultaneous pair of events in frame *K'* from the pair of events

$$(x, t) \text{ and } \left(x + \frac{Tc^2}{V},\ t + T\right) \tag{10}$$

In frame *K'*, their distance is one period, which is equal to the sought wavelength λ'.

The event (x, t) is transformed to the coordinate

$$x_1' = \frac{x - V\cdot t}{\sqrt{1-\frac{V^2}{c^2}}} \ , \tag{11}$$

as the event $(x + T\, c^2 / V\, , t + T)$ is transformed to the coordinate

$$x_2' = \frac{x - V\cdot t + \frac{Tc^2}{V} - V\cdot T}{\sqrt{1-\frac{V^2}{c^2}}} = x_1' + \Delta x' \quad . \tag{12}$$

In frame *K'*, the distance of these simultaneous events is

$$\Delta x' = \lambda' = \frac{\frac{Tc^2}{V} - V\cdot T}{\sqrt{1-\frac{V^2}{c^2}}} \quad . \tag{13}$$

Based on this, we get the result

$$\lambda' = T\sqrt{1 - \frac{V^2}{c^2}} \cdot \frac{c^2}{V} \quad . \tag{14}$$

Therefore, if we have a standing wave of *infinite* wavelength and angular frequency $\omega = 2\pi/T$ in frame *K*, we get a propagating wave of wavelength λ' and phase velocity of c^2 / V in frame *K'*. (As it is well known the phase velocity of a wave is the velocity of the propagation of a given vibration-state.)

Let us consider what happens in frame *K* if the frequency is equal to the rest frequency m_0c^2/h of a quantum. In this case $T = h / m_0c^2$ and we get the relation

$$\lambda' = \frac{h}{m_0c^2} \cdot \sqrt{1 - \frac{V^2}{c^2}} \cdot \frac{c^2}{V} = \frac{h}{mV} \ , \tag{15}$$

with $m = m_0 \big/ \sqrt{1 - V^2/c^2}$. This result is equal to the de Broglie wavelength in a general, relativistic case. Thus, the standing waves with *unlimited* wavelength (vibrations) are converted by Lorentz transformation into de Broglie waves.

We may apply a similar derivation when we would like to know the temporal periodicity in frame *K'*. In this case, we make the coordinate *x'* be fixed instead of *t'* in frame *K'*. This setting creates the condition $\Delta x = V \cdot \Delta t$ within which we have to choose the time span $\Delta t = T$.

Let us transform the events

$$(x, t) \text{ and } (x + V \cdot T \ , \quad t + T). \tag{16}$$

The time coordinate of event (x, t) in frame *K'* is

$$t_1' = \frac{t - \frac{Vx}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}} \tag{17}$$

while the time coordinate of event $(x + V \cdot T , t+T)$ is

$$t_2' = \frac{t + T - \frac{V(x + V \cdot T)}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}}. \tag{18}$$

The difference between the two time coordinates is

$$T' = t_2' - t_1' = \frac{T - \frac{V^2 \cdot T}{c^2}}{\sqrt{1 - \frac{V^2}{c^2}}} = \frac{T \cdot (1 - \frac{V^2}{c^2})}{\sqrt{1 - \frac{V^2}{c^2}}} \tag{19}$$

based on that we can come to this relation:

$$T' = T\sqrt{1 - \frac{V^2}{c^2}}. \tag{20}$$

The same quantity is present in the relation derived for λ'. It refers to the fact that at the selected point, the vibrations happen with a reduced period *T'*, thus with an increased frequency of $\nu' = 1/T'$ in frame *K'*. The formula

$$\lambda' = \frac{T' c^2}{V} \tag{21}$$

shows that the vibrations in frame *K'* propagate as a wave of phase velocity

$$V_f = \frac{c^2}{V}. \tag{22}$$

Since $V < c$, the phase velocity is faster than the speed of light. The phase velocity depends only on relative velocity *V*. The velocity *V* of frame *K'*, which is compared to frame *K*, can be considered as the velocity of the quantum (in a sense, we can consider it as group velocity). According to the given relations, the product of phase velocity and group velocity is c^2. If relative velocity *V* approaches zero, the phase velocity will approach infinity.

The frequency of the de Broglie wave that we get in frame *K'* is

$$\upsilon' = \frac{\upsilon}{\sqrt{1-\frac{V^2}{c^2}}}. \tag{23}$$

This frequency gives the total energy of the micro-object. If the rest mass, namely the rest frequency ν is doubled, the frequency ν' is duplicated too, and the equality

$$V_f = \frac{c^2}{V} = \lambda' \cdot \upsilon' \tag{24}$$

shows us that the de Broglie wavelength is also halved, since the phase velocity is constant. In frame *K*, only the rest energy $h \cdot \nu$ is present and it is related to the periodicity of time; on the other hand, in frame *K'*, there is a part of the total measurable energy $h \cdot \nu'$ which is connected with spatial periodicity (momentum *p*) and the periodicity of time. The disintegration of the total energy *E* into these two components is reflected in the formula

$$E^2 = m_0^2 c^4 + p^2 c^2. \tag{25}$$

The direction of momentum *p* is given by the direction of velocity *V* of frame *K* in frame *K'*.

CONCLUSIONS

The formula (14) derived for the wavelength in the moving frame *K'* provides the de Broglie wavelength if the rest frequency m_0c^2/h is substituted into it. Therefore it can be concluded that de Broglie waves are basically the relativistic transformations of standing waves with frequency m_0c^2/h. The relativity of simultaneity plays a crucial role in its derivation. Based on this the de Broglie wave cannot be understood outside the frame of relativity. This is not contradictory to the fact that these waves play a role in interference experiments, also in the case of small relative velocities.

ACKNOWLEDGMENT

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APPLICATION OF COMPUTER SIMULATIONS IN MODERN PHYSICS EDUCATION

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ABSTRACT

Teaching modern physics is an essential, yet challenging part of our curriculum. When introducing the main scientific theories and discoveries of the past century, we often find ourselves with a lack of experimental resources in it. My goal is to develop and test computer simulations which can be used in high school teaching as a virtual science lab, where students do not only passively observe, but also interactively perform measurements of modern physics phenomena. In most cases the technical conditions for real students' experiments are not given, or the observed phenomenon runs in an uncommon (ultra-fast or ultra-slow) time scale. Thus, a simulation is able to complete the students' experience already based on real observations.

INTRODUCTION

There are at least four essential questions that shall be answered according to modern physics education. "What shall we teach?" "Who shall we teach?" "When shall we teach it?" And finally, "how shall we teach it?" These questions are fundamental for all subdisciplines of course, but for teaching modern physics, they get a little more problematic.

In my paper, I aim to introduce the main challenges in teaching modern physics and give an idea on how to solve these problems. I will discuss the general role of computer simulations in teaching modern physics and present one of my simulations – the photoelectric effect – in detail.

TEACHING MODERN PHYSICS IN GENERAL

It is not in question that motivating our students to study or even love physics is one of the biggest challenges today. Surely there is a great amount of publications on developing teaching methods for enhanced motivation, but teaching physics – or science in general – shall always contain experiments for gathering knowledge. "Performing experiments is the basic and typical method of scientific research, learning and education. […] Experiments in teaching is typically the base in determining laws of physics and chemistry, and also the only (exclusive) tool of validating these deduced laws, hypotheses and theories, as well as the diagnostic tool for their validity limits" [1]. This excerpt is from the Encyclopaedia of Pedagogy published in 1997. It clearly shows how important scientific experiments are in our physics teaching but it's also a key method in keeping students motivated.

Also, the constructivist approach of teaching, particularly IBL – inquiry-based learning/teaching – moves several steps forward claiming that experiments shall always be executed by the students, letting them gather own experience, and allowing them to observe, measure, draw up a hypothesis and then validate it on their own. This is the ideal approach of motivating and teaching physics to our students. Chris Chiaverina and Michael Vollmer gives a statement based on results from a discussion workshop during the 2005 GIREP seminar in Ljubljana that experiments in future physics education will always play a central role, "however more will be computer based. Computer aided experiments will allow the inclusion of frictional and other effects in simple experiments" [2]. They also state that "Experiments will always be needed to motivate students."

As for modern physics, I believe it is motivating itself, most of my student referrals in my classes state that modern physics was their favourite part of our physics curriculum and there are even ones admitting that learning about modern physics was the first time they ever wondered about studying science in the future. Therefore motivation is necessary, but manageable, though there is another challenge in teaching modern physics.

It is that it's challenging itself, and – by a very thoughtful idea – it all comes down to the aspect of scales [3]. In classical mechanics we are working with relatively low speed and big sizes, which makes our student experiments easier to handle. The IBL approach of physics teaching works with a question-observation-hypothesis-experiment-answer system, where students are able to do their own experiments basically every lesson, not to mention the possibility of bringing these experiments home, as project works for example.

But topics in modern physics tend to happen at really high speed or/and in really small sizes. This itself makes experimenting difficult. Not to mention its theoretical challenges being far from our everyday-approach theories. (Wave-particle duality, theory of relativity, mass-energy equivalence, etc.) Students don't observe electrons, only traces of electrons, or signs of traces of electrons, like a number on a counter. Time and number scales are also an issue, for the time of an event is often too long, too short, or it consists of too many participants.

These are the reasons why showing modern physics experiments is extremely difficult in a classroom. And even if there are really creative experimental tools, the cost of these makes it practically impossible to allow anything but a rare experimental presentation from the teacher.

Another key problem is the lack of time. Though it is part of the Hungarian physics curriculum, it is not uncommon that a student finishes high school without hearing anything about modern physics.

In the next section, I will give a brief overview on how computer simulations can help in solving the abovementioned problems.

INTRODUCING COMPUTER SIMULATIONS

For clarity we first make a clear distinction between simulations and animations. In our understanding animations can only be passively watched. In contrast, simulations are much more interactive: the students can set values of different parameters, sometimes even add new devices, or remove others, observe the results, perform measurements. They are much closer to the real world than simple animations. Whereas animations consist of a series of pre-recorded images playing in sequence, behind the simulations there is always a working mathematical model which constantly calculates the outcome.

As for the theoretical challenges, computer simulations always give us simplified images which could be visually helping in the understanding process. There are recent studies of how we can simplify even particle physics and make it understandable to even the youngest student groups [4]. It is vital to keep an eye on all these simplifications. The picture of a ball-shaped electron in a computer simulation can easily distract the students' ideas from their wave function. But there is no doubt that the understanding process is enhanced when we see something leaving the cathode, not only a trace or a counter.

With the previously mentioned scales in time and numbers, we have a lot of freedom. One of the key possibilities of using a computer simulation is that we can set the time scale dynamically, allowing functions like switching between the time lapses (e.g. speed up or slow down a reaction), pause or even turn back the time. Also, we can work with a lot of particles simultaneously.

It is obvious how these simulations can make up for the lack of experimental tools in the physics departments. Surely, a simulation will never be able to fully replace the educational role of a real-life experiment. But seeing an electron beam's trace on a fluorescent plate is visually similar to see it on a computer screen, while in the latter case students can also investigate the base principles of the phenomenon and perform their own measurements. This final potential brings us to the possibility of expanding our classrooms' borders, creating virtual laboratories and helping students to do experiments at home, for a project work or further analysis of a problem. Through internet-assisted teaching they can help with the issue of the time frames, not only extending our teaching time, but adjusting it to the students' needs.

"What makes a good simulation?" If we strictly keep an eye on the goals to help out high school physics education, I would take the following attributes:

1) Accessibility. A simulation shall be available to run on all the student's current devices, including smartphones, tablets and notebooks, and on any operation systems without using separate applets. In 2015 the majority of the popular browsers dropped support for NPAPI, which impacted plugins for Java (only the applets) and Silverlight. This would require the majority of the currently available physics simulations to be rewritten to a more broad usage. With the quick spreading of smartphones and tablets, we introduce our students to teaching resources available on these platforms. Simulations written in HTML5 don't require applets, therefore they are considered safe.

2) Diversity. Simulations applied in high school education shall offer various possible activities for the students or the teacher. This makes them easier to implement in the lessons, personalize and also allows to differentiate and extend the time of student experimentation. A simulation which takes more time to prepare on a lesson than actually working with it, usually isn't worth the time, and it always takes a few minutes just to introduce how the controls work.

3) Simplicity and challenge. Students are different, therefore simulations shall have different layers of difficulties fitting the diverse abilities and motivation, in help of teachers to differentiate. Not all students will understand a method of a measurement, and not all of them will be satisfied with only a dynamic animation. The layers should be easily separated not to confuse students.

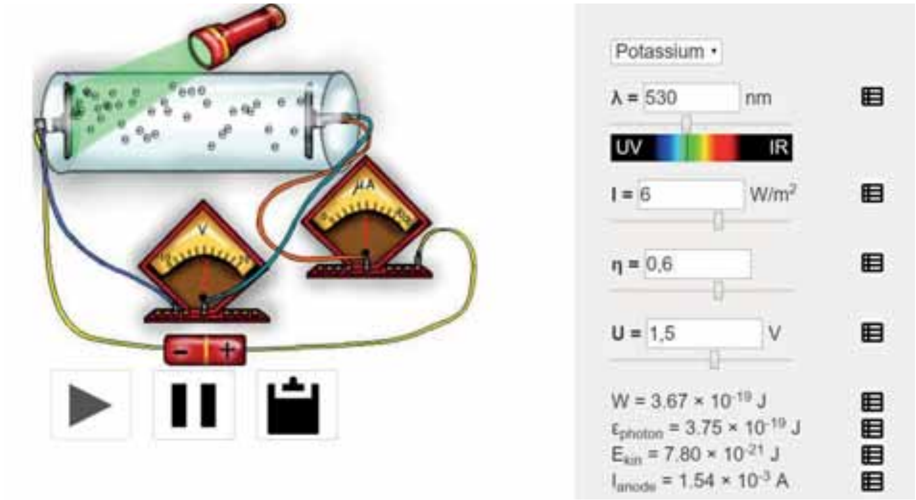
Not many of the currently available simulations fit these conditions. I looked up working simulations on a specific phenomenon – the photoelectric effect – and I found only one HTML–simulation out of five most popular ones [5]. The others required downloading an applet or adding the webpage to the browser's exceptions. This requires a careful preparation for the simulation-supported lesson, and means a lot of problems with the students' own devices.

