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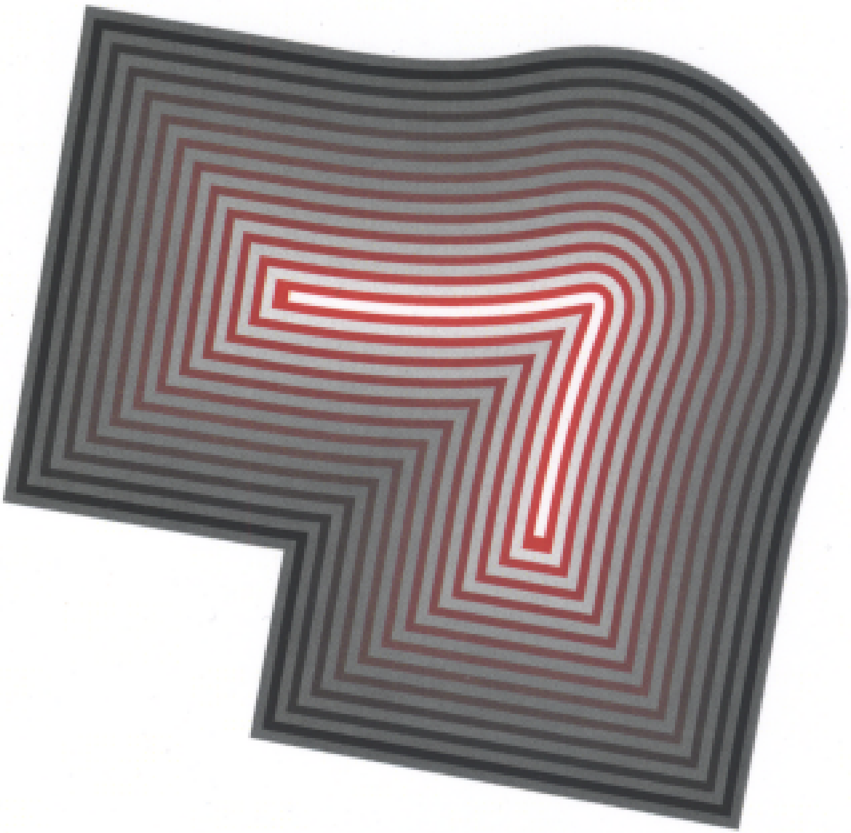

CURRENT TENDENCIES AND PROBLEMS IN EDUCATION - 2015

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CONSTRUCTIVISTIC PATHS IN TEACHING PHYSICS: FROM INTERACTIVE EXPERIMENTS TO STEP-BY-STEP TEXTBOOKS

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Abstract

Teaching Physics, in-between theory and technical applications is nowadays a tedious task. Apparent abundance of web resources makes access to information easy, but its use by pupils is quite unclear. These difficulties, added to less importance held by physics nowadays than in the last decades, inside the national educative system, caused in many countries a fall of interest in studying science and technology.
Within several national and international programs, involving mainly Poland and Italy, various recipes for school education at lower and higher secondary level were developed in our group. All these recipes were oriented towards real experiments and constructing the discovery paths with pupils. The school (and extra-scholastic activities for primary-age pupils) included: collections of simple experiments "Physics and Toys", interactive lectures for children, itinerary exhibitions, innovative textbooks inviting the reader to a heuristic dialog, computer-guided experiments, and collections of problems in physic solved step-by-step. We resume some of these implementations and draw main results.
Actions were undertaken with three cultural goals: trigger a wide interest in physics through "Fun in Physics" activities, improve didactical efficiency at schools, induce students' initiative in an independent discovery of science.
In detail, for a lower secondary school simple interactive experiments on electromagnetism were introduced, and a textbook on mechanics. For higher secondary schools – a textbook on modern physics and computer-guided experiments; for children aged 5-10 – interactive lectures on mechanics, electricity, acoustics. Evaluations were performed by qualitative and quantitative measures, in Poland and Italy, in collaboration with several teachers and PhD students.
All these, constructivist applications show an improved efficiency and find positive evaluations among teachers and pupils. However, partial and sporadic actions do not lead to significant results. Only conjugated implementations of new experimental tools (real objects) and didactical methods (inquiry-based teaching) shows achievements congruent with the Lisbon EU declaration on Knowledge-based Societies (EU Commission White Paper: Education and Training, 1995).
Key words: *educational systems, teaching physics, interactive exhibitions, simple experiments, computer-guided laboratories, constructivism, cognitive sciences.*

Introduction

National Education Systems and Macroeconomic Predictions

A traditional model of the European university, born somewhere in-between medieval Paris and XIX century Berlin, hardly corresponds to the modern demand for job competenc-

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es. Macro-economical indicators, like the unemployment rate (above 10% in many European countries, 14% in Poland), the unemployment rate among young people (about 40% at the age 16-25 years in Spain and Italy) and growing age to reach the economic independence (2/3 of young people below 35 years in Italy live with parents), testify it clearly. Predictions of OECD for the 2055-year labor market (Johansson 2012) are even more sinister: in Poland and Italy barely 40% of the adult population will be professionally active. OECD related these predictions to national demographic trends and to educational attainments.

Clearly, competences given to young populations by national education systems do not match with the social needs. In some opinions, this is due to the whole educational "chain" – from the elementary school, that is oriented as if all pupils should become scientists. The question is not only physics: in Poland, Boole's algebra is taught in elementary school and in secondary - the taxonomy of *Lumbricus terrestris*. Formal and full of detailed information are also textbooks in Italy.

Decreasing Interest in Physics

At the end of 20th century a significant fall of interest in studying physics was observed in Europe: the number of physical science graduates fell by 50% in Germany, France, Netherlands in the period 1994-2003 (Rocard, 2007). This negative trend was stopped in several countries, including Great Britain. In Italy, in 2001, the number of students enrolled to Faculty of Law of Turin University was higher than the number of all students entering Physics Faculties in the whole country. Therefore, the Italian Ministry of Education in 2004 undertook an action "Scientific Laurea". It consisted in opening science faculties to the external world: lessons run by professors in schools, scientific exhibitions, science festivals, see (Karwasz 2010c). As a result, more students enrolled into Physics - in small universities a rise by a factor of four in the period 2004-2008. Poland in recent years followed a similar cycle: after a temporarily rise in 1990-2000 (related to general economic changes in the country), a drastic fall to almost zero enrolments in Physics is seen now, even at big universities. Tendencies in Italy and Poland seem to be "shifted" by some ten years.

