ENERGY – HISTORICAL, INTERACTIVE AND PEDAGOGICAL PATHS

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ABSTRACT
Should be elementary school pupils more wise than Aristotle was? If not, let's start from his statement that heavy objects fall towards the centre of Earth. Also Galileo was saying that objects fall down, but why? If, by a double, down-and-up inclined plane we show: first, that objects not only fall down but, second, that they also come back, than it becomes intuitive that they posses a special quality. Let's call this quality "energy". Now, we can play not with objects, but with this special quality. An intuitive, strictly sequential path, was constructed inside a long corridor, with about 40 interactive objects, with growing conceptual complexity (friction, rotations, moment of inertia etc.). We tried it during Science Festival with elementary school pupils. At the end of the path, everybody, including university professors, made their own discovery: energy. Teaching "energy", even at the very basic level of knowledge in Physics, proved be possible.

KEYWORDS
Energy, interactive experiments, Galileo's inclined plane

1. Introduction

When we ask a pupil (or a teacher), why objects fall, they answer "because they are attracted by Earth". Then, for the following question "- And we they are attracted?" the usual answer is "Because of the gravity". "-And the gravity?". "The gravity is a general force making masses attract." With these three questions we close the loop of the tautology: "Objects fall because are attracted by the gravity and the gravity is the force attracting objects".

With modern physics we can go further, saying: "Object fall, because they follow geodetic lines, and these are towards the center of Earth as this makes the space-time curved." It does not help much, neither "two masses do attract as they exchange gravitons (bosons with spin =2). The ancient explanation by Aristotle "object fall as they are heavy and the natural place of heavy objects is in the centre of Earth" is almost better. An unexpected help can come from the idea of "energy", but first let us discuss its historical development.

2. Historical path

The term „energy" comes from Greek. The word „wergon" meant English „work". Later it changed to „en-erg-eia" and evolved to an abstract meaning. Aristotle used the term "energy" (ἐνέργεια) as the principle determining the motion. However, he (or the modern translations [1]) was confusing the meaning of the power (*potenza, dynamics, δύναμις*) force, momentum and energy. Aristotle seemed to be far from using the term "energeia" as the reason for making the objects fall. For Aristotle, following the principle of teleology, the heavy objects fall as their natural place is in the center of Earth [2]. We will come to this problem later.

The bizantine philosopher Joannes Philoponos (500-560 AD) supposed that the reason making objects fall was the "kinetic force" acquired from the human hand. First separations of concepts of the energy, force and momentum (impetus) come from Middle Ages (St. Thomas and Buridian). This latter (and in following also Copernicus) noticed that the steady motion does not require a force, and introduced clearly the principle of inertia. Modern formulations of the principle of inertia and the conservation of momentum come from Descartes and Newton; but still without the proper identification of "energy".

The step-by-step distillation of the terms leading to the concept of mechanical energy includes the works of J. d'Alembert, Jean Bernoulli, Danish scientist Jeans Kraft and later Lagrange and Laplace. Only in 1860 thanks to works of Carnot, Joule and others the principle of energy conservation in the Universe was formulated by Clausius. At the same time, the distinction between the heat and useful energy was established in the second principle of thermodynamics, Finally, in 1855 the Scotish engineer Rankine defined the energy as "the capacity of the object to perform the work" [3]. In late XIX century thanks to works of E. Mach the mechanical energy was divided into the kinetic and potential. But soon the concept of energy was generalized into the concept of mass by Einstein in the $E=mc^2$ equation How can we teach all this to elementary school pupils? The recent Polish CV proposal says "in intuitive way" [4]. We agree, but how?