The lack of diversity and possible student interaction was also a returning problem. It doesn't mean that the simulations are wrong, it just means sometimes the only possible way of using them is a brief show or tryout. Only one of them offered an idea on possible classroom differentiation, whilst the others were too simple or too difficult to understand for some students. A pleasant surprise was that three out of five offered the possibility of measurement. Trying out these in my classes I found that only one (the PhET simulation) can be used effectively, but it lacks a helping grid for recording the data, so needed real rulers for the students to make their calculations.

Out of the five, the PhET simulation was the most complex, which wasn't a surprise, knowing how much research and effort was implemented in their works, but there were some points missing, like accessibility and some extra possibilities in students' measuring exercises. My motivation in creating a new simulation of this phenomenon was to add these functions and to create a simulation that fulfills all requirements above that did not exist so far.

APPLICATION OF A SIMULATION ON PHOTOELECTRIC EFFECT [6]

I used the JetBrains WebStorm [7] program to develop the simulation. It works with HTML5, which means you can run this on any device including smartphones. The simulation adapts for the device we are running on, rearranging the simulation plane and the icons.



Potassium

λ = 530 nm

I = 6 W/m^2

η = 0,6

U = 1,5 V

W = 3.67×10^{-19} J

$\varepsilon_{photon} = 3.75 \times 10^{-19}$ J

$E_{kin} = 7.80 \times 10^{-21}$ J

$I_{anode} = 1.54 \times 10^{-3}$ A

Fig.1. My simulation on the photoelectric effect

The main interactions of the simulation are the following. Students can set (see Fig.1.) the desired cathode material they are experimenting with, also the wavelength of the light, the intensity, and the percentage of the photons producing an actual photoelectric effect (as the efficiency). They can also give an accelerating or decelerating voltage on the photocells, thus making the electrons stop and turn back. The simulation solves the mathematical model of the photoelectric effect on the one hand, and the motion of charged particles (electrons) in electric field on the other. The result is visualized as (non-ball-shaped) electrons moving toward the anode, and the following output parameters are calculated: the photon energy of the selected light, the kinetic energy of the electrons when they leave the cathode, and the anode current.

The strength of the simulation is the possibility to make simulated measurements with the side icons. Students can save any or every data to a chart. Every time they change any of the settings, the data will be created in a new column. After the end of the measurement, they can export it to an Excel file, and they can freely work with it. There are many possible measuring tasks. For instance, wavelength versus kinetic energy, or wavelength versus stopping voltage which we can use for measuring Planck's constant.

As mentioned, we need to keep an eye on this simulation's simplifications. The simulation relies on fundamental physical laws (such as Coulomb's law and the photoelectric effect itself) but it does not include either the electron-electron interactions, for example, or the small fluctuations in the energy of the electrons. In my experience the simulation in its current form can be a helpful tool in classroom education, as mentioned below, although future improvements might be added for increasing the number of observable phenomena.

IMPACT ON STUDENTS' PERFORMANCE

For observing the impact of the simulation impact on students' performance I also give them an exercise on the topic taken from the Hungarian physics graduation exams, where they have to find the wavelength limit, the speed of emitted electrons and the stopping voltage of a given photocell. Then, without any further discussion they are introduced to the simulation with a user's guide on its key functions. Then, after several minutes of independent work, they are asked to solve a similar exercise. The first results were recorded in two half-class sized groups with a total number of 27 students. I used the authorized correction key provided for the original graduation exam and split the total 12 points into 10 parts, as the correction key did the same. Then added up all the points of the students before and after working with the simulation. They used it for only 25 minutes though (with 10 minutes for each task). Use of a calculator and also a table containing the primal scientific functions and laws – as in the real exam – were allowed. The results can be seen in Fig.2. below:

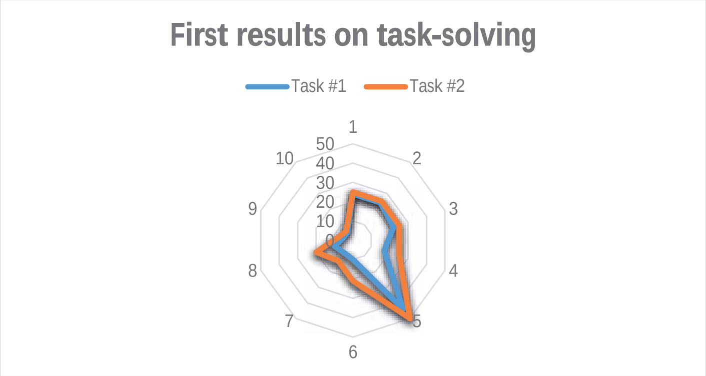


Fig.2. First results on solving a calculation task about the photoelectric effect

As one can see, all the parts showed slight or bigger improvement. The students didn't get any help on how to solve the problem between the two parts besides using the simulation. The three biggest differences were on the 4th, 6th and 8th parts of the task. The 4th one was the last part of the first question, about findig the wavelength limit. The 6th (and 7th) one was the last part of the second question, about finding the speed of the emitted electrons. There wasn't much difference on parts 1-3 and 5. These points were given for finding the correct physics laws and writing down the needed equations. Points 4 and 6-7 were given for using and transforming the equations to find the solution. As the equations were known (or could be looked up in the table of functions) this is hardly a surprise. It is comforting though that the simulation helps to make these equations be understood. The 8th part (containing two points) was understanding how the stopping voltage works and writing down the correct equation. This was the hardest one for the students, but many gave good explanations after using the simulation, for instance “the energy loss of the electron in the field of the stopping voltage equals its initial kinetic energy” – even though not being able to find the correct relation between the energy and the voltage (U·e).

There are examples on giving more detailed and more correct explanations on the calculated problem after using the simulation.

The research was done on a regular physics class without previous notification of the students. This means that a vast part of the students were naturally unprepared for it, though they were all introduced to the topic and calculation examples before in the previous classes.

CONCLUSIONS

Of course, further investigation is needed for a complex view on the efficiency of using these simulations, but my first feedbacks show that even if the performance on solving the concrete task doesn’t change, the students’ answers are more complex and precise, not only writing down equations but also trying to explain the phenomenon. I believe computer simulations are not the exclusive method, but a great source as teaching materials, helping in many of the challenges we face while teaching modern physics.

ACKNOWLEDGMENTS

I would like to thank my supervisor, Dr. Csaba Sükösd for his lot of patience, help and great ideas in working on my topic and developing my simulations.

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LET'S BUILD PARTICLE PHYSICS!

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ABSTRACT

Particle physics is one of the fastest developing areas of science in the world. High schools do not have time to deal with this topic, so the students can get to study it after the regular lessons only. The students consider this topic too difficult. There are many unknown terms, they are hard to imagine, because particles are very-very small, they are invisible and their size is below 10^{-18} *meters. I have developed a low-cost educational material on particle physics for teachers and students. It is easy to make and students can learn with them while playing with paper cubes.*

INTRODUCTION

Having taught physics for several years at secondary level I realized that one of the areas of the subject that is very difficult for students to comprehend is particle physics. The main reason for this is that the sizes of the particles are below10^{-18} meters so they are very hard to imagine as they are invisible. Although particle physics in not yet part of the curriculum, I feel it is vital to deal with this topic as this is one of the fastest developing fields of science in the 21st century.

Students like doing experiments, but unfortunately, there are no good tools for explaining the particles. I have developed a tool and a method for this using paper cubes. My goal is to introduce the basics of particle physics with the help of an easily made and cheap instrument, to help to understand the structure of the small particles and their behaviour in different reactions. At the same time I want to help other teachers to deal with this topic.

THE TOOL

The basic set (Fig.1.) consists of

- 15 cubes of size 5x5 cm,
- 4 small cubes of size 2x2 cm,
- 2 large cubes of size 12x12 cm,
- 1 tetrahedron of 10 cm edge size and
- a lot of Styrofoam filling material.

The cube was chosen as it has six surfaces, and we know six kinds of quarks with antiquarks and six leptons with antileptons.

At present this programme is recommended to be implemented in extracurricular study circles as it is not part of the regular curriculum and unfortunately there is not enough time for this during regular classes. Preparing the cubes will take about two hours and understanding and effectively using it about five to six. As for the age group of the students: I have used the tool from the age of 13-14 upwards.

Fig.1. The basic set

PEDAGOGICAL ASPECTS

Students like playing and in my opinion we must teach them while playing, because as I see it, the motivation of the students to study natural sciences is very low. Numerous studies have shown that knowledge is best retained when students not only verbally or visually receive information but also have a chance to actively participate in the learning process. Besides it also meets the requirements of visual and kinaesthetic learners. So in this project the most important part is the „hands on, mind on" method. The teacher is not an authority figure but rather the facilitator in this process, so students feel they play an equally important role, thus become more motivated to learn. I experienced with my students that they were very open to this new method. During the work they also learn the basics of particle physics.

GETTING TO KNOW THE QUARKS

First students need to make quark and antiquark cubes. For that we need red, blue and green cardboard paper. The sides of the cubes will have the signs and charges of the quarks. While making the cubes the students will memorize the signs of the quarks and their unnatural charges. In the beginning the emphasis is on getting to know the quarks, but even at this stage we emphasize the three colours for the quarks and the complementary colours for the anti-quarks (Fig.2).

Fig.2. Quark and antiquark cubes

For example if one of them is red, the other cubes will have blue and green colours. This expresses quantum colour dynamics. In nature there is just white colour. The colour white consists of red, blue, green, or colour-anticolour pairs. Those particles which contain quarks are called hadrons. Inside the baryons there are three quarks, their colours are red, blue and green. Inside the mesons there is one quark and one antiquark, colour-anticolour pair.

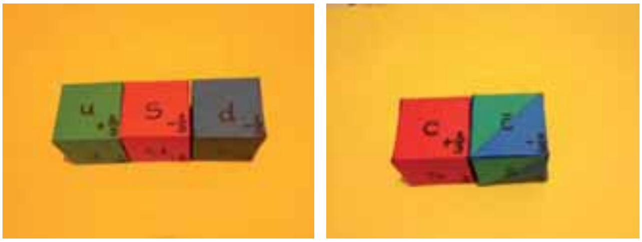

Fig.3. Left panel: baryon; Right panel: meson

The students make different hadronic particles, baryons and mesons (Fig.3.), and they write the signs and charges of quarks on the surfaces. So they can check the sum of the charges. In these examples they will learn expressions which are quite far from everyday life, and they can observe the systematics of particle physics.

THE STRUCTURE OF A PROTON

Unfortunately, in chemistry, while studying the atomic structure the students meet just the names of the electron, proton and neutron and most of the textbooks call all of them elementary particles. In order to fight this misconception I apply a very demonstrative method. In a large cube we place 3 quark cubes, a pair of quark+anti-quark cubes and many little coloured Styrofoam "worms" representing the gluons (Fig.4). This shows that the proton consists of three quarks, gluons, and sea quarks.

Fig.4. Composition of the proton

The electric charges of the nucleons, the protons and neutrons are generally known, but the cubes help students to understand how they are composed of the fractional charges of the quarks.

Fig.5. The charge of the proton

In this way it is easy to remember that the proton is a hadron, a baryon, because it contains three quarks, two up-quarks and one down-quark. The electric charge of the proton is plus one. The charges of quarks are 2/3 and minus 1/3 (Fig.5.).

ELEMENTARY QUANTUM NUMBERS OF THE QUARKS

The quarks are presented in the chart of Fig.6. There are the names, signs, charges and other parameters. Using that table the students can prepare their own quark cubes.

English name	Sign	Rest mass (GeV/c^2)	Electric charge (e)
Up	*u*	0,0016-0,003	2/3
Down	*d*	0,0045-0,0051	-1/3
Charm	*c*	1,25-1,3	2/3
Strange	*s*	0,09-0,1	-1/3
Top	*t*	165-180	2/3
Bottom	*b*	4,15-4,21	-1/3

Fig.6. The chart of quarks

THE GLUONS

The gluons, the bosons mediating the strong interaction, carry two colours actually, but they are painted white here. While painting the gluons the students learn the basics of quantum chromodynamics. As they are painted white they should carry a colour and an anti-colour, although not necessarily of the same kind. The fact that of the 9 possible colour+anti-colour combinations allowed only 8 gluons exist belongs the group theory, well over the high school level.

FURTHER USES OF THE TOOL

Having learnt the basics, it is interesting to know what else the cube set can be used for. During my research work I regularly participate with a group of high school students in the development of gas-filled detectors for the detection of cosmic muons at the laboratory of the High Energy Physics Department of the Wigner Research Centre for Physics. During this work we study the various production reactions of those particles. There are detailed explanations in the literature, but in my experience the students cannot understand them. For a demonstration I developed the following method.