A question arises from these comparisons on the necessity of changing the paradigm: from sophisticated science discoveries ("ivory towers" as named by famous Italian nuclear physicist, A. Zichichi) to "Physics is Fun", as we called the European "Science and Society" Project (Karwasz, 2005b). Universities are not any more reserved for elites. Therefore, physics should also become: fascinating, easy, useful. A spectacular success of the "Conceptual Physics" (Hewitt, 2009) using little mathematics and "connecting physics to their everyday experiences" proves that it is a realistic goal. In this paper we discuss some examples of teaching strategies based on simple experiments and cognitive teaching paths. Obviously, mathematics is equally important in understanding physics, as we treated it in a separate paper (Karwasz, 2008). Here we discuss how cognitive teaching can be into didactical requirements: knowledge, understanding, applicability in typical and new situations, completed with social competences.

Recipes for Teaching Physics: Constructivism and Cognitivism

The crisis of enrolments in Physics, as seen in Poland, indicates that the traditional ways of teaching, still in majority based on chalk and blackboard, must be changed. The new didactical methodology should reflect not an *elite* mental abilities, but "common" ways of reasoning. Already in the first part of the 20th century Piaget (1928) and Vygotsky (1934) indicated that learning is not a *state* but a process of development of *spaces* for knowledge and successive filling-up these spaces: a child constructs his/her knowledge by him/herself. In the 60s (Berger, Luckmann, 1966) the con-structivism produced its social variation. Somewhat over-simplifying, the objective truth does not exist and the knowledge is constructed in social interactions as a kind of consensus. Although we do not agree with this conception, we show later that this methodology can be very useful in didactics, especially at the early-school stage: it triggers kids' and teachers' creativity, see (Trnova 2014).

The cognitivism was born also in the 60s, as described by Jerome Bruner (1990) from discussions among philosophers, psychologists, specialists in linguistics, information processing etc. J. Bruner writes that the aim of cognitivism was "to discover and to describe formally the meaning that human beings created out of their encounters with the world, and then to propose hypothesis about what meaning-making processes were implicated." (Bruner, 1990, p. 2). The study of processes in which the information is elaborated is the basis for pushing the algorithmic computers into an artificial intelligence. On the other hand, the cognitivism influenced significantly modern didactics, in particular physics: it is not only the scientific contents that should be taught. Teaching should consider also cognitive aspects – building up meanings and allocating practical functions to these meanings. Pedagogical Contents Knowledge (Schulman 1987, Viennot 2005) unifies a general scientific culture and pedagogical competences. Model of Educational Reconstruction (Duit 2005) considers three elements: i) scientific contents, ii) pre-knowledge of pupils, iii) learning environment. Unfortunately, theoretical indications for didactics not always find practical impacts.

Reforming National Systems

On the basis of new understanding of cognitive processes, contents of teaching physics have also been changed in many EU countries. In the Netherlands at the beginning of this century a ten-year reform was introduced. The reform substituted in school curricula the classical, law-like conceived physics by modern applicative aspects: in medicine, in communications, in microelectronics. At the leading UK e-learning institution, Open University in Milton Keynes, with some 200,000 students enrolled, the first-level physics is not divided into classical schemes – mechanics, electromagnetism and so on but immediately enters into the contemporary discussion on important issues, like "Global warming" (McBride 2007), "From Quarks to Quasars", "Life in the Universe".

Poland underwent a reform in 1999; it organizationally brought the division of elementary school into two levels and shortened the lyceum, introducing test-like exams at the end of each level. Visibly, the reform resulted in improving Polish PISA scores, but, as spotted even by Polish OECD experts, the improvement was only apparent: "Results are striking. Whilst the overall performance of Polish students improved significantly, the difference between students in vocational and other tracks remained the same and even increased for 17-years-olds" (Jakubowski, 2010, p. 25).

The structural reform in Poland was accompanied by the change in curricula in 2007: physics *de facto* disappeared from lyceum, substituted by general "Science". In this way, teaching Mechanics stops at the first class of the middle school. Pupils of the first class of all third-level schools (i.e., vocational schools, technical secondary) study only modern physics (atomic physics, gravitation, elementary particles, cosmology) within 30 hours. If compared to the UK, Polish system is "upside-down": general science - in lyceum and specific sciences, as physics, chemistry, biology – before.

Need for Cognitive Ideas in Teaching

A really weak point of Polish recent reform is that neither new teaching methods nor contents were introduced. Teachers' training is run by numerous local institutions, frequently without adequate expertise. Textbooks continue to copy old contents; no new laboratories were introduced, in spite of formal declarations in the 2007 ministerial "Program Basis". Poland is not the only case, which shows that the spirit of the EU indications for "inquiry-based teaching" is ill-understood.

Italy also undergoes these days (March 2015) a broad national school reform, aiming to increase the amount of foreign languages and informatics. The OECD studies (TALIS, 2009) showed that it is rather the attitude of teachers which has to be changed: Italian teachers are the most conservative in introducing cognitive recipes into teaching. In Poland teachers *declare* cognitive attitudes, but the highly centralized scholastic system does not favor constructivist school *practice.*

The two countries, Poland and Italy, show similarities in educational systems and approaches. Differently from the UK, Germany and Austria, the two systems are centralized and dominated by state schools. Both in Poland and Italy, the gymnasium is the weakest step in education. In both countries cognitivistic teaching is sporadic, compare (Crispiani, 2006) and (Siemieniecki, 2012). However, new forms of divulgation and contacts to schools, like interactive exhibitions and "Lauree Scientifiche", saved university Physics in Italy. Therefore, we concentrate on experiences in these two countries, as possible practical recipes for teaching Physics in quickly changing environments.