Extensive studies of concepts used by students revealed that they tend to use frequently pre-scientific meaning of energy, "which have strong roots in every day language and experience" [5]. As stated by van der Walk et al. [5] "these frameworks are not simply replaced by the physical energy concepts during instruction, but remain present […] giving rise to conceptual teaching problems" [5]. Van der Walk et al. accept therefore, unwillingly, different ways for teaching energy as fuel (the casual agent), consumable (i.e. chemical energy), or a storage good. This seems the most common approach, substituting "energy" with "alternative energy" or "renewable energy", and deviating somewhat from the physics meaning of kinetic, potential and so on energy.

A different approach has been proposed by Papadouris, Kyratsi and Constantinou [6]. In alternative to energy "as the ability to do work" [6] they propose the concept of energy "as a model that accounts for changes in certain physical systems". We will come back to this concept after describing our didactical experience. This experience follows somewhat the construction of the scientific concept of energy as outlined also by Trumper [7].

3. Intuitive and interactive path

The tautology described in the introduction is highly deleterious, as we miss teach the gravitation, the accelerated motion, and energy, what would be possible with a more careful approach. From the point of view of pedagogical clarity, it would be much better to use Aristotle's the "natural place" as the reason for the motion. The need for new teaching of the kinetics, not starting from the path, then velocity as the derivative and then acceleration but vice versa was discussed at 2007 GIREP by I. Lawrence [8].

By coincidence, we came to the same conclusions in the same time. In April 2007 at University of Nicolaus Copernicus in Toruń, we experimented a whole didactical path [9], consisting of about 50 interactive objects, all dealing with the inclined plane, see photo 3. We tried to invert the traditional teaching of the inclined plane as *sin* and *cos* (students usually mix them) or Galilean "odd numbers (*numeri caffi*) of the path in following time intervals". [This latter is in fact just a mathematical coincidence $(n+1)^2- n^2= (2n+1)$.]

During experimenting, different objects showed different level of amusement but some turned out to be extremely useful in constructing the didactics path on energy. The key object turned out to be just a piece of path, slightly lower in the centre, see photo 1. Teaching energy turned out extremely easy, just in few steps, and spontaneous, not requiring other notions. Here are the steps:

1) First we take a ball and let it roll down the inclined plane: both explanations, that of the gravity pulling the ball down and that of Aristotle, with an intelligent ball tending down are plausible.

2) Than we take another trajectory – a guide starting and ending at the same height and lowered in the middle, see photo 1. We repeat the experiment, letting the ball roll down but we stop it in the lowest point. The pupils asks "Why have you stopped it?" – „Because it should go down, this is his natural position!" Obviously, pupils protest.

3) Then we take the ball, whisper on it saying:- "I give you a fantastic feature: energy. Go down and come back!"And that's the end of the lesson. It explains both going down and up of the balls: these are simply transformation of energy. The whole path is constructed as an interactive exhibition, with as many as 50 objects – inclined planes with and without friction, rolling empty and full rings, Maxwell's and Newton's pendula – all governed by the conservation of energy. All these objects are unified by a short label: "going downhill by rolling, jumping, steps, sliding and so on". Rigorously three-word description, not more.

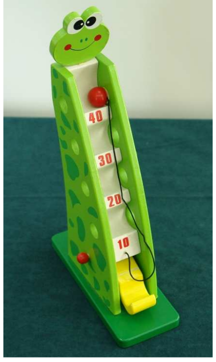

Photo 1. A simple experiment introducing the concept of energy, as the cause for the motion. See tect for explanations.
Photo 2. A wooden play introducing the concept of the potential energy: more kinetic energy given to the ball from the launch hook, higher the final potential energy.

In another exhibit, from a shop with wooden toys in Karlsruhe, see photo 2, the potential energy is defined intrinsically. With another object, the horizontal guide ending with a rising path, son of one of us (AK), at the age of 2 years played for an hour, amazed how a ball launched up on the inclined plane comes back punctually with the same velocity. He discovered the conservation energy a the age of two!