HADRONIZATION

Using quark cubes the process of hadronization can be well demonstrated. In Fig.7. you can see how the pions are generated. A proton collides with a nucleus, say, of an oxygen atom (as depicted by the quarks, gluons and sea quarks in Fig.7). During the collision one of the quarks is separated from the others and produces a gluon string. One of the gluons splits into a quark+anti-quark pair and the anti-quark creates a meson with the distant quarks. The pion, the lightest meson, is produced in the simplest picture this way.

Fig.7. The creation of a meson

THE PROCESS OF BETA DECAY ON QUARK LEVEL

There is another field of particle physics the processes of which can be demonstrated using the cubes: the beta decay. Here the rotation of the cubes can be used when different properties are depicted on the different sides. Teachers teach beta decay in high school and the students use the reaction formulas, but they do not understand the essence of the process. Actually, in the beta decay the type of one quark is changed, the d-quark of the neutron becomes a u-quark. The d-quark decays into a u-quark plus a W^--boson and that in turn decays into an electron and an electron antineutrino [1-4] (Fig.8.)

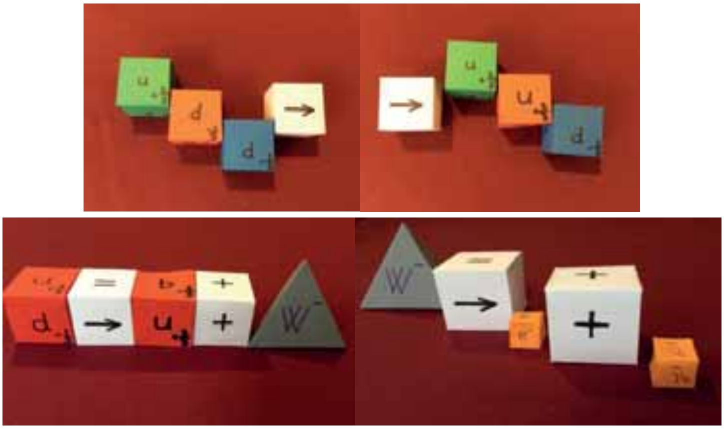

Fig.8. The process of beta-decay

DECAY OF THE NEUTRON

Using the cubes the students understand the beta decays. In this exercise every cube represents one particle with its conserving quantities on the sides; by turning the cubes the students themselves find out the kinds of beta decay. They have to apply the conservation laws. They check the conservation of charge, baryon number, lepton number etc. If they turn the cubes, they see different conservation laws. The sums standing on the left and right side of the equation are equal. In Fig.9. the neutron decay to proton, electron and electron anti-neutrino is presented. Under the names of the particles there are their electric charges. By comparing the sums on the two sides the students can think that the equality is fulfilled without the anti-neutrino cube. If now we rotate all cubes the same direction to see their baryon numbers (introduced by the teacher beforehand as +1 for baryons, -1 for anti-baryons and 0 for all others) which are also conserved without the anti-neutrino cube. However, with the next turn of the cubes the lepton numbers (to be also introduced) show up. As all leptons have a lepton number L = +1, while for anti-leptons L = -1, the antineutrinos are necessary to keep the conservation of lepton number. The other conserving quantities, like energy, are more complicated to account for, so they are shown on the cubes just for completeness.

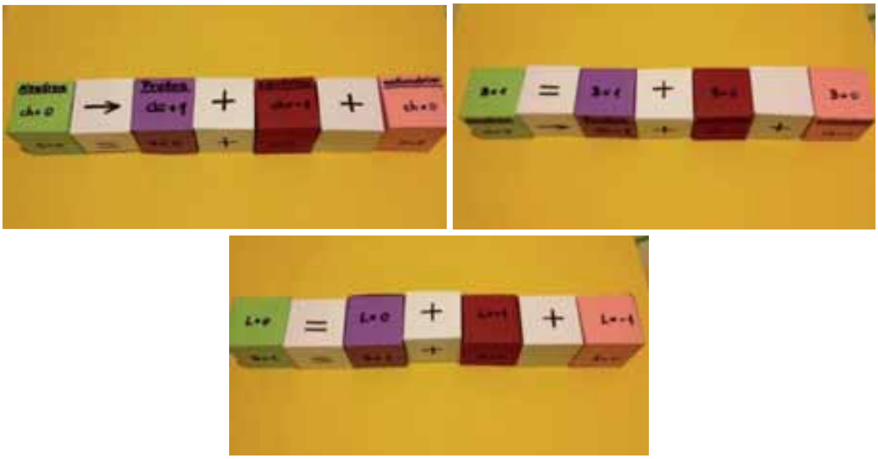

Fig.9. The decay of the neutron

The other two kinds of beta decay can also be demonstrated with the cubes, and the students will learn the essence of nuclear reactions while rotating the cubes. During this "discovery learning" with my students they also contributed to the project. It was their idea to add the Higgs boson with its decay modes to the set as the Nobel Prize was awarded for it in those days.

CONCLUSIONS

I experienced that students are very enthusiastic when they have to work on tools that will eventually help them discover the wonders and secrets of the micro world. While working, they get familiar with previously unknown terms and expressions, and through games understand the basic ideas of a very complex subject, particle physics. It was a great experience for me to do it together with the students as they contributed quite a few ideas to the project. I have made several presentations to fellow physics teachers with the cubes, giving methodical help to deal with modern physics in this unusual way and already in several school were similar cube sets made.

ACKNOWLEDGMENTS

I would like to express my special appreciation and thanks to my advisors Dr. Dezső Horváth and Dr. Dezső Varga who have been tremendous mentors for me. I would like to thank you for encouraging my research and for allowing me to grow as a research scientist.

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IX. NUCLEAR ISSUES

NUCLEAR ENERGY AND PUBLIC AWARENESS

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ABSTRACT

The Hungarian government signed an intergovernmental agreement with Russia in 2014 on the construction of two new units at the site of the currently-four-unit Paks Nuclear Power Plant. This decision – based on the National Energy Strategy adopted in 2011 – maintains the capacity of the Hungarian nuclear based electricity production for the next decades. Public acceptance of a new nuclear construction, which is determined by the public awareness, is a key point of the success of the project. It is essential to educate environmentally and socially conscious youth, but also to provide them with the necessary technical knowledge to ensure that the next generation can have a well-based judgement of energy-related issues instead of an emotional approach. The presentation gives an overview about the Paks 2 project and the possible methods of information and education of the next generation concerning the energy policy including the new nuclear units.

INTRODUCTION

The Paks Nuclear Power Plant (Paks NPP) has an inevitable role in the Hungarian electricity system: it has a share of more than 50% in the domestic electricity generation, and a 36% share in the electricity supply of Hungary. There are four Russian designed nuclear units operating at the Paks site with a total electric output of 2000 MW. The units started commercial operation in the ’80s, so they are reaching their originally planned 30-years lifetime in this decade. After a comprehensive preparatory program, the units are now in the lifetime extension licensing process, as a result of which they would be able to operate for a further 20 years (having their lifetime extended from 30 to 50 years). However, even after the lifetime extension the units will be shut down between 2032 and 2037, so there is an urgent need to ensure their replacement capacities.

The idea of constructing new units at the Paks site has been on the agenda since the ’80s. The site itself is suitable for hosting two further units and has the necessary infrastructure for the construction; moreover, it is the most explored and best-known potential site in Hungary. In addition, the surrounding population supports the project, recognizing the positive economic effects of the construction on the region.

Following several years of preparatory work of the project, the Hungarian government signed an intergovernmental agreement with Russia on 14 January, 2014. The intergovernmental agreement (IGA) includes the construction of two pressurized water reactors with a capacity of at least 1000 MW each at the Paks site. Regarding the financing of the project, the IGA lays down that the Hungarian state would get an interstate loan from Russia.

After the announcement of the IGA, intensive negotiations started between the parties about the exact technical, legal and financial details of the cooperation. As a result of these negotiations, three contracts (the so-called Implementation Agreements) were signed by the Hungarian Paks 2 Development Ltd. – the future licensee of the new units – and the Russian JSC NIAEP company on 9 December, 2014. The Implementation Agreements covered the engineering, procurement and construction details (EPC contract), the operation and maintenance support and the nuclear fuel supply. The basis of these agreements is a set of a significant number of safety-related, technical and legal requirements defined by the Hungarian party. These requirements ensure that a state-of-the-art, Generation 3+ nuclear power plant will be built at Paks, with the reasonably highest possible safety level.

ELECTRICITY – DEMAND AND SUPPLY

One of the most important challenges to be solved by our society is the secure energy supply. We can read different expert statements and analyses about the ideal energy sources. However, it is obvious, that there are some misunderstandings and misinterpretations of natural and technical facts among laypeople in the subject of electricity supply.

Electricity is one of the most important products in our life. Unfortunately, unlike other everyday goods, electricity cannot be stored in industrial scales. Of course, there are several solutions for the small-scale electricity storage – e.g. batteries – but the possibilities are very limited in large dimensions. Among the exceptions the pumped-storage hydroelectricity shall be mentioned, which is a high-efficiency, proven method for a short term electricity storage.

The most important feature of the electricity system is the consequence of restricted storage possibilities, which means that the balance of the generated and consumed electricity shall be maintained in each moment for the whole electricity system. The quality of this special product (i.e. the electric energy) in the electricity grid can be described by the frequency. It is 50 Hz in Europe, and the system operators and even the power plants have to keep this 50 Hz frequency very precisely to maintain not only the quality, but the stability, or even functionality of the whole system. If the frequency increases or drops beyond certain limits, the electricity system will collapse, causing a severe supply problem as well. Keeping the electricity system between the required frequency limits needs lot of efforts. So-called primary, secondary and tertiary reserves – i.e. dedicated power plants – shall be ensured for the electricity system to cope with the unforeseen demand or generation fluctuations. The different reserve types are responsible for the different levels of electricity grid control.

If the electricity production and consumption get unbalanced, the frequency of the system deviates from the nominal value. For example if a power unit gets shut down because of technical reasons or if the increase of the electricity consumption (e.g. in the morning hours) cannot be fully covered by operating power plants the frequency decreases. Immediately after the decrease of the frequency the primary reserves are necessary: these power plants are running and parallelized with the 50 Hz system, so if there is a load increase, these primary reserves can be started or their power can be increased to supply the necessary electricity to the grid (immediate intervention). The secondary reserves can interact with the system within few minutes – these are shut down power plants (or ones operating at low power), which are able to get started very quickly after the frequency change. The tertiary reserves are usually shut down power plants, used for the mid-term balancing of the electricity grid. To keep the system operating, very precise planning and high availability of the power plants is necessary.

Having a look at the daily change of the electricity demand (this is the so-called load curve, see Fig.1.), different daily load curves can be observed, depending on the season, on workdays / holidays, or on special weather conditions. Even an important and very popular sport event or TV program can influence the load curve. Their common feature is that there is a minimum in the electricity consumption in the pre-dawn hours, when the electricity demand is only about 60-70% of the peak load. The value of the daily peak load in Hungary is about 4000-6300 MW – larger in winter season and on workdays, lower at summer weekends. However, with the increasing deployment of air-conditioning, the summer electricity load is approaching or even exceeding the winter demand peaks, as it is well-known for example in the USA.

The shape of the load curve depends on the value and time point of the peak load, which can occur during working hours or in the evening. In some cases, even two peaks with very similar height can be observed. We can make a difference between the typical load curve with the help of two animals: the load curve with one load peak is similar to the back of an elephant, whereas the two-peak curve is similar to a two-humped camel.

The knowledge of the shape and values of the load curve is essential for the planning of the generating capacities. The constant part of the demand (i.e. below the minimal demand) can be supplied with cheap, continuously operating power plants, these are the so-called baseload power plants – typically the nuclear power plants are in this category. Baseload plants are necessary for the secure, inexpensive electricity supply. The load-following power plants are responsible for the supply of the foreseeably fluctuating part of the load – these are typically the flexible fossil-fuel-fired power plants, mostly gas-, but recently often coal-fired power plants. In the short, high-electricity-demand periods, peaking power plants are used, which can be started very quickly, but usually with high generating prices – these are typically gas turbines.

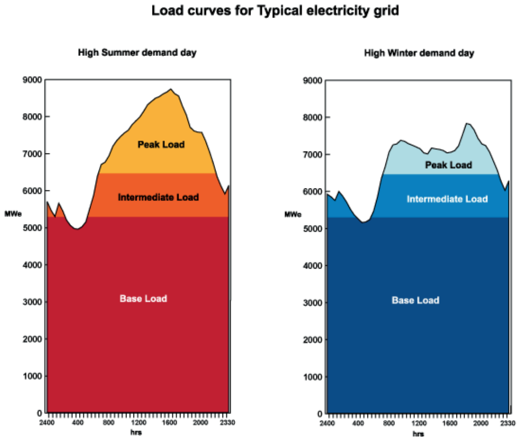

Fig.1. Typical daily load curves (Source: World Nuclear Association) [1]

ROLE OF RENEWABLE ENERGY SOURCES IN ELECTRICITY GRID STABILITY

Considering the renewable energy sources, a difference shall be made between the weather-dependent and the continuously operating power plants. Plants with continuous operation (as large hydroelectric power plants or biomass-fueled plants) can act as part of the baseload generation. The pumped-storage hydroelectric plant is a typical peak-load plant – the upper water reservoir can be filled up in the demand valley time period with cheap electricity coming from baseload power plants, and the energy can be recovered in peak-load periods.

However, the situation is totally different in case of the weather-dependent renewable sources, as wind power or solar power. The forecast of the electricity generation from these sources is very complicated, causing difficulties in the electrical grid control.