Two Recipes for Teaching Physics: Neo-Realism and Hyper-Constructivism

Teaching Physics by Interactive Exhibitions

Traditional methods of teaching Physics in Italy (and Poland) triggered in the late 90s, at University of Trento and then at Pedagogical University in Słupsk, a series of small, interactive exhibitions, see (Karwasz, 2000a). Primarily, those were small, simple "gadgets" that could be found in any souvenir shop, like plasma ball, Newton's cradle, balancing puppets, see (Karwasz 2004). Objects were organized in "nests", being at the range of visitors for interactive trials, see fig. 1a. Two first exhibitions in Poland were organized in Warszawa and Słupsk, in 1998, gathering several thousand of visitors in two weeks. Next year the exhibition has been invited to the National Congress of Polish Physical Society (Karwasz, 2000b). In 2003 three interactive exhibitions, including "Modern Physics" were presented at the Congress in Gdańsk (and in Warsaw in 2005). Practical pedagogical arrangements for these latter exhibitions were diversified (Kamińska, 2009): the exhibition on "toys" and on electromagnetism were targeted to teachers, see Figure 1b and "Modern Physics" - to university students and researchers, Figure 1c. The low cost of objects, simplicity in organizing, versatility of con-tents and variety of target groups make "Physics and Toys" a prototype for interactive exhibitions.

Figure 1: Different contents and different pedagogical approaches to interactive physics at authors' exhibitions.

a) "Physics and Toys" for broad public, Słupsk, 1998 – thematic nests with objects, b) National Congress of Physics in Gdańsk, 2003 "Volta and his pile" – didactical experiments in electromagnetism for school groups with teachers; c) "Modern Physics" for students and researchers. (Source: Authors' records)

Our "interactive physics" developed in a short time to nationwide and international initiatives. Within EU projects both "Physics and Toys" and "Modern Physics", were shown: in Trento, Paris, Berlin, Ljubljana, see fig. 1c. Science centers opened, in Gdańsk - "Hewelianum" in 2009, in Warsaw "Kopernik" in 2011. The latter in the first year hosted 1 million visitors. In spite of the great success, the number of visitors was hardly translated into a higher efficiency of teaching: objects were treated from a merely phenomenological standpoint (see Karwasz, 2012a). As it will be discussed later here, single objects do increase the teaching efficiency, but should be incorporated into more complex, school scenarios. Therefore, integrating physics with pedagogy is necessary.

Neo-realism: Go Beyond the Phenomenology of the Physical Object

As far as the cognitivism proved to be a long-term idea, the extremely rapid evolution in informatics and, even more, in the access to the global information (Google, Wikipedia, Youtube) changed proportions between *single information* and *structuring* the information. Pupils have an easy access to information, but the information is frequently uncritical. This blocks the will to learn: a kind of cultural shock is needed to trigger again pupils' *curiosity* about the external world. We propose two recipes, based on practical implementations.

The first recipe is to base the didactics on real objects, and back-up these objects by virtual mirrors. Real objects should be, if possible, small and simple, like "toys" (Karwasz, 2004). But this is not an object which is the center of attention, but a physical process or law. With two balls, rubber and ping-pong, we can show the independence of gravity acceleration of mass, but also air friction, and exchange of energy in collisions (see Karwasz, 2005a) or reversibility of time in classical physics. Real objects are starting points for teachers to construct their own scenarios. A gravitational funnel illustrates three Kepler's laws; but any funnel shows open orbits, therefore it is also useful to explain the precession of Mercury and introduce elements of General Relativity, see Figure 2. Broad conceptual analogies, constructed on a simple object aim to stimulate the imagination: a real experiment is the basis, computer modeling is the explanation, and a visual representation serves to reinforce the idea.

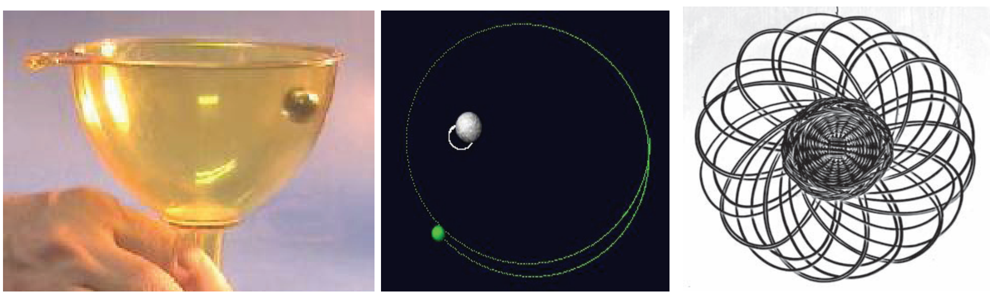

Figure 2: Neo-realism - any object is useful in explaining physics.
a) kitchen funnel as illustration of open orbits of planets in General Relativity, b) open orbits for non-Newtonian potential – computer simulation (M. Brunato, Trento University), c) ethnographic artifact made of wicker in Belarus (Collection: G. Karwasz)

Also Modern Physics can be shown with real objects: modeling Planck's black body by a box with a small hole, lasers mirror by semitransparent sun-glasses, mass spectrometers by shaking containers with various-size balls, see fig. 1c. Models can be completed with complex experiments, like measurement of temperature by a pyrometer, sun glasses by a real He-Ne laser tube, shaking plastic balls by electron charge-to-mass experiment. The idea of neo-realism is to explore real objects as much as possible, in order to illustrate complicated and abstract physical ideas. Collecting together simple objects, computer models, pictures, descriptions, video-clips contribute to the pedagogical idea of neo-realism: anything that students can touch or see they should touch, and even if objects are scientifically *impossible* to be visualized, like quarks or electrons, they should also be able to touch them, see our models in Figure 3.

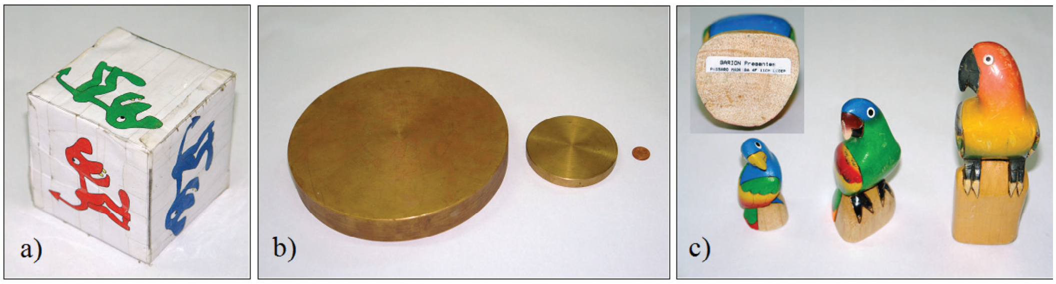

Figure 3: Neo-realism extrapolated beyond limits of imagination: typically atom, electron, neutron are shown as small balls; but like Earth seen from space, also neutron:

(a) made of two quarks *down* and one *up* has its own structure. b) assuming 1 euro-cent (Greek: lepton) as electron, *tau* is a big copper disk; c) alternatively we can imagine a neutron, proton and the heavier hyperon lambda as three-color parrots (Collection: G. Karwasz).