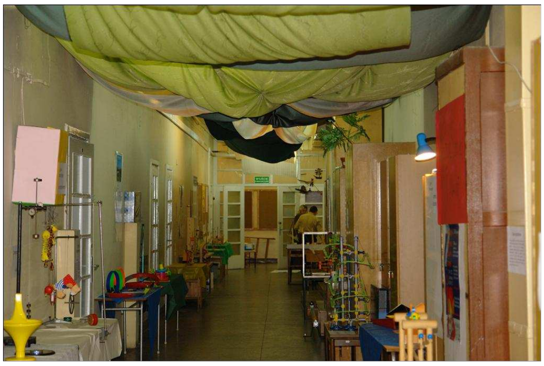

Photo .3. A didactical path on energy and Galileo inclined plane: about 50 experiments in Physics Institute UMK
Photo 4. “Ski-jumpers” – an interactive play on energy and the launches.

4. Heurestic and pedagogical aspects

Using an intuitive and interactive educational path stimulates the learning activity. A direct relation exists between spontaneous manipulations, formulation of hypothesis on the behaviour of objects and their physical features, up to fully intuitive formulation of the laws of Physics. The interactivity and the possibility of independent exploration create conditions for emotional involvement, which activates all learning abilities of pupils, concentrating their attention and giving a deepen dimension for the acquired knowledge.

Activities that valorize learning at interactive exhibitions resemble closely the scientific research. Their common features are: searching and discovering by poli-sensorial activities and experimenting by continuous formulating and testing hypothesis. Such an example is testing the law of conservation energy with the “ski jumper inclined plane”, see photo 4. The experiment was projected as a competition between four launchers. Obviously, the range of the launch was determined not by the skills but by the choice of the launching path. Children discover step-by-step, but quickly, the relations between the range of the launch and: 1) the point of departure, 2) the angle of launch, 3) the mass of the ball (?). The participant learns to predict the behaviour of the ball, confirming or denying his/ her intuittions, trying to understand the physical laws, as he/ she formulates it n the process of the discovery. Such an experience for sure will stimulate further learning activities and will deepen the knowledge acquired.

5. Conclusions

The richness of meanings for „energy" and the bibliographic record on it make difficult unique conclusions. Without any doubt, the attributing to a physical body an abstract feature, almost spiritual at the first glance, but at the end rigorously mathematical one, called energy, does not exceed the comprehension capabilities even of small children. We avoid in this way "and intuitive understanding of energy", as proposed, for example in recent Polish Ministry of Education proposed cv for secondary schools [4].

On the other hand, not all forms of energy "can perform work", as in the definition of Rankin (which we still consider the best). The thermal energy, or better the heat, as follows from the second principle of thermodynamics, not always (and never in 100%) can perform the work. Even we limit the definition to the internal energy (U=kT) or free energy F=U-T*d*S, this "energy" can perform the work only in the case of the difference of temperature with the environment. The reason is, that this (thermal) energy can not flow to another (higher temperature) reservoir. The similar situation is with the relativistic energy: the mass have to decay or annihilate to something else, like photons, in order to be useful.

In this way we come back to the proposal by Papadouris, Kyratsi and Constaninou [6], to stress the aspect of energy as "a flowing agent". The energy appears, if objects exchange it. This makes objects fall, when they are free to change their potential energy to kinetic one, and hitting the floor to produce the heat. At the end, this is not far from Aristotle's meaning of energy, i.e. the reason for bodies to move!

Acknowledgements

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References:

[1] Aristotele, Metafisica, Bompiani, Milano 2000, p. 395.

[2] Aristoteles, De celo, Polish translation, PWN Warszawa 1980, p.148.

[3] Holton G. Introduction to Concept and Theories and Physical Science, Addison, Warley Publ. Company Inc. Massachusetts, 1952.

[4] CV Reform in Poland (Reforma programowa), Ministry of Education Proposal, July 2008, http://www2.reformaprogramowa.men.gov.pl/?redirect_count=1

[5] A. E. van de Walk, P. L. Lijnse, R. Taconis, H.F.H. Bormans, A Research Based