Germany, on the road of its energy transition to the clean renewable sources is a good example for the difficulties caused by the weather-dependent energy sources. (The German energy policy aims the total phase-out of nuclear power plants until 2022 and sets out a target for 80% share of renewable sources in the German electricity consumption by 2050.). The daily peak load in Germany nowadays is about 60-70 000 MW. There is an installed wind based production capacity of more than 40 000 MW and solar (photovoltaic, PV) capacity of roughly 38 000 MW – so these renewables would be able in theory to cover the demand by themselves. However, the real feed-in from the renewables is much smaller; the PV panels can generate only daytime, and the wind power plants are not able to generate continuously either. Additional to that we have to mention that the wind feed-in never reaches 100% of wind production capacity.

In Fig.2, the electricity production in Germany is shown in January of 2014. It can be clearly seen, that the baseload power generation comes from large hydro, biomass, nuclear and lignite-fueled power plants. The generation from the wind power plants is uncontrollable and weather-dependent, so the necessary production-side control takes place with coal-fired and natural gas fueled power plants.

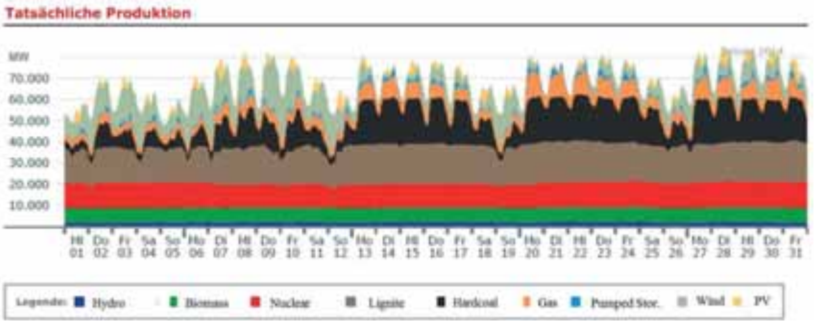

Fig.2. Electricity generation in Germany in January 2014 [2]

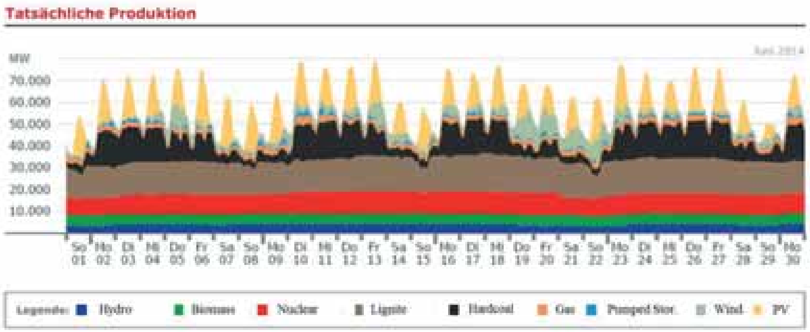

Fig.3. Electricity generation in Germany in June 2014 [2]

Fig.3. shows the electricity generation for another month, for June of 2014. In summer, daytime feed-in from solar panels is much higher than it was in winter, as it can be observed

in the figure – combined with a very low but fluctuating wind generation. The role of the natural gas was almost negligible in the electricity generation in that month, however gas played important role in short-term balancing.

The result of the large renewable production can be observed in Fig.4, which shows the data for a selected week in August 2014. The grey sector is the electricity generated by the conventional (i.e. nuclear plus fossil-fired) power plants. The green part shows the wind production, and the yellow humps represent the solar generation. There are some periods, when the feed-in from wind is over 20 000 MW, but there are long hours when the feed-in from wind is negligible. The sudden changes of the wind production can cause serious grid control problems – the necessity of keeping the frequency stable is the main rule, so the high rate of wind power requires large capacity of reserve power plants, which makes system operation even more expensive and technically more complicated.

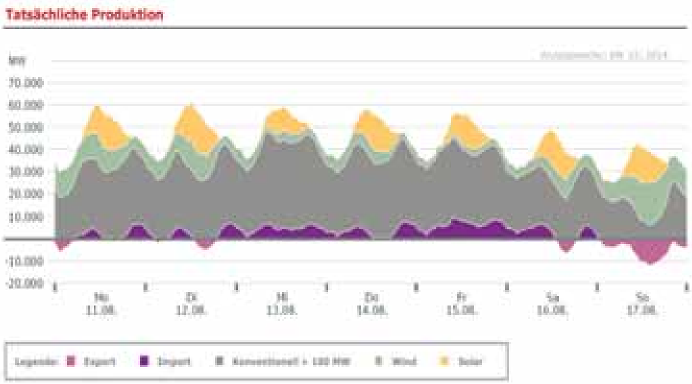

Fig.4. Electricity production in Germany from renewable sources, August 11-17, 2014 [2]

According to the figure, the daily peak production of conventional power plants varies from 30 000 to 50 000 MW, and the export-import balance varies from -10 000 MW (export) to +5000 MW (import). The large changes in the generation can cause forced (not planned and not contracted) export to the neighboring countries, causing grid instability in these countries as well. An extreme consequence of the unforeseeable production changes is the presence of negative electricity prices as it happened at the end of August 2014: in some cases of sudden renewable overproduction – combined with a drop in grid loads – the operators of the baseload power-plants cannot shutdown their units for few hours therefore they had to pay for taking over the electricity generated by them. In the events on the weekend of August 17th 2014 between 12:00 and 16:00 the spot price of electricity has been climbing down to minus (!) 60 EUR per MWh. These are definitely symptoms of a distorted market which is characterized by high subsidies of renewables. This distortion materializes in a market environment where electricity markets are not giving real, long-term price signals and seriously endanger the future investment in dispatchable power plants that ensure electricity supply security. This development, namely the lack of new investment in dispatchable power plants, a worsening future supply security is clearly against the most important energy policy objective of Europe.

It is unclear at this moment how these issues can be resolved. However this is evident that stable, controllable power plants are henceforward necessary to ensure reliable electricity system operation, security of supply and system safety. Large capacity of power plants is inevitable which are independent from weather conditions and are available in all seasons. By the selection of future energy mix we have to consider many different factors including economics and targets for combating climate change.

ROLE OF NUCLEAR POWER PLANTS IN THE ELECTRICITY SYSTEM

Now, at the beginning of 2016, there are 442 nuclear power reactors in operation worldwide, with a total net installed capacity of 383 GW, covering about 11-12% of the annual global electricity production. After the Fukushima accident (2011) some countries decided to phase out nuclear power plants – for example Germany, as mentioned earlier. However, at the moment 66 nuclear units are under construction, and many countries are planning to maintain or expand their nuclear generation capacity.

According to the forecast of the International Energy Agency (IEA, see Fig.5), after the post-Fukushima stagnation of the nuclear industry, the total installed capacity of the nuclear power plants will increase in the next decades, mainly because of the fast nuclear expansion in China and other developing countries. However, in the EU the sustainment of the nuclear capacities is forecasted until 2040 (see Fig.5).

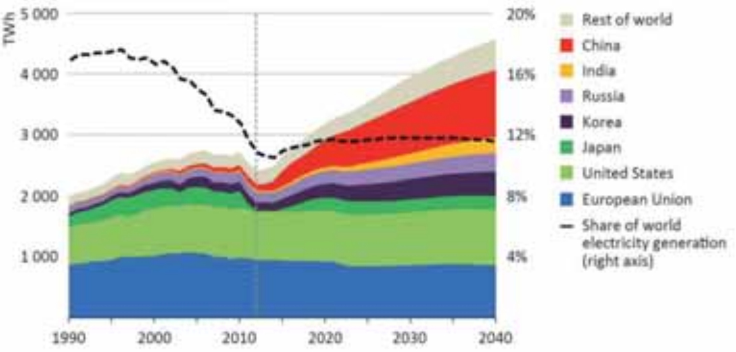

Fig.5. Installed capacity of nuclear power plants until 2040 according the World Energy Outlook [3]

The member states of the European Union have the right to choose their own energy mix, including the mix of primary energy sources in their electricity production (the combination of the applied electricity generation methods), as far as they are consistent with the energy policy goals of the EU. These goals – to increase the competitiveness, to ensure affordable electricity prices, to enhance supply security of the Union and to help the battle against the climate change – can be met with the use of nuclear energy as a part of the energy mix. Nuclear power plants can operate without emitting carbon-dioxide, and also their CO2-emmission during the whole life-cycle (per kWh) is in the order of the emission of renewable sources (wind, PV). The security of the energy supply can be improved as well, because fresh (unused) nuclear fuel assemblies are easy to handle and to stockpile reserves, even for years. The uranium, the raw material for the fuel is available from different, politically stable countries. By given technical and commercial conditions the fuel assemblies can be procured from different fuel vendors. For the transportation of the fresh fuel alternative means e.g. rail and air transport are available, which is much more flexible than gas import through pipeline or electricity import by transborder power-lines.

A special feature of nuclear power plants is the relatively high investment cost, together with low operation-maintenance and fuel costs. As a result, if appropriate financing is available, electricity generated in nuclear reactors is especially competitive with other electricity generation technologies (see Fig.6). Because of the favorable financial conditions of the new Paks units, the levelised cost of electricity of the new units will be even lower than the values of the IEA forecast for Europe.

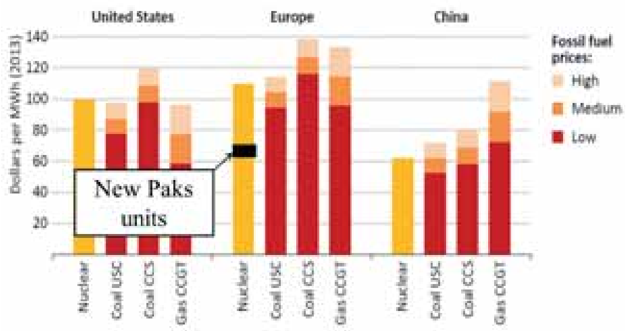

Fig.6. Cost of electricity generation for different sources according the World Energy Outlook [3]

NEW UNITS AT THE PAKS NUCLEAR POWER PLANT

The annual total gross electricity consumption of Hungary is about 44 TWh (2015: 43,75 TWh, see data of MAVIR) with a peak load of about 6500 MW, while the installed capacity in the Hungarian power plants is only 9000 MW and is decreasing. In the next decades, the annual total gross electricity consumption, together with the peak load is expected to increase with a rate of about 1% / year. Combined with the shutdown of old Hungarian power plants, these developments result in a need of about 7300 MW new generating capacity to be built until 2030. The Hungarian energy policy aims to increase the security of electricity supply that makes the construction of new nuclear reactors necessary.

The Hungarian parliament approved the preparation of new NPP construction on March 30, 2009. After this decision in principle of the parliament, the Hungarian electricity utility MVM established the Lévai-project with the task of performing the further preparatory works. In July 2012, the Paks II NPP Developing Company has been established, which is now responsible for the pre-construction and construction works.

On 14 January, 2014 the Hungarian government signed an intergovernmental agreement with Russia on the cooperation in the peaceful use of nuclear energy, including the construction of two new units at the site Paks Nuclear Power Plant. The choice of the Russian supplier can be explained with the very favorable loan conditions and the long experience of the Hungarian institutions in the application of Russian nuclear technologies.

The offered reactor design is the VVER-1200/V491, which is a state-of-the-art pressurized water reactor (PWR) type with 1200 MW gross electric output – the same design has been selected for the Finnish Hanhikivi project. The design can be classified as a Generation III+ reactor, i.e. with improved safety and economic performance compared with the actually operating Generation II reactors. The Generation II and Generation III/III+ reactors use low enriched uranium, which is unsuitable either in fresh or in spent fuel form for production of nuclear weapons. These type of units are designed to fulfill wide range of nuclear safety, nuclear security and also non-proliferation requirements.

For the commissioning of the units altogether about 6000 different permissions are necessary (see Fig.7). The licensing process has already started; recently the site licensing and the environmental licensing processes are underway. Concerning the environmental licensing, the EIA (Environmental Impact Assessment) report was submitted to the competent authority on 19

December 2014. During the spring of 2015, 41 presentations were given during a public information roadshow in the settlements around the site, and a public hearing was also organized in the town of Paks. In the frame of the preliminary international consultation process (began in 2012), the preliminary consultation document (PCD) was sent to 30 countries, among which, 11 countries have been registered to take part in the environmental licensing process according to the Espoo Convention, the biggest part of which took place in 2015. Expert consultations and public consultations were organized in 7 countries by the Ministry of Agriculture; another 4 countries requested written consultations. The EIA – published on the internet – described the expected environmental effects of the construction, operation and decommissioning of the new units. The results showed that the largest impact on the environment would be the heat release from the power plant into the river Danube during the operation; however, this heat load is still tolerable for the flora and the fauna living in the vicinity of the plant. In the international section of the licensing process, the potential consequences of severe nuclear accidents were demonstrated as well.