However, real objects and funny experiments bring a cognitive danger: visitors concentrate on appearance of physics, not trying to understand the mechanisms and to highlight the laws. So an opposite action must be undertaken: objects should not be touched, until the visitor is able to identify, *why* he/she wants to touch it. As resumed by Bruno and Munoz (2010, p.372) "Artifacts used in a specific situation need to be cognitively constructed by the subject." Again, not an object but the idea we need to develop is the priority. The mentor/ teacher should predict a *cognitive path*, on which students construct a proper knowledge step-by-step, based on own discussion (only guided by mentor) and with the whole group consensus. We call this method ***hyper-constructivism*** (Karwasz, 2011a) as it goes beyond Piaget & Vygotsky's psychological and Luckman & Bergman's social constructivism. The teacher defines the cognitive goal, and by asking *directional* questions, leads pupils to new knowledge.

Implementations

Cognitive innovations in teaching physics were introduced at Pomeranian Pedagogical Academy (PPA) in Słupsk already in the 90s of the last century. The Academy is the only pedagogically-oriented high school in the region of Gdańsk, with almost 2 million inhabitants. The first forms were interactive exhibitions: on educational software (1997), on interactive physics - "Physics and Toys" in 1998 and "Modern Physics" in 2003. Successively more complex, interdisciplinary exhibitions were developed at Nicolaus Copernicus University (NCU) – a monothematic, itinerating art-and-physics collection on optics "Fiat Lux" in 2008 (Karwasz, 2010a) and a sequential pathway of discovering mechanics on Galileo's incline plane "Going downhill".

The "Going downhill" exhibition, possessing a very clear didactical scenario, - from laws of the free descend to energy-conservation laws, kept its educational function well hidden. Far more important was to involve children into a free playing with physics. As seen from fig. 4, depending on the kind of the exhibit, children organized themselves into groups with clearly divided functions: the physical objects trigger social interactions – learning by playing. A measure of the "Going downhill" educational success is that, in spite of the professional science center recently born in Toruń, this exhibition is permanently required in different variations – as small playgrounds for pre-school children, as labs for UniKids students, as interactive stands during Science festivals and so on.

Figure 4: Sequential discovery pathway – "Going downhill or everything on Galileo's inclined plane, in other words, how potential energy changes into kinetic and how one can play with it.", corridor of Didactics Physics Division, NCU 2007.

A social interaction in learning physics: a) explaining how the descending "bird" works, b) a four-stand competition – whose ball will fly further?, c) "speedy wheels" play for 4-year olds. (Authors' resources, photos taken at NCU premises, with agreement of educators in charge)

The idea of interactive exhibitions is that a visitor can construct his/ her own path in learning physics (Kamińska, 2008). However, as already mentioned, the educative results of such actions are somewhat limited: a broad spectrum of visitors does not allow preparing specific lessons. In order to influence school curricula, several other, targeted actions were undertaken. EU Leonardo da Vinci Project "Minds-on experiments on electromagnetism and superconductivity" (MOSEM) scientifically coordinated by NCU (Karbowski, 2008) was intended to produce a series of simple experiments that were tested in Poland and Italy (Viola 2009). Additionally, as an indication for constructive ways of teaching within the recent Polish reform, two experimental textbooks were prepared at NCU – "Mechanics" for lower secondary school (Karwasz, Sadowska, Rochowicz, 2010b) and "Modern Physics" (Karwasz, Więcek, 2012b) for upper secondary school. All these actions in Poland are still under testing – in the following we describe the main methodological concepts and some qualitative evaluations. First, we describe different forms of introducing cognitive physics, later – we sketch some evaluations of didactical efficiency of these forms.

Simple Interactive Experiments: "Physics and Toys"

The advantage of simple objects is that they can be collected by any teacher, being cheap and available in many variations; see (Kamińska, Karwasz, 2008, Karwasz, 2005a). Detailed descriptions of these objects were made available on PPA and NCU sites, contributing to their rapid spread. Partially thanks to it numerous similar exhibitions were organized all over Poland and several "toys" were incorporated into science centers. The virtual exhibition has two versions – one with more objects, better described physically but only in Polish (Karwasz, 2004) and an international version (Karwasz, 2005a) with 96 objects, in 5 languages, better organized didactically. In the latter version, objects, apart from being divided into mechanics, optics, thermodynamics, electromagnetism, are grouped into classes of four, with a rising level of difficulty. In mechanics, in the subsection "equilibrium" initially, point-like objects are introduced then objects with continuous mass distribution but still static, then object oscillating but suspended in one point (i.e. physical pendula) and finally, objects making complex oscillations, see Figure 5.

Objects from "Physics and Toys" were used in different types of lessons performed at different, even university, levels. They have been incorporated into other activities: to prepare complete cognitive sets of school experiments on chosen subjects like electromagnetism (Karbowski, 2009a), to teach specific ideas (like "energy") in extra-scholastic activities (Karwasz, 2011b), to improve teaching efficiency at secondary schools.

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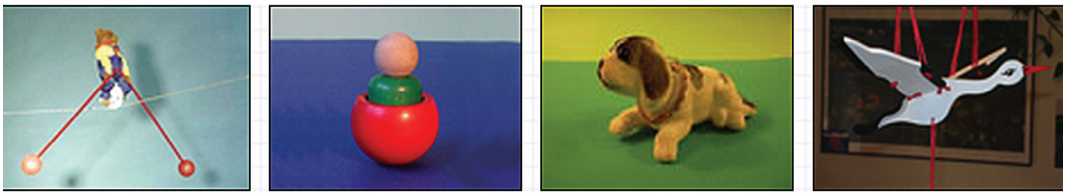

Figure 5: Simple didactical objects organized in a sequence of rising *difficulty*: from equilibrium of point-like puppet (a), through a continuous distribution of mass (b), to oscillation of complex bodies (c, d). Collections and photos: (Karwasz, 2005a)

Minds-on Experiments in Electromagnetism: Collection of Experiments for Schools

MOSEM concentrated on electromagnetism – 44 experiments on static magnetic fields, on interactions between electrical currents and magnetic field, on the electromagnetic induction (Karbowski, 2009a) were developed. Differently from "Physics and Toys" collection, MOSEM objects were organized "spatially" rather than conceptually, see fig. 6. Unfortunately, descriptions were prepared only in Polish (and partially in Italian) what hindered the diffusion of results; only few experiments have been exploited in separate publications (Gołębiowski, 2009). This, as discussed below, caused rather poor didactical efficiency. More precisely, experiments organized in cognitive paths showed a better didactical outcome. This was, for example, the case of different methods of visualizing magnetic fields: with a magnetic fluid, with the fluid between transparent foils, with iron fillings, with iron scratches, with children "magic screen", see figure 6a, and the case of the electromagnetic induction, see figures 6b-6d.

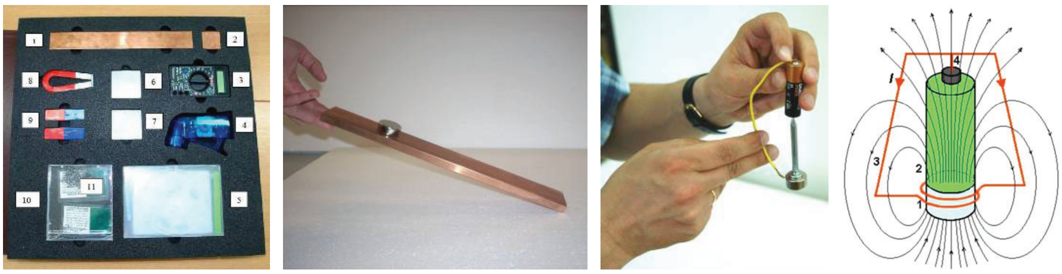

Figure 6: Developing simple objects into laboratories for schools (MOSEM Project, NCU).

A) Well-organized experimental kit – three types of magnetic-field visualizers, magnets, thick copper bar, hand-dynamo; b) electromagnetic induction: a neodymium magnet sliding on the bar; c) a simple electromagnetic engine and d) its explanations. (Source: Karbowski 2008)

MOSEM experiments have been produced by NCU for 7 countries taking part in the Project (Italy, Poland, Austria, Czech Republic, France, England) and tested in different environments. Later in this paper we describe didactical results relative to Poland and Italy only, as the two countries show some common features of educational systems, as outlined above.

Thematic interactive exhibitions: "Fiat Lux!"

A thematic exhibition, dedicated to optics, "Fiat Lux! Playing with light. From Witelo to the optical tomography" was developed in 2008 in collaboration with the Regional Museum in Toruń. „Fiat Lux" conjugated the history of science (Witelo, Kopernik, Galileo, Kepler) with modern achievements of optics (scanning tomography for ophthalmologic diagnosis), simple interactive objects - with scientific posters and computer presentations, didactical sets for adding colors - with impressionists' paintings, science - with humanities (Karwasz, 2010a).

Figure 7: "Fiat Lux!, From Witelo to optical tomography" interactive, interdisciplinary exhibition (Karwasz 2010a) on optics.

a) interactive lenses, telescopes, playgrounds with colours and didactical posters inside the medieval Town Hall in Toruń; b) cat's profile inside a glass cube with different projections on two walls is used to discuss „Schrödinger's cat"; c) elementary school pupils studying spontaneously the colors with diffraction glasses (Source: Authors' resources, photos M. Karwasz)

"Fiat Lux" tries to transmit science to "humanists", as frequently persons who do not love mathematics define themselves. This exhibition is a partial answer to the Polish reform, which excluded physics from teaching in non-science lyceum classes. Therefore, when speaking about the 3D vision, we show both physics and Picasso drawings from his cubism period. While explaining the 3D perception – we do not speak about brain functions but we cite the medieval treaty by Witelo and his Aristotle-like expression on the "judging function of the human soul".

"Fiat Lux" in 5 years had 20 editions, in regional science centers, arts and ethnographic museums, with some 80,000 visitors. Fig. 7 shows the first edition, in the medieval cellar of Toruń Town Hall, an example of interdisciplinary item (Schrödinger's cat, visible from two profiles at the same time) and the exploring, spontaneous behavior of pupils of lower secondary school.

"Why do Objects Fall?" Interactive Lectures for UniKids

"Going downhill" exhibition used extremely short, few-word descriptions of experiments, in order to avoid overloading the visitors with information. However, the contents of physical ideas in this exhibition allowed using the same objects in interactive lectures for children. The inclined planes, and falling balls, see fig. 8, are used to construct a lesson on the energy conservation law (Karwasz, 2011b). A heuristic, step-by-step reasoning, guided by the lecturer discusses the question "why do objects fall?" The typical answer – "because of gravity" is a tautology, as "the gravity is the Earth's attraction" and this is caused by the gravity. An alternative answer would be that given by Aristotle: "objects fall because they are heavy and the *natural* place of heavy objects is the center of Earth."

At this point, in the spirit of neo-realism, we ask, if objects can jump spontaneously, like in telekinesis. In spite of collective efforts, see fig. 8b, the ball does not jump up. So, the crucial experiment enters: if the ball is allowed to roll down freely on the curved guide, it climbs up on the opposite end of the guide: a kind of miracle! Children discover the energy conservation principle. By analogy, objects fall because they possess energy; we call this energy *potential*. A good theory explains additional phenomena: it is enough to launch "energetically" the ball towards the floor and it will jump into ceiling! As compared to other approaches, see for ex. (Bécu-Robinault, 1998), this is not only adding experiments to teaching, but a step-by-step, social dialog with the audience.

Figure 8: Hyper-constructivist learning path, using real objects and collective discussions, "Why do objects fall?"
a) inclined planes, carts, balls and a bent guide for them, to illustrate energy conservation law; b) joint efforts in telekinesis "Jump up, ball!" do not help much; c) "Yes! They really roll down with the same velocity, independently from the weight". "Lessons for Kids", Universities in Brzeg, Gdańsk and Leszno. (Scenarios and lectures: G. Karwasz, photos Maria Karwasz).