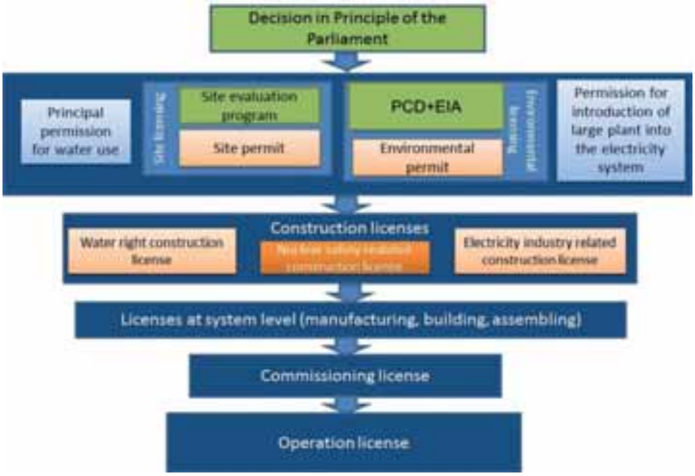

Fig.7. Licensing process for the new units

Concerning the site licensing, the site investigation and assessment program has been already accepted by the Hungarian nuclear safety authority. Based on this program, 3D seismic measurements were performed in August-September 2014 as the first steps of the investigation. The Geological Research Program started in May 2015 with the first geological drilling. The Program includes on-site measurements and laboratory investigations as well with surface and underground research processes.

According to the schedule, the first new unit would start commercial operation in 2025. This requires the start of the construction in 2018. Until this date, the construction licenses should be obtained from the different authorities, requiring hard work in the upcoming years from the licensee and the regulatory bodies as well.

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PHYSICS TEACHERS ON TEACHING THE RADIOACTIVE DECAY LAW

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ABSTRACT

Teaching the law of radioactive decay is a mandatory task in Hungarian secondary schools. It is also one of the major problems in methodology. A survey was done among practicing teachers of physics in secondary schools in this topic. I am seeking to answer the questions below that were asked in the survey:

- *How do colleagues cope with this task?*
- *What aspects and motives can they rate high or name as the main insufficiencies?*
- *What methodological solutions are known? Which ones are in use? Which ones are liked?*

*The survey aims to suggest what conditions and needs are to be met in the methodological solutions in order to support success in the teaching practice in the secondary school classrooms. I will also present a project which can give a new solution in didactics to the problem. It is planned based on the "*hands-on, minds-on*" approach.*

INTRODUCTION

The law of radioactive decay is well known in two ways. The law can be put like this using the number of radioactive nuclei:

$$N(t)= N(0)\cdot 2^{-t/T} \qquad (1)$$

The law of radioactive decay is also known using the concept of activity:

$$A(t)=A(0)\cdot 2^{-t/T} \qquad (2)$$

In both formulae the concept of half-life is essential. As we can see from the formulae above, this law is a representative of the exponential laws in science. Teaching the law of radioactive decay is one of the most problematic issues in physics didactics.

In Hungary the radioactive decay law is in the syllabus of the compulsory physics course for all high school students. According to the national syllabus, the law is to be studied in grade 11, at the age of 17-18.

In a survey a number of active high school physics teachers were asked to report on how they can cope with the task in their everyday practice.

COLLECTING THE DATA

In Hungary there is an annual meeting for physics teacher organized by the Roland Eötvös Physical Society. The one organized in 2015 was held at Hévíz (Fig.1.) from 27th to 30th of March.

The attendance of the event was about 160 people, from which the estimated number of high school teachers present was 65-70. We estimate the number of practicing high school physics teachers at 2500+ in Hungary. Others at the conference were lecturers, experts from companies or universities, colleagues who work in primary schools or others who are interested in physics teaching.

Fig.1. Hévíz, the Hungarian spa

We left the survey sheets at the registration desk, but only five colleagues took one with themselves to support our work. Personal contacts are very important, so based upon this, 47 accepted the sheet, and 35 of them returned it filled.

THE SAMPLE OF COLLEAGUES

First, we need to see who are represented in the survey. The first task was to circle the type of high school the respondent has practice in. Some of the colleagues had practice in several types of schools. We counted each answer as a separate one, so we had 39 checkmarks. Table 1 shows what background of experience we can get information from.

Table 1. Number of teachers who gained experience in the given type of school

type of high school	top third	medium third	bottom third	number of checkmarks
secondary grammar	7	10	4	21
secondary technical	5	7	3	15
vocational	3			3

MONITORING REALITY

The survey was anonymous, because in our country following the syllabus is a compulsory task for the teacher. We chose this since we wanted to find out as reliably as possible how or whether teaching this law really happens in the Hungarian classrooms.

The second task in the survey was to provide information at what extent teaching the law happens in practice. Many of our colleagues made a note saying “depending on the class”, so we considered each mark as separate answers. We gained 46 answers this way. The results the respondents gave are shown in Fig.2. In Fig.2.a) you can see the full scale, whereas in Fig.2.b) we specify the answers of those who need to face problems in their practice.

We can conclude that one third of our colleagues are not satisfied with the work they can perform in their practice. It is definitely an issue we need to pay attention to.

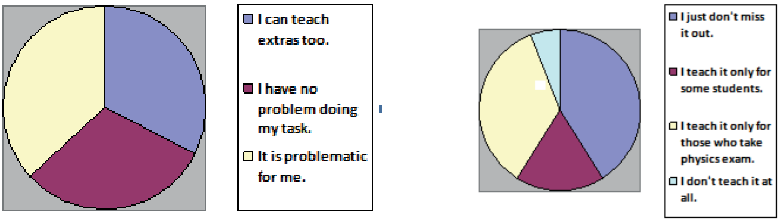

Fig.2. a) Can you teach it? b) Do you mention it at all?

A SURVEY OF THE MOST OUTSTANDING PROBLEMS IN TEACHING THE LAW

We asked the teachers to grade 10 statements. To match the Hungarian evaluation system as much as possible, the grades were 1-5. (1 showing that the statement does not have a great influence on the problems, 5 meaning it is a very important factor.) The statements were put into 3 sets according to the potential causes. Table 2 shows the sets of statements.

Table 2. Types of statements

questions	sets of influence
A1, A2, A3, A4	the students' attitude as a factor of the problems
M1,M2, M3	mathematical skills as causes of the problems
S1, S2, S3	monitoring some scientific issues

Monitoring the students' attitude

We mentioned four aspects in this set (Fig.3. shows the grades for the "A" statements):

A1 Physics among our students is not popular: they don't like, understand, or study this subject.

A2 The attitude of our students is negative to nuclear physics.

A3 They already have fact-fragments in this topic from the media.

A4 This topic is in the last year of the secondary physics course, and it is not a compulsory subject in the High School Leaving Exam (érettségi).

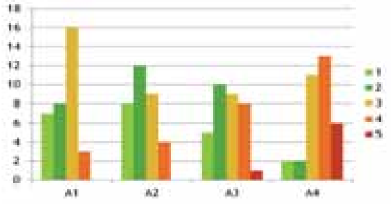

Fig.3. "A" statements graded

Monitoring the students' poor mathematical skills

We mentioned 3 aspects of mathematical skills (Fig.4. shows the grades for the "M" statements):

M1 The law is one of the exponential formulae. The students don't know the exponential functions properly.

M2 The effect of the low mathematical competence of the students is that they are not able to apply their knowledge.

M3 In mathematics classes there are not enough exercises for using mathematics in real problems and applications.

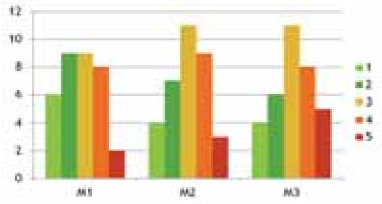

Fig.4. “M” statements graded

Monitoring scientific issues

On the sheet the respondents found 3 statements. They had to grade them just like the previous ones (Fig.5. shows the grades for the “S” statements):

S1 There is no possibility to carry out experiments.
S2 The scientific model students should use is too abstract for them.
S3 There is a lack of knowledge in the model they should also study it in chemistry.

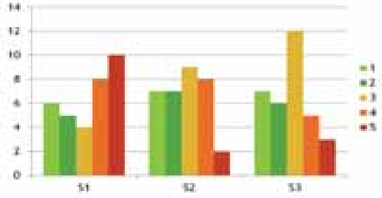

Fig.5. “S” statements graded

Analysing the data

The mean values of the grades for the statements are given in Table 3.

Table 3. The mean values of the grades

	Attitude				Mathematics			Scientific issues		
means (statement)	2.44	2.27	2.70	3.56	2.74	3.00	3.12	3.33	2.73	2.73
means (set)	2.75				2.95			2.93		

So the main problems that were highlighted by the teachers are as follows:

1) 3.56 (A4) This topic is in the last year of the secondary physics course, and it is not a compulsory subject in the High School Leaving Exam (érettségi).
2) 3.33 (S1) There is no possibility to carry out experiments.
3) 3.12 (M3) In mathematics classes there are not enough exercises for using mathematics in real problems and applications.

When studying the answers, two remarks arose. These are really worth mentioning.

* We can envy some colleagues: they graded each but one problem to 1 (2 for S1). It might mean that they don’t find teaching this law a problematic task.

* International surveys show a bad attitude. Hungarian colleagues don’t experience it, they think about it as a result rather than as a cause, or just don’t rate it high as a problem.

Further causes

In the survey we gave opportunity to share further causes and remarks to the mentioned topic for those who gave their opinion. It was an open ended question. The remarks we got are all listed. Our remarks are in brackets.

- “Many have misconceptions; they can’t differentiate it from the distorted esoteric knowledge.”
- “Hungarian physicists’ activity in the last century.” (We can’t see clearly what is meant by this remark. But we do not have a chance to figure it out.)
- “They study no other exponential law, they have nothing to bind to.” (A very important point was highlighted.)
- “In mathematics the statistical nature of the phenomenon, the incidental events are difficult to comprehend. But some students can get fired up just because of this.” (We find it a very important comment from a colleague.)
- “I didn’t rate anything to 5, because my highest mark goes to *Severe Literacy Problems*.” (It is a problem far beyond the physics methodology.)

INTERPRETATION OF DIDACTICAL SOLUTIONS

The evaluation system

We also studied what methodological or didactical solutions are liked, known and used in the teaching practice among our colleagues. We provided a list of didactical solutions they had to grade from two perspectives:

in column 1	in column 2
A – “I know and like the mentioned solution.”	A – “Mostly this is used in my classes.”
B – “I am familiar with the method.”	B – “I have experience with the method.”
C – “I don’t know that method.”	C – “I have no experience with it.”

Evaluating the didactical solutions

Table 4 shows the listed didactical solutions and the results of the evaluation.

Table 4. Evaluation of the didactical solutions

didactical solution	Known?			Used?		
	A	B	C	A	B	C
Presentation & interpretation by the teacher.	22	9	0	30	3	0
Presenting on an educational film.	11	18	3	8	16	7
Processing literature (alone or in a group).	5	20	7	2	9	23
Project or drama pedagogy.	1	13	19	0	3	31
Home essay or student’s presentation.	13	16	1	8	16	8
Computer simulation.	18	9	4	13	15	6
Simulation game.	7	9	15	2	7	20
Data-processing, simulation game, in-situ measurement project, “hands-on, minds-on” way.	4	10	17	0	10	23

We found that our teachers present and interpret the law for their students, and a third of them adds spice to it with a computer simulation or in some other way. A number of methods are known, referring to the fact that our colleagues are open to widen their palette.

Notes, remarks

As an open ended question we asked those who answered to share their further comments in this topic with us.

We can gain ideas from the comments (our notes are added):

- “I am not familiar with the hands-on, minds-on method, though I’d expect I’d like it.”

- "I organize a presentation of measurement for the entire school every year. I warmly recommend it to others!" (Great idea, really!)
- "Keep in contact with companies, and visit a factory." (Great, but not exceptional.)
- "Measuring activity with a Geiger-Muller tube, the sample is prepared with vacuum-cleaner and gauze." (A great idea from the "Physics Teachers in the CERN Program".)
- "Modelling the decay with beer-foam." (This process hasn't an exponential nexus.)

CONCLUSIONS OF THE SURVEY

- The respondents are not a representative group of active physics teachers in Hungary.
- One third of the respondents has problems with teaching the law of radioactive decay.
- Most teachers alter the methods they use to best suit the classes.
- In the opinion of the colleagues mathematical and scientific issues are more influential problems than the students' attitude.
- In the respondents' opinion the most outstanding problems are respectively: no compulsory test in physics, no experiments, not enough applications in maths classes.
- Teachers' presentation and interpretation spiced with computer simulation are the methods used in the Hungarian classrooms.
- These colleagues know other methods as well and might be persuaded to try them.

"PROBLEMS CANNOT BE SOLVED BY THE SAME MIND SET THAT CREATED THEM"

The quote mentioned above is attributed to Albert Einstein [1]. The fact that there are more wordings in the original English suggests that it is a paraphrase of what we can read from him published in the New York Times on 25th May 1946 or 23rd June 1946.

Didactical research had been in progress since the autumn of 2012. Four classes in a Technical High School were divided into eight groups. Four were taught using the "hands-on, mind-on" method. These were tested against the other four groups as reference groups.

As an introductory part of the project, a topic titled "The wonderful world of measurements" gave a base to in-situ measuring project in classical physics. Having experience with the method, special attention was drawn to the exponential laws. First, the "Newton's law of cooling" project represented these tasks: sensing + measuring + data processing. Then, the project titled "Discharging a capacitor" provided measuring + data processing tasks to the students.

In a period lasting from February to April in 2015 the students investigated half-life by data processing. They studied the decay with a simulation game relying on their active participation. Finally, they estimated the number of nuclei in a sample based on "in-situ" measurements and commented on the reliability of the outcome.

This method is appropriate to teaching and also meets the needs and suggestions of experienced colleagues.