Anticipating didactical results we stress high efficiency of the interactive teaching in introducing, from "scratch", the basic notions on laws of kinematics and dynamics. A more formal discussion on the concept of energy has been presented elsewhere (Karwasz, 2010d).

Computer-aided Experiments

The Polish Physical Society, aware of problems with didactics, in 2007 established a special commission for development and introduction into schools of computer-aided experiments (Karwasz, 2009b). In Toruń, every December an international workshop "Computer in school science lab" is held, with the aim to bring together teachers, students in physics education and scientists. From technical point of view, different standards (PASCO, Vernier, Texas Instruments, National Instruments, LabView, Amsterdam Coach") are tried; from didactical point of view – the search for a high educational impact is discussed and teachers present their own experiments.

One of the examples is the third law of Newton. Teaching this law is somewhat mysterious: do the two forces act at the same time? Are they really equal? In the experiment developed at NCU (Sadowska, 2009) two PASCO force sensors are connected to the same interface. The experiment is done in two versions: i) first, the student pulls in opposite directions two carts posed on a friction-free rail; ii) later, the carts are positioned on a rough-surface wooden axis and only one cart is pulled. In the first experiment the forces vary gradually, in the second – by rapid jumps. In both cases the two forces are perfectly equal in any moment, see (Sadowska, 2009). The experiment was tested in secondary schools – the results are shown in successive paragraphs.

Constructivist Text-books for Secondary Schools

With the hyper-inflation of information, a modern textbook must refrain from giving notions, and avoid filling students with non-necessary details. A constructivist text-book must be a kind of narrations, where the reader is pulled inside a story on physics. It also must be a continuous surprise for the reader: showing physics in many different phenomena, i.e. relating physical laws to the external world. Examples from the textbook on mechanics for gymnasium are shown in Figure 9.

Figure 9: Constructivistic textbook for gymnasium: unknown states of matter (even if commonly present) – glass window in Cluny, liquid crystals in cell-phone screen, "jumping" plastelline – silicon, non-Newtonian liquid, sipping liquid – polymer with ultra-high viscosity, TiNi memory alloy. Source: (Karwasz, 2010b).

Qualitative and Quantitative Evaluation of Didactical and Heuristic Results

Simple experiment "Toys and Physics" in lower secondary school

An unexpected diffusion of "Physics and Toys" collections into numerous school laboratories, regional and national science centers, proved their didactical attractiveness. Evaluation of the use of simple experiments was tested, among others, at a gymnasium (lower secondary school) at Nożyno, that is, a village 40 km from Słupsk and in a lyceum (higher secondary school) in Słupsk. Three methods of teaching were compared: i) a traditional one, with a textbook and some experiments done by the teacher, ii) with multimedia (computer animations and films), iii) with experiments performed by pupils themselves. Two lessons were prepared. The lesson in the gymnasium was on electrostatics: in the experimental class pupils tried to charge plastic bars and measure charges with an electroscope. The lesson in the lyceum was on the electromagnetic induction. The experimental group used a hand-dynamo from MOSEM, a plasma ball, interacting magnets and a magnetic perpetuum mobile (i.e. two oscillating balls, driven by a hidden electromagnet) from "Physics and Toys", see Karwasz et al. (2004).

Results are somewhat unexpected: with the same teacher and the same methodology, a much higher improvement with experiments was achieved in the gymnasium – by about +40% as compared to multimedia and traditional classes (left panel in Figure 10).

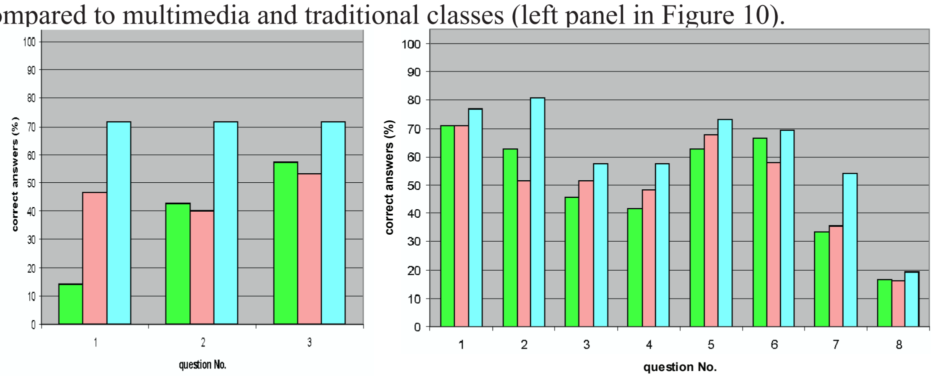

Figure 10: Simple hand-on experiments in teaching electricity and electromagnetism in Polish gymnasium (left panel) and liceum (rigth panel). Comparison of traditional (left bars), multimedia (middle bars) and experimental (rigth bars) classes: as far experiments in gimnasium bring significant improvement of knowledge and understanding, experiments done in lyceum were not much effective – probably objects chosen were not didactically significant (Source: A. Kamińska)

In the lyceum all three groups performed similarly well, at 40-80% of correct answers, with the experimental group being slightly (10-20%) better (apart from question 8, on the force acting on proton in a magnetic field – neither experiment nor multimedia were presented). Note that the initial level of knowledge in the lyceum was very low – only on two questions the correct answers were about 30% and on next 5 questions – less than 10%; no significant differences were observed between the three groups in pre-tests. This research was based on limited (groups 15-17 students at gymnasium and 24-28 in lyceum) and was used as a starting point for development of more complex, blended approaches, like MOSEM Project.

Experiments in Electromagnetism: Effectiveness in Secondary School (Italy)

Extensive studies of effectiveness of MOSEM experiments in primary, lower and higher secondary schools in Italy were performed by Rossana Viola (Viola 2009). Artifacts generally triggered interest of pupils, particularly at the elementary school. Viola, studying the sample of 220 students identified, how pupils spontaneously develop specific concepts, starting from magnetic forces (age 6-7), magnetic poles (7-9), and magnetic fields at the age of 9-10 (Viola 2009, pp. 77-98). In those experiments pupils used a whole series of complementary artifacts from MOSEM collection: compasses, bar magnets, iron balls, matrices of compasses, iron fillings, field indicators, see (Karbowski, 2008). The high efficiency and correctness of pupils' interpretations has to be attributed to the extensive character of the laboratory equipment.

In the case of secondary school (15-years olds), the results of test on teaching electromagnetism were not so excellent. Viola (2009, p.120-121) chose 10 experiments on the interaction between currents and magnetic fields, among others those on "eddy currents" and magnetic engines, shown in figure 6. The interpretation of phenomena, although it was not considered wrong, does not report the very nature of the interaction between magnets and eddy currents, i.e. Faraday-Lenz- von Neumann's principle. For the neodymium magnet sliding on the copper bar, see fig. 6b, seven students gave the interpretation as an attractive (static-magnet like) force, 9 students interpreted the slowing as the interaction between generated magnetic poles, 8 – as the induced currents (but not showing forces) and only 2 as the force opposite to the direction of movement (Viola 2009, p. 129-132). Similar, rather not convincing interpretations were given for the attenuated motion of magnetic pendulum and the magnetic engine.

These rather disappointing results have to be attributed to the lack of the "teaching path" that was elaborated (Karbowski, 2009b) only after Viola's didactical testing was performed. The efficiency of this new path is still under testing.

"Fiat Lux!" - Visitors' Impressions

Testing didactical results within an exhibition which is a mixture of physics, science history, philosophy and arts (cubism, impressionism) is not easy. Even if particular lessons on geometrical or wave optics were organized for individual school groups, the main goal of that exhibition was to "open eyes and minds": the action was based on the fascination rather than on reasoning. Any pre- and post-test would spoil the expected outcome. Therefore, we based the evaluation on the visitors' book, where they were invited (not forced) to write their opinions.

Some records in the book of visitors at "Fiat Lux" are worth being cited: "- We learned more on optics in 45 minutes than in whole our life" (a couple of adults from Argentine).

"- I'm a student of the 5th grade and I think that the exhibition is very cool, but the best part was that we could touch every pieces of exhibition"

"-My kids were fascinated by this exhibition - great idea!"

"- Awesome exhibition!!! There are so many interesting things I've never known since this exhibition. COOL - Aśka 12 years old".

PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Volume 64, 2015

Evaluations from adults were generally very positive, and clearly referred to their experience.

„-Wonderful exhibition, it reminded me my school times and extraordinary experiences during experiments on physics and chemistry lessons. Thank you!"

Reviews from foreigners were very positive, but also revealing that this exhibition was not the first that they visited:

"-This is brilliant. Thank you for your thorough explanations. David, London".

"- I have seen better but other than that it was really good"

The shortest review was made by a man, probably unemployed, who was visiting the exhibition accidentally: "Mister, How it's interesting! My head's spinning!

Resuming the impact of interactive exhibitions, like "Fiat Lux" and "Physics and Toys" we note, that these are perfect places to perform didactics, but only with a teacher that is previously prepared. Professional guides from science museums are not able to adapt the narration to the needs of every school group. Exhibitions play a role of a "hook" in catching the cognitive attention of pupils, but do not assure the didactical output. However, the success of science centers on the national scale in Poland, all developed in-between 2009-2011 show that the idea of interactive physics is highly attractive.

"Why do Object Fall? - Free-hand Records

Highly inhomogeneous groups of children (usually 1/3 of them are 5-6-years-olds, with no writing abilities and about 1/3 are 11-12-years old, knowing the notion of "gravitation") make UniKids lectures particularly challenging, see (Karwasz, 2014). Again, as in the case of "Fiat Lux", the main goal of such a lesson is to trigger children enthusiasm for physics, and not to substitute school curricula. However, tests performed in two groups half a year after lectures indicate that children almost perfectly report main points of the lecture. Some of them remembered the whole scenario (figure 11a) but majority of young students reported "clue" experiments: the inclined guide with the ball climbing up (figure 11b), the transfer of energy in collision of two falling balls (figure 11c). The oldest girl (12 years) made the best resume': objects move because of energy!

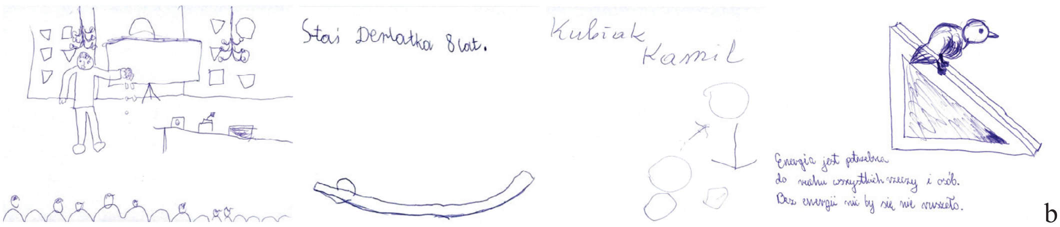

Figure 11: "Draw what you remember!" from the lecture „Going downhill" for UniKids in Brzeg and Namysłów, four months year later: a) an accurately reported show of experiments (8 years old); b) the most important experiment: the introduction of the energy conservation principle c) spontaneously reported vectors representing of the experiment of colliding balls (8 years old); d) the essence of the lecture – „ Energy is the cause of motion of bodies" 12 years old girl (source G. Karwasz).

III Newton's Law with Computer-aided Experiments: Tests in Lyceum

A wider introduction of computer-aided experiments into schools finds an economical barrier: schools being governed by local authorities receive very small funding for laboratory equipment. Therefore, testing is possible only on the basis of collaboration with universities. An example of tests performed by PAP Słupsk in a lyceum (2nd class – 16-years aged, 17 persons) is shown in Figure 12. The test on mechanics consisted in two arguments: 3rd Newton's law and conservation of energy. Both subjects were explained to pupils in June, and a test performed shortly after. Questions 1-4 (see Figure 12) and 7, 8 concerned identifying acting forces, other questions – defining the potential and kinetic energy.