ACKNOWLEDGEMENTS

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NEUTRON CAPTURE NUCLEOSYNTHESIS

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ABSTRACT

Heavy elements (beyond iron) are formed in neutron capture nucleosynthesis processes. A simple unified model is proposed to investigate the neutron capture nucleosynthesis in arbitrary neutron density environment. Neutron density required to reproduce the measured abundance of nuclei assuming equilibrium processes is investigated as well. Medium neutron density was found to play a particularly important role in neutron capture nucleosynthesis. Using these findings most of the nuclei can be formed in a medium neutron capture density environment e.g. in certain AGB stars. Besides these observations the proposed model suits educational purposes as well.

INTRODUCTION

Nearly sixty years after BBFH [1], it is possible and necessary to review and rethink our knowledge about the neutron capture nucleosynthesis. The result of the formation of the nuclei is shown in the various abundances. It is important to mention that the unstable nuclei decayed into stable nuclei and we are only able to observe the abundance of the remaining stable nuclei. "The success of any theory of nucleosynthesis has to be measured by comparison with the abundance patterns observed in nature." – say Käppeler, Beer and Wisshak [2], that is, we need to create such model that gives back the observed abundances.

Since the formation of nuclei takes place in a variety of conditions, the experienced abundance is a result of several processes. Therefore, more models are necessary for different conditions. According to the conditions of the models the nuclei are classified into categories as s-nuclei, r-nuclei etc.

It seems that the reverse approach is also useful: the observed abundances preserve the conditions of the formation of the nuclei. Instead of investigating whether the theoretical model fits the observed abundance, we look for the circumstances when the observed abundance is known. To do this, we need suitable data: the half-life of unstable nuclei and the neutron capture cross section of nuclei. These data are not always constant. For certain nuclei the half-life depends on the temperature [2], [3] and [4]. Fortunately, the reaction rate per particle pair $<\sigma v>$ is constant between 10 and 100 keV because of the energy dependence of σ [2], [3]. So we can use the σ values at 30 keV [5]. The possible resonances only improve the capture capabilities.

OVERVIEW

Many nuclei are known (Fig.1.). Processes that are used to describe the formation of nuclei of elements heavier than iron were defined by Burbidge, Burbidge, Fowler and Hoyle (B2FH) in 1957 [1]. In sixty years the model was refined such that element abundances in the Solar System are reproduced with less than one percent error. Such accurate quantitative description leads to the general and unquestioned acceptance of two main processes that describe neutron capture nucleosynthesis in the literature: the s-process (slow process) in low neutron density environments such as helium- and carbon-oxygen-burning asymptotic giant branch stars and the r-process (rapid process) in high neutron density environments, typically supernova explosions. This separation relies on the fact that an unstable nucleus can either decay or first capture another neutron. Assuming individual nuclei and s-process a neutron capture is expected every ten years. Nuclei having a half-life less than a year almost certainly decay. Formation of elements occurs along a path (s-path) in the nuclear valley of stability, from the light towards the heavy elements. Only nuclei having a lifetime longer than ten years must be considered if the strictly classical approach is followed. So the question arises: Does the neutron take part in the neutron capture process during its full fifteen-minute lifetime at all?

Obviously, the classical approach needs refinement if the neutron capture time and decay time are of the same order. The notion of branching was introduced for such cases in the s-process [2] and even the latest literature relies on this view [5], [6]. The r- and s-nuclei are important observation evidences of the two processes. According to the classical model, s-nuclei can only form in s-processes and r-nuclei can only form in r-processes.

In the classical model nucleosynthesis by the s-process occurs in a path along the valley of beta stability and it is generally accepted that the s-process nucleosynthesis terminates at bismuth by the fast alpha decay of polonium [7]. Only with the r-process is it possible to go further from the valley of beta stability to the neutron rich region of nuclei, towards the neutron drip line. And only by the r-process is it possible bypass the trap of polonium.

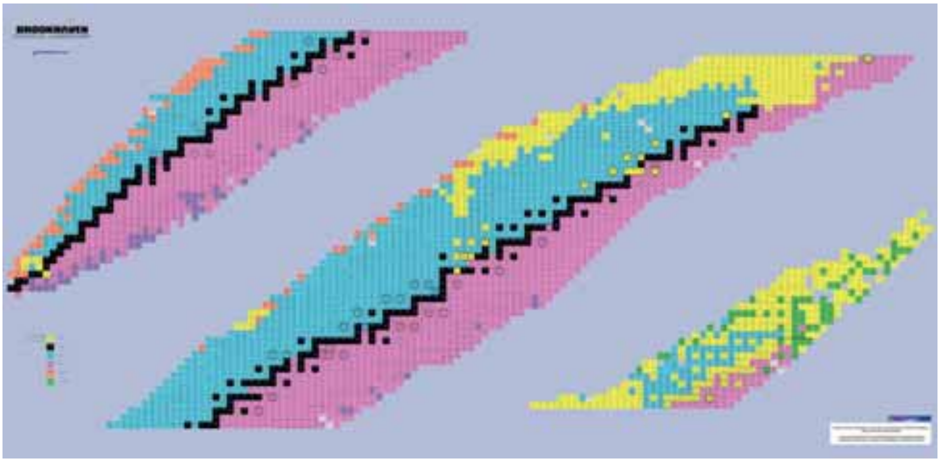


Fig.1. The Chart of Nuclei [8]

THE NUCLEOSYNTHESIS BASED ON OUR MODEL

A computer simulation program was created in order to make a graphical representation of nucleosynthesis by neutron capture [9-12]. The illustrative presentation made the formation and abundance of nuclei visible. Previously unknown details of nucleosynthesis became observable. In the differential equations that provide the basis of our model, the nuclei are distinguished by both atomic and neutron number. The possible values of the neutron density were not limited. The formation of elements is determined by the half-life, the neutron capture cross section, the neutron density and the amount of their parent's nuclei (overstep threshold). The model allows to investigate the role of the individual parameters in the formation of nuclei as well.

Our model requires specific nuclear data for each individual nucleus. Some of these (such as half-life, decay mode and branching ratio) can be found in the literature, but neutron capture cross sections were missing in some cases, mostly for those nuclei that are not used in the classical s- or r-processes. Due to the lack of these data we have investigated both measured and calculated neutron capture cross sections at 30 keV from different sources. Studying published values of Maxwellian averaged neutron capture cross sections we found that those obeyed simple phenomenological rules as a function of proton and neutron number. We found some simple rules for the location of the highest capture cross section on the Z-N plane (Ridge of neutron capture cross sections) and also its maximum value. We used these rules to make predictions for cross sections of neutron capture on nuclei with proton number above 83, where very few MACS data is available and needed for our model [13].

Exploiting the capabilities of our model we have investigated the formation of the elements using various assumptions. We have established that that nucleosynthesis of heavy elements occurs along a wide band near the valley of the beta stability. Our model, named band-process, is based on simple physical assumptions [9-12]. The width of the band and the isotope with the maxima amount in the band depend on the neutron density. The initial amount of nuclei is also important and it depends on the mass and metallicity of the star.

If we use a long time for step and a small amount initial iron nuclei, then we exclude the most of the nuclei from formation. Using a short time interval (one second or shorter) and sufficient amount of initial iron, we can see the true nature of the processes, the band formation of nuclei during the nucleosynthesis by neutron capture. The neutron capture process at low neutron density ($n_\mathrm{n} \sim 10^7 - 10^8\,\mathrm{cm}^{-3}$) is called s-process and the neutron capture process at high neutron density ($n_\mathrm{n} \sim 10^{20} - 10^{25}\,\mathrm{cm}^{-3}$) is called r-process. Based on our model we can see what these concepts mean during nucleosynthesis and how the bands evolve in the different cases.

We have found that the processes that occur at moderate, $n_\mathrm{n} \sim 10^{10} - 10^{14}\,\mathrm{cm}^{-3}$ neutron density (m-process) are very important. They typically take place during the TP state of AGB stars [14], [15].

The nucleosynthesis in stars with moderate mass and low neutron density occurs in a band along the valley of beta stability and is terminated at Z=83 by the alpha decay of the polonium. If the neutron density exceeds $n_n = 10^{12}\,cm^{-3}$, the evolution does not terminate at bismuth. In AGB stars during a thermal pulse the neutron density significantly exceeds this value so the valley may proceed to fermium. The simulated abundance approximates well the observations, only the abundance of lead is higher than the expected value. Our program indicates the production of r-nuclei at low neutron density and s-nuclei at high neutron density. The r-nuclei found in SiC meteorite grains demonstrate the possibility of their formation in slow or moderate processes [5].

The band of nucleosynthesis reaches the adjacent r-nuclei even at low neutron density, although the amount of these nuclei is negligible. At moderate neutron density the amount of these nuclei increases to the empirical abundance found in the Solar System. However, the experienced abundance can be reproduced with nuclei produced at processes with low, intermediate and high neutron density.

In the case of high neutron density, if the neutron density does not significantly exceed the $n_n = 10^{20}\,cm^{-3}$ value then some s-only nuclei are also produced with some exceptions (${}^{176}_{72}Hf_{104}$ and ${}^{192}_{78}Pt_{114}$) [9].

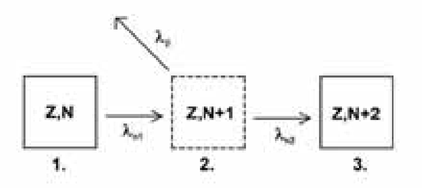
We found that neutron capture process in the AGB TP phase at intermediate neutron density forms elements heavier than bismuth, the formation of nuclei can evolve even to fermium [9]. Although "sweep-out" obscures this situation, there is an empirical argument that confirms the predictions of our model. This argument is the anomaly of the isotopic abundance of tellurium, namely the two most abundant tellurium isotopes are r-nuclei with thirty-thirty percent abundance. This anomaly is unique; there are no other elements with such a strange isotopes anomaly. It seems that there are two arguments: 1. the formation band which includes these two nuclei, 2. fermium that forms in the AGB TP phase goes through spontaneous fission and results in unstable tin isotopes. The unstable tin isotopes decay into ${}^{128}_{52}Te_{76}$ and ${}^{130}_{52}Te_{78}$, and that is the other way part of these two abundant isotopes come into existence [9]. We can reproduce the distribution of tellurium isotopes with a linear combination of isotope distributions obtained with slow, moderate and rapid processes. According to our model the most important places of element formation are AGB stars. This is in agreement with the recent results in the literature [6], [15]. The observation of radio nuclei ${}^{26}Al$ and ${}^{60}Fe$ in the Milky Way and the discovery of the daughter isotopes in the pre-solar grains provide further confirmation of the conclusions of our model [5], [16].

VERIFICATION

Currently, verification of a model almost completely relies on one criterion: the abundances of elements in the Solar System [17] should be correctly reproduced. However, observed abundances include the aggregate effects of multiple processes that take place during nucleosynthesis. It seems reasonable to assume the existence of an intermediate neutron density nucleosynthesis to bridge the gap between the s- and r-processes. Anomalous isotopic ratios observed in early meteorites substantiate such assumptions [5]. Intermediate processes take place in AGB stars.

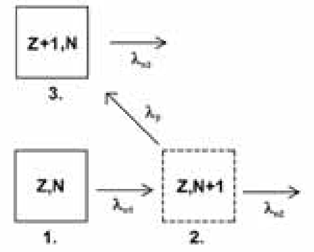
There are several ways to verify the model. Besides the ratio of r- and s-nuclei, mainly the accurate reproduction of the abundances measures the goodness of the model. The latter however, depends on many other parameters, because the elements form in stars of different states under different conditions. The abundance of isotopes is very important for verification as well. Discovery of radiogenic nuclei with long half-life in the Milky Way or elsewhere in the universe could be an important evidence, too.

An independent way of verification is the rate analysis [18]. Abundances of elements can be classified as elemental abundance, isotopic abundance, and abundance of nuclei. In our works the nuclei are identified by (Z,N), which allows reading out new information from the measured abundances. We are interested in the neutron density required to reproduce the measured abundance of nuclei assuming equilibrium processes. This is only possible when two stable nuclei are separated by an unstable nucleus. At these places we investigated the neutron density required for equilibrium nucleosynthesis both isotopically (Fig.2.) and isotonically (Fig.3.) at temperatures of AGB interpulse and thermal pulse phases. We obtained an estimate for equilibrium nucleosynthesis neutron density in most of the cases. Next we investigated the possibility of partial formation of nuclei. We analyzed the meaning of the branching factor. We found a mathematical definition for the unified interpretation of a branching point closed at isotonic case and open at isotopic case. We introduced a more expressive variant of branching ratio called partial formation rate. With these we were capable of determining the characteristic neutron density values. We found that all experienced isotope ratios can be obtained both at $10^8 K$ temperature and at $3 \cdot 10^8 K$ temperature and at intermediate neutron density ($\leq 2 \cdot 10^{12} cm^{-3}$).



$$n_n = \frac{\lambda_\beta}{v\left(\sigma_1 \frac{N_1\sigma_2}{N_3\sigma_3} - \sigma_2\right)}$$

Fig.2. The isotopic case and its equilibrium neutron density



$$n_n = \frac{\frac{N_1}{N_3}\frac{\sigma_1}{\sigma_3} - 1}{\sigma_2}\frac{\lambda_\beta}{v}$$

Fig.3. The isotonic case and its equilibrium neutron density

EDUCATIONAL USAGE

The origin of heavy elements beyond iron is an important and interesting problem; therefore, it is worth discussing it in the classroom. Recently these questions are presented in the final exam of high schools [19].

Traditionally we speak only about fusion and decays, but it also is an interesting question how the elements heavier than iron are formed. The primary purpose of our investigation was educational. With the model the processes can be followed and demonstrated easily and can be integrated into education.