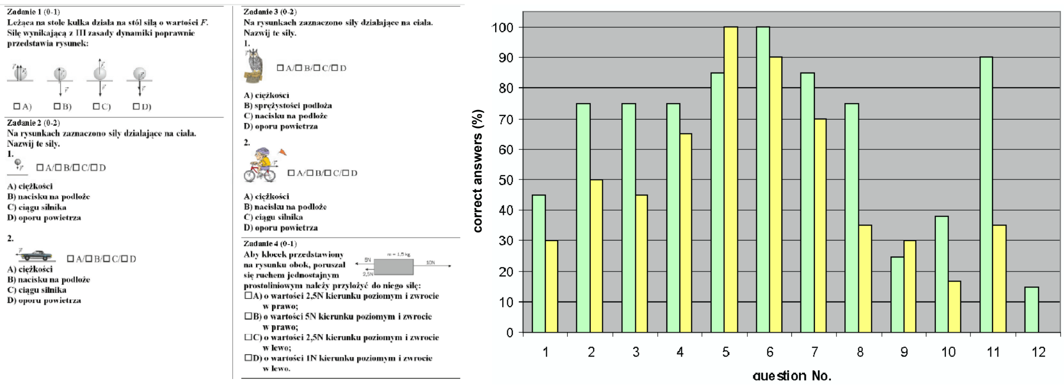

Figure 12: Test on computer-guided experiments in III Lyceum in Słupsk. Left panel – first four questions, those on Newton's 3rd law; right panel – comparison on number of correct answers in experimental and control groups: experimental group (using Coach system to perform experiments) left bars (lighter), control group – right bars (darker). Source: AK

Computer-aided experiments allow not only to explain more clearly difficult concepts of physics, to project new experiments, to visualize complicated mathematical dependences in real time, but also to develop skills of working in group and abstracting from the "hardware" experiment into the world of virtual representations.

Testing Constructivist Text-books: Mechanics, Gymnasium

Tests of "Toruń text-book Mechanics" for lower secondary school were performed, in independent works, by M. Sadowska (2012) and K. Wyborska (2012) in the schools in which they teach. That was a middle size town (Kalisz), and a village (Dąbrowa Biskupia), collecting children from a wide neighborhood (about 200 students in classes 1-3), respectively.

K. Wyborska (2012) tested two subjects "Energy, work, power", and "Kinematics" using "Toruń text-book" and another textbook from a well-established national publisher. Questions were divided into three categories: knowledge, understanding, abilities to use in typical and problematic situations. Synthetic results are shown Figure 13. Whereas, in the experimental group the percentage of positive results of testing was 81% (and the mean score 2.31) it was only 56% (1.75) using the traditional text-book. A particularly high rise of efficiency was obtained in knowledge and in usage of knowledge in problematic situations (almost 50% rise of positive answers). An even better result, almost 100% positive answers (and the mean score 3.54) was obtained in the subject of kinematics (mean score in control group 2.43), Figure 13d.

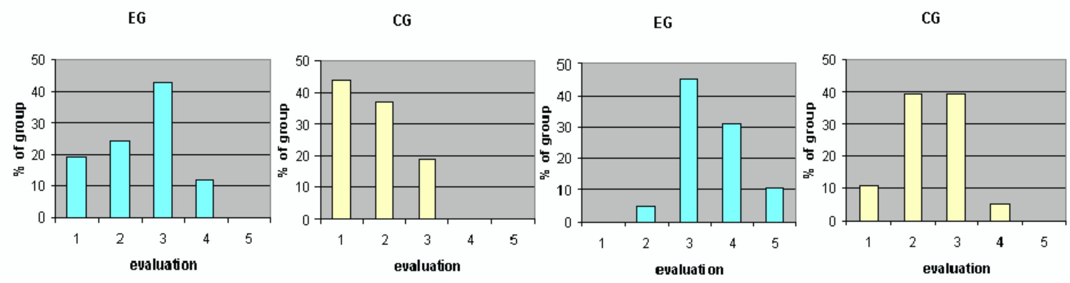

Figure 13: Comparison of experimental (EG) group using "Toruń text-book") with control group (CG) using a traditional text-book: the scores in EG groups are significantly higher that in CG, and with much uniform distribution. Left panel – test on energy, right panel - kinematics (Source: Wyborska 2012, p. 57).

Also, the textbook on "Modern Physics" (Karwasz, Więcek, 2012b) received a positive opinion. Sadowska in 2013 (private correspondence) writes: that "the most striking feature of 'Modern Physics' is the narration, which guides the reader through a fascinating world of physics. This is not only an interesting presentation of facts, definitions and formula, but references to the external reality, objects of every-day use, information from media. The knowledge is presented in a way interesting both for science and humanity classes."

Conclusions

A number of strategies that authors developed on the edge of XXI century and tested in Poland and Italy have been discussed. These were: - i) simple, portable experiments, ii) experimental sets for schools, iii) itinerary, interactive exhibitions, iv) narrative text-books, v) computer-aided experiments. Some of these actions showed a significant improvement of the efficiency, some of them an overall high efficiency, some – a low efficiency and an insignificant improvement. The outcome was strictly related to completeness of the didactical path prepared: not only objects, but also clearly defined goals and detailed scenarios.

A somewhat surprising success of interactive exhibitions, like "Physics and Toys", that in 10 years "exploded" to national-wide science centers, shows that new forms of teaching are desirable. But this result is only a preliminary condition for improved teaching – at the same time only 4% of student chose physics at the maturity exam. With science centers physics is already "fun", but still not clear and not mentally involving. Careful elaboration of sector by sector, as we did in "Mechanics" or "Modern Physics", training of teachers, manuals for simple experiments, integrating school laboratories with computers – all these are steps in re-gaining the cultural attractiveness of physics in XXI century societies.

Two actions brought excellent results: - tests on magnetic field in elementary schools in Italy (Viola, 2009); ii) „Toruń" textbooks for gymnasium (Wyborska, 2012). In both cases *cognitive* paths were rather complete, even if of a different nature. In teaching magnetic fields it was a complete set of experiments, with various magnets and field visualizers. In the case of the cognitive textbook, it was an extended narration – a dialog with the reader, with many practical examples and linking the mathematical formula to written communication.

Important for long range socio-economic targets are permanent, not temporary and partial improvements like PISA tests. In this sense, a success of national science centers in Poland has not been translated into improvement of scholastic efficiency: changing the ways and contexts of teaching physics in gymnasium is urgent. As shown by OECD predictions, educational reforms are necessary, both for Italy and Poland. New methods and contents shown in this paper should become a part of a broader, international discussion.

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PROBLEMS
OF EDUCATION
IN THE 21st CENTURY
Volume 64, 2015

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