Our model is capable of demonstrating the decay processes, the decay trees from arbitrary initial nucleus (i.e. isotope) as well. So we can follow the change of the amount of seed isotopes and the daughter isotopes as well.

CONCLUSIONS

The neutron capture formation of nuclei occurs in a band. There are no r-nuclei (in exclusive meaning). Most s-nuclei can form in r-process. The bypass of bismuth is possible at medium neutron density. All experienced isotope ratios can be obtained both at 10^8 K temperature and at $3 \cdot 10^8$ K temperature at intermediate neutron density (10^{12}-10^{14} cm^{-3}), so the m-process and the AGB stars are probably one of the main places of nucleosynthesis. It seems that the so-called r-nuclei can form in intermediate processes as well.

Our model is also capable of visualizing the processes of neutron capture nucleosynthesis and the decay processes as well.

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VISIT TO THE MAINTENANCE AND TRAINING CENTER AT PAKS NUCLEAR POWER PLANT

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ABSTRACT

The last official program of the Teaching Physics Innovatively (TPI-15) conference was a visit to Paks Nuclear Power Plant (NPP) in particular to the Maintenance and Training Center (MTC), with approximately 30 participants. The scope of MTC is the preservation of staff competence and training for any new activities in a non-radioactive environment. Besides this work, the MTC offers for the public guided tours for the better understanding of the basic nuclear processes and operational techniques of a modern NPP.

1. HISTORY AND IMPORTANCE OF PAKS NPP

Paks is a small town located in the middle of Hungary on the shore of the river Danube. Here is the Paks Nuclear Power Plant (NPP) [1] located, which operates 4 nuclear units from the 1980's. The type of the units is VVER440-213 [2] which denotes a Russian-designed Pressurized Water Reactor (PWR). The first unit produces electricity since 1982 and the youngest unit is in operation since 1987. The nominal electric power of the reactors was 440 MW, however, through the years the reactor powers have risen to 500 MW. The planned operation time of the units was 30 years, but thanks to the operation lifetime extension programs this period will be expanded by another 20 years [3]. The total power of the four units is 2000 MW, which covers approximately 50% [4] of the Hungarian electricity production and approximately 40% of the electricity consumption. Thus Paks NPP plays a very important and unique role in the Hungarian electricity market.

But why is it so unique? In our world the global warming and the reduction of the emission of greenhouse gases has become a major and urgent global problem. To solve this problem the use of renewable energy sources together with the nuclear power [5] could be the key, since the greenhouse gas emission during the normal operation of these technologies is zero. Modern countries around the world, for example the counties of EU agree that the greenhouse emission should be decreased step by step in the future. The use of nuclear power totally satisfies this modern demand.

To understand this claim we should explain the principles of operation of a NPP. In a NPP the energy is released from a nuclear fission reaction, in the particular case of Paks NPP, where enriched UO_2 is the material of the fuel, the following reaction releases the energy:

$$n + {}^{235}U \rightarrow 2 \text{ fission fragments} + \text{new neutrons} + \text{radiation} + \text{kinetic energy} \qquad (1)$$

The average energy that is released in one fission reaction is about 200 MeV. This energy is distributed as the photon energy and kinetic energy between the released particles. The kinetic energy of the β particles and the fission fragments will be dissipated in the vicinity of the fission event (in the UO_2 matrix) while neutrons and γ radiation can very easily leave the fission fuel. After the thermalization of the new neutrons they can close the loop causing new fission events. This loop is also called nuclear chain reaction.

The Paks NPP is a PWR reactor which contains a huge amount of water. The water in this system has a double purpose: it is used as a moderator or neutron slowing material and water is also used as a coolant.

The moderator material is essential because only relatively slow neutrons, so-called thermal neutrons can cause easily nuclear fission in the ^{235}U, but the neutrons born in the chain reaction are with relatively high energies (~2 MeV).

As mentioned above, the fission fuel will absorb a great fraction of the released energy, thus it will be heated up, and it will transfer its heat to the coolant, the water. The water is circulated in a closed circuit through the reactor core (so-called primary circuit), where the typical temperatures are around 270 ^{o}C and 300 ^{o}C in the inlet and outlet points, respectively. For these high temperatures an increased water pressure is also needed to prevent the boiling of the water in the reactor core. The typical pressure in the reactor core is about 120 bar. The primary circuit can transfer its heat to another closed circuit called secondary circuit via a heat exchanger, so-called steam generator.

The pressure in the secondary circuit is much smaller, therefore a huge amount of hot steam will be generated, absorbing the heat transferred from the primary circuit. The steam drives the turbines and the turbines drive electric generators.

After the foregoing it is clear that NPPs do not produce greenhouse gases, and the clouds which are released from their cooling towers contain only evaporated water. In Paks the cooling towers are missing since the cooling of the closed secondary circuit is solved with fresh water from the Danube.

2. THE ROLE AND MISSION OF THE MAINTENANCE AND TRAINING CENTER

The Maintenance and Training Center (MTC) [6] is located at the Paks NPP site. The MTC is a unique place where the workers of the NPP can be trained and prepared for any kind of work in a non-radioactive environment since 1997. The spectrum of these trainings is very wide, from the occupational safety and health (OSH) trainings to the specialized maintenance works everything takes place here. But the MTC fortunately offers even more, there is the possibility for visitor groups to participate in guided tours. These tours introduce every aspect of the work on a real nuclear unit from the clothing and proper use of work protection techniques to the detailed working scheme of motors, pumps, armatures. Moreover, from the point of view of a visitor the MTC provides a unique opportunity to see and touch (or even crawl inside) a full-scale (original) steam generator and a reactor core. The reactor core contains every part of a real reactor except the nuclear fuel assemblies so the reactor tank, reactor shaft, control rod drives etc. These original reactor equipment were transported to Paks from a built but never used nuclear unit in Poland. During the guided tours the visitor can listen short presentations and they can ask questions according to their field of interest. While this is a non-radioactive facility of the NPP, it is ideal for visitors, where they can really see and learn how large and complex an NPP is. For a layman the visit of the MTC is advised after the visit of the Visitors Center.

3. THE ADVANTAGE OF A VISIT AT MTC IN PHYSICS EDUCATION

The traditional way of teaching nuclear physics or nuclear techniques in Hungary is mainly based on strong theoretical education or hands-on trainings with small isotope sources, but there is no chance for real application-oriented training, or to experience the real industrial scale of modern nuclear facilities. This is also the situation in high school even during the higher educational training (except for a few specializations). However, Hungary is in a special situation because there are 6 nuclear reactors in operation: 4 NPP units at Paks and two smaller reactors at Budapest. There is an Experimental Reactor at the Hungarian Academy of Sciences (HAS), Centre for Energy Research (EK) and the Training Reactor at the Budapest University of Technology and Economics (BME).

For nuclear physics and technology education the training on the two units at Budapest is essential, however, these facilities cannot introduce the industrial scale applications to the students. Therefore, even for university students it is a great opportunity to visit the MTC and experience the real industrial environment for their own. This type of visit is periodically organized for mechanical engineers and physicists, where Hungarian students and also students from abroad (Slovakia, Brazil, Vietnam) can participate.

For high school students the visit of the MTC can be even more beneficial. Many physical education topics are related to NPP and the electricity production process, for example mechanics, thermodynamics, nuclear physics, electrodynamics, etc. During a visit it is easy to demonstrate how physics is working in real life applications from all of the above mentioned topics.

4. DESCRIPTION OF A VISIT

For the visit a prior appointment is necessary, which can be done through the Information and Visitors Center of the NPP. It is recommended to devote at least 2-3 hours or more for a visit if a visit to the Information and Visitors Center or to the Museum of Nuclear Energy is also included. Visiting groups over 16 year of age can visit the power plant's operational area as well, then a longer time is needed. The standard maximum size of a visiting group is 40 people, this group size is ideal for a secondary school class. Catering can be organized at the NPP's canteen.

During a visit in the MTC the visitors can look at some 1:1 scale original primary and secondary circuit components, the same types that are in use at the Paks NPP: The visit includes a hands-on experience with the steam generator and the reactor vessel. The guides who are active trainers at the maintenance center kindly answer any kind of NPP- or MTC-related questions. During the tour teaching aids, nameplates of components and even film screening helps the better understanding of the ongoing physical and operational processes of the NPP. The attendance is free of charge.

5. SAFETY ISSUES TO EXPERIENCE

The safety issues used in a nuclear power plant have significantly high importance during the operation. This is one of the keys to the operation without accidents, incidents or malfunctions. Nuclear power plants use the concept of defense in depth, which means every system is redundantly installed and the reactors are inherently safe. To understand this concept visitors can see every safety barrier to prevent the release of radioactive materials to the environment. The first barrier is the fuel ceramics matrix, which retains fission products in the fuel itself. The second barrier is the fuel cladding, which encloses the fuel in zirconium-alloy tubes. The third barrier is the primary circuit itself, and the last barrier is the airtight reactor building called box or containment. To experience these safety concepts is useful even if the students won't choose a related profession in the future, because generation of fear and rumors increasingly appear in the media.

SUMMARY

During the last day of the TPI-15 conference a visit to Paks NPP, in particular to the Maintenance and Training Center took place, where the participants could experience the advantages of such a training center in physics teaching on their own. During a few hours of guided tour several physics area are brought up in the explanation of the basic operational processes of the NPP which can be extremely fruitful for secondary school students. This type of visit is ideal to experience the complexity of an industrial facility but keeping always in foreground the underlying physical processes and the most important aspects of nuclear safety.

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An areial view of the Paks NPP with river Danube in the background (source: [1])

The main buildings of the Paks NPP (source: [1])

Vessels in the NPP that the visitors can touch or even crawl inside (source: [1])

X. ROUNDTABLE DISCUSSION

ROUNDTABLE DISCUSSION ABOUT SOCIALLY SENSITIVE ISSUES IN PHYSICS EDUCATION

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László Egyed: Some twenty or fifteen years ago, researchers at CERN looked around and said: “We have excellent instruments, but who will operate them, work on them in twenty years? Children are turning away from science, all around Europe, and without researchers, scientists, these instruments by themselves are useless!” So, they organized the first big conference called “Physics on Stage”. I was so fortunate to participate in this event. They collected physics teachers from Europe to discuss and show each other, how they can teach physics in a more interesting way. This movement has expanded since, and became Science on Stage, an international science communication landmark, and David Featonby is one of the leaders of this movement. A conference is organized in this spirit every second year: teachers show each other, how science can be taught in a more exciting manner, how they can raise interest in science among their pupils. How can they make their talented students interested in a science career? And I think this is the most important socially sensitive issue nowadays: how to raise interest in science. How successful is this movement? Professor Featonby, have you experienced the increase of students in science?

David Featonby: I think this philosophy about enthusing teachers to enthuse the children, is very important. To comment on the beginning of your talk, to raise interest in students: we live in an interesting society. Society doesn’t understand numbers. And that is a big problem. My wife is mathematician. We go to a party and people there are saying: I don’t understand maths, I could never do maths. This is what I call *innumeracy,,* which can be experienced in lots of ways. For example, the ways in which people don’t understand statistics, probability and so on.

On the other side of things, is that we don’t balance views. If a hundred people think one thing and one person thinks another, we look at the television and that one person gets two minutes and the hundred people get two minutes. And so people don’t understand the balance, don’t understand the essence of things very much. They may think something is a problem when it isn’t And therefore we get all this misunderstanding around us. For instance, when I am going home later this week, what is the most dangerous thing I will do? People probably think: getting on the airplane. That is probably the safest thing that I will do. The most dangerous thing will be crossing the road outside. This *innumeracy,* or lack of number sense comes back again and again. And we have to get over with the „I don’t like, I can’t do math” stand, before people get engaged with the real issues.

Now, coming back to your question: Science on Stage, is all about enthusing teachers to enthuse the children. That is one step towards making that difference. We particularly believe that encouraging giving enthusiastic teachers the opportunity to share with each other can have a very significant impact. It’s a massive issue right across Europe, where children are dropping out of the sciences. We do think that we have made some inroads in England and it seems that we could turn around the numbers taking science, not massively but I think the downward tendency has turned. This comes back to how society looks at things. When I was first married, every weekend I was fiddling with my car, and, if I wasn’t mending the car, I was inside the washing machine, repairing it. Nowadays we have a black box society, very few people understand how anything works. If it doesn’t work, throw it away and get a new one. This all links to this lack of real scientific understanding. And yet, when you can engage the children, when you can strike that light, when you can make them interested, you have hit the jackpot.! What a joy for us as teachers when a child’s eyes, (or adult’s eyes) light up the the glow of understanding. “Well, is that all it is! I can understand it.!” And people are genuinely surprised by the joy of learning. And that’s the road we are trying to travel.

László Egyed: I must add that it is the goal of the manufacturers to turn things into black boxes – if anything goes wrong, you buy a new one.

Hannu, science centres are very important places to teach science to children and also to adults. You worked for Heureka, the Finnish Science Centre for decades.

Hannu Salmi: First of all, they are important, but are not the centre of the Earth or the centre of the Universe, or the centre of the society, so there are many inputs around them. But for sure, science centres have been developing into some kind of key players in public understanding of science and became forums of science. I think that maybe the most important thing is that they have been diminishing the false kind of negative emotional attitude towards science. But I think science centres are not so important for those already eager for science and want to engage in it, they come there, they enjoy it, they bring their own input, but an even more important role of science centres is to diminish this negative emotional attitude towards science, technology, research etc. In my opinion, it is false trying to direct young people to science, – young people choose their own directions. And the biggest mistake is if you give false promises to young people. You have to show reality.

Contrary to the UK, in Finland and in some other countries, the lack of people being interested in science and technology is not the main dilemma. Some people in technology should look into the mirror, I suppose. It was so easy to choose a career in science and technology, when I went to university in the seventies. The big thing is that still half, no, fifty one percent of the population is really a big resource for science. Ad now, to refer to this eternal gender issue, that there certainly is a lot to do in this field. And the point is how you make it somehow meaningful to work for something.

And there is this constantly growing impact of informal learning. Not as a drive to obtain more knowledge, but as an emotional quest. For example. when we made a survey with the participation of one thousand and one hundred students in all the faculties of the University of Helsinki, and we put a question: „How did you choose your career?” we received different answers. One reason they mentioned was social pressure: you do what your mother tells you, or your uncle is your role model, etc. Or you follow the course of your friends. Other people want to choose a profession for money. Then there are people who say: “I want to follow my interest and my spirit, I want to learn aesthetics and I don’t go for a good job or a good salary. Though sometimes they go to work in a museum or become an art director and actually get a good salary in the end. These are the four alternatives in career choices, but the fifth one is an option that has becomes more and more important: informal learning. Not as a source of knowledge, but as some sort of a hobby, for entertainment. You can’t find a veterinarian doctor who did not have a rabbit, or a pony, as a young girl or boy.

László Egyed: Well, let's speak about a really socially sensitive issue, nuclear power. Once I listened to a discussion about nuclear power with Nobel laureates, and at this session, Carlo Rubbia summarized the three points nuclear power plants should fulfil. First, there must be no connection between power generation and the manufacturing of nuclear weapons. Second, the laws of nature must exclude the probability of accidents, and third, the amount and the lifetime of nuclear waste must be reduced drastically.

Attila Aszódi: I think, Professor Rubbia is right, and these are key elements in the acceptance of nuclear energy. Let's start with the waste. The nuclear industry is a very special case. This is in fact the only industry which is collecting its waste, collecting, handling and treating and finally disposing of it. In nuclear industry the waste is in a much higher concentration, this is well understood but therefore we really need the facilities, and we have appropriate facilities. The issue is how the public, how members of society accept that we really do that. Finally we need some facilities for the final disposal. The amount of this waste is not that high, but because we do not distribute this waste into the environment, we need something for the final storage. I think Germany is a very… – I try to say it is a good example, but in fact it's a bad example of how the society could be turned against the final solution, and through that route make nuclear energy unacceptable for society. But there are lots of misunderstandings. Professor Featonby mentioned what a big issue it is for a lot of people to understand math, and I say, that understanding of probability is even more complicated. And nowadays this knowledge of probabilities would be extremely important because without them, the risk, the evaluation of the risk and the evaluation of probability the real decisions can't be made. I can't say how we can resolve this issue, because probability is one of the most complicated parts of math. But the lawmakers and the decision makers and maybe the wider public should understand much more about risks and probability.

David Featonby: Can I add something? One of my old pupils worked in the nuclear industry and his task would be an inquiry on a nuclear power station in England. And of course you are not allowed any lee way in the nuclear industry - you simply can't afford to have any accident. None at all. And then this former pupil got a job in the gas industry. "It's really great, David, he said, we are allowed nine deaths a year" The reason is that in the gas industry that (i.e 9 deaths) is acceptable for society. For nine deaths in the nuclear industry, there would be a shutting down of power stations. If coal was discovered tomorrow, that would be banned before the end of the week, because of the number of accidents occurring in the coal mining industry, not only in the mines but also the transport of it, etc. It comes back to this probability thing as well, and the sort of social understanding and misunderstanding. Nuclear industry is one of the safest industries in the world, the public perception of nuclear industry is that it is the most dangerous industry in the world. So that's why we got to inform people.

Attila Aszódi: But you know, the reason for this has been very well described by social scientists. As I mentioned at the end of my presentation, it is hard to love nuclear energy because it is complicated, and its risk perception is totally different.

László Egyed: Similarly as in the case of an airplane crash and a road crash.

Attila Aszódi: Exactly. It is very subjective, so if something happens in a nuclear power plant, it draws a lot of attention. The other factor is the way future generation will be influenced by this kind of difference. If you just look at the news of the last days, there was a terrible industrial accident in China, maybe more than one hundred death cases, but nobody is speaking about that any more. On the other hand, if you remember, the Fukushima accident, had been covered by the whole press for one and a half years, although it only caused two deaths, not more.

But please remember that it is described by social science why the perception is so different for different risks. Let me just shortly answer your other two questions. So I think especially for Hungary, but for other countries as well, nuclear weapons and nuclear power plants are well separated, I think for the developed world, nuclear bomb production, and nuclear industry are totally separated, so I do not see it as a big problem. And the third point that you mentioned is safety, and I think this is a field where nuclear industry has developed a lot. The nineties and the last decade have been used to develop the so-called generation 3+ and 3 reactors, which really have the safety features, applying passive safety solutions, so the robustness of the plants, the redundancy of the safety systems is much more developed than in the past. In the new constructions, safety level is at least two or three order of magnitude higher as compared to generation 2 reactors which are well accepted worldwide.

Hannu Salmi: Just a short comment. It is interesting that in Finland many people have been great supporters of nuclear energy for decades. They changed their minds during the last five years, for two reasons, which have nothing to do with the safety issue. First, one is that this Areva reactor that should have started yesterday is now seven years late … no ... they are not disclosing anything about a timetable anymore, so that other people can’t say that you are late. It’s the same thing why there are timetables of trains in Congo, not that you know when the train comes, but to know how late it is. So that is one issue: the new reactor is late. Seven years and four billion euros late. Even the biggest nuclear energy supporters can’t say: well, I like this. I want to have more of this. And the second issue is that nuclear energy politics are increasingly out of the control of democratic decision making, and that has turned many people.

Attila Aszódi: I totally disagree. It’s nice to have this comment on democracy but could you explain how democratic are the Kirchoff’ laws? They are laws of physics. And the physics laws are not democratic because they are regulated by nature. I think you are right saying that politics is highly involved in the whole picture but it is not only a nuclear issue. It is a very big contradiction that the security of supply is the responsibility of the government, and you or others could think that the electricity system can be developed in a democratic way. Electricity supply security cannot be ensured if everybody does what he or she wants. The electricity system is much more complicated, and, as I explained in my presentation, there are different means needed in the system, to make it stable, and this a really big challenge. How politics can make it understandable for the public is another issue. But really hard decisions are needed not only today but also in the future. Related to your Finnish problem, I have to tell you that the delay of Areva in Olkiluoto 3, is a very good example of how Europe can lose a competence which has been a major competence in the past. Because of the low interest in physics, because of low interest of public in science, and because of the low development in the industry. So, if Areva and other European nuclear companies would have been able to construct nuclear power plants in the last 20 or 30 years, there would be no problem at all in Finland with Olkiluoto 3. This is fact.

László Egyed: In the ATOMKI, the Nuclear Research Institute in Debrecen, you are trying to bring nuclear physics closer to people, to make it “user-friendly”.

Zsolt Fülöp: Well, we are acting even broader. If you go to a hospital, for a kind of health checkup, and you don’t have your x-ray, you don’t have your CT, you don’t have your ultrasound, you don’t have your NMR, and then you are complaining that you are not treated well. This is the basis when you enter the hospital, that you have this and this and this medical stuff. So I think, if we can just make people understand that physics and nuclear physics are present everywhere, and the one I mentioned is a real-life example, then you can change the world. You see, because for them, even for the kids, it is evident, that it is there. Mobile phone, GPS, I don't want to list everything, but somehow you can always make the connection between physics, physics research, or high level research and those new things or, I wouldn't mention any new, absolutely useful and necessary things, which you would miss, if those weren't available. I think this is very important. Moreover, I think we should really emphasize this list.

And there is again, I would say, another big problem, that if you compare, let's say modern physics research, and let's say, mathematics research, and you go to a high school kid, if there is a smart kid, who actually learned some mathematics, for example number theory, you can quite easily explain what kind of big problems you can solve in number theory. Maybe he can't solve it, but he can understand it, and say, "Yes, this is a very interesting problem". But with the present high school physics curriculum, of course, you have to teach those knowledge elements that have been taught before, because if you taught them, you wouldn't have time to teach new things. And then I see a gap actually between the classic and modern curriculum content. If you want to explain modern physics to students, it's very difficult, because there is this gap. I suspect that in mathematics, this knowledge gap is not so huge, because you can teach the basics much more easily.

László Egyed: There is a lack of time at school.

Zsolt Fülöp: There is a lack of time. So what I do and say, probably nobody agrees and that's why when I am offered to go to a high school, to give a special class, for example, for students, I have two requests. Prerequisites, so to say. One: the teacher can't be there. If they ask me to give a talk to the kids, I don't want to have the teacher there, I want to talk to the class. As a teacher. And I don't want the teacher sitting next to me analysing what the kids are asking. Because the kids are afraid that they ask something stupid. And everything is frozen. And the second thing is, if I am invited, then I should have the right to two or three good marks for the kids if I think that they were so good. No wonder, I am not invited. But you understand that there is a big difference between a scientist – and this is the bottom line –, who does physics day by day and follows his science, and let's say the layman, even an interested layman, who can read many things, but because there is this information overload, it's very difficult to distinguish what is, how to say, "clear information", and what is "not so clear information". And I think this is the responsibility of the society to make this difference. But it is very very difficult, and I am not so sure if we can solve this problem

David Featonby: I always say to children that a hospital is just a physics lab with a few bodies. You look at the physics in a hospital and that's true. Unfortunately the doctors often do not understand physics. That's a different story, but when you ask how is this working, when they poke in something in you, they say: "oh, I don't know, it is just a black box". I recently had an operation under general anaesthetic, the operating theatre was full of interesting measuring devices, I was just beginning to find out what they all were when I fell asleep! But even the bed I was on when I came round was a masterful example of technology. But basically a hospital is a physics lab with bodies. I ask the students "Do you want to work in a physics lab with bodies, or in a physics lab without bodies?"

Zsolt Fülöp: I always say to children that a hospital is just a physics lab with a few bodies. You look at the physics in a hospital and that's true. Unfortunately the doctors often do not understand physics. That's a different story, but when you ask how is this working, when they poke in something in you, they say: oh, I don't know, it is just a black box. But basically it is a physics lab with bodies. Do you want to work in a physics lab with bodies, or in a physics lab without bodies?

László Egyed: The problem is, and this is true in the case of socially sensitive issues too, that science sometimes needs complicated explanations, which people do not understand, they understand simple explanations of an antagonist of nuclear power better. For example, if I explain nuclear power, it is complicated, but if the opponents say: it is radiating – people understand it at once. How can you resolve this problem?

David Featonby: Can I just say that for us as science teachers, our teaching should be like peeling an onion for our students. And our skill is to know how far into the onion to go. One of my favourite topics is spinning tops. I can explain the behaviour of a spinning top by saying: this top has a pointed end, and that top has a round bottom. Ninety percent of the population is happy with this explanation as to why one top folds over and this one regains an upright position. But then for the remaining five percent I include an explanation about the centre of mass and centres of curvature,. And so on and so forth. To another few I will give a description using a right hand rule, you can explain with that, taking friction and couples into consideration. If we go too deep, we lose people. And that is the danger – my son has a PhD, the first chapter of his thesis was great, but after that I really didn't understand a great deal. So our skill as teachers is to get the right level that gives enough explanation to make informed decisions. We have to do that for politicians as well, if we talk science with politicians, we begin to peel the onion. (Maybe we don't have to peel too deeply!) We have to gently peel the onion for the general public too, so that we don't appear to be talking a foreign language whenever a scientific topic comes up. The skill is to get to the level that people are at, and go a little deeper. That's our skill as teachers, get to a student's level and then stretch just enough, but not to breaking point. And it's a challenge, but it applies to all sort of things. That's our business.

László Egyed: Professor Fülöp, what is you experience with explanations?

Zsolt Fülöp: A year ago I had a one hour radio program in the Catholic Radio, where there were three persons invited. I was there as a physicist, there was a priest, and there was the leader of the show, and we were discussing the Big Bang. And I survived. So I think you – whatever the circumstances are, you have to accommodate yourself, and always understand a bit of your audience. And if you do this, then I think you are on the right track. So you shouldn't hold a lecture, and go along with this regardless your audience, and that's why, for example, Attila Aszódi asked some questions from the audience. I also like this approach. Here, at least you know if there is a reflection and not just sleeping people there. I think it is very-very important.

Hannu Salmi: One of the biggest truths in pedagogy and education is that you can teach something to someone else only if you know it yourself. And you know something probably only if you can teach it to someone else. You experience it very often nowadays: for example, I have a problem with a computer, then I'm asking the helpdesk and he comes there and solves the problem: look, now. But if I ask: let me know how I should do it, then even this most skilful ICT expert realizes: he can't do it, he is just trying several things and now it was there. And this is I think also one of the dilemmas of public understanding of science, that there are so many examples of people doing something in a mystical and arrogant way and saying that this is so difficult to understand. And then there are the best examples like Carlo Rubbia or Hannu Miettinen, his right hand, or many other scientists who can really make complicated things understandable without making the mistake of making it too trivial, but showing it. Recently I have made this related to your topic the Boltzmann constant. How the molecular movement is related to the energy. So that warmth is not Celsius or Kelvin but it is energy. Here is this nitrogen molecule which moved there with a given speed, but here it moves faster, because here there is so much energy coming from all of us and warmed it. So one thing is that you must have the message and the other, equally important thing is that you should be able to tell it clearly.

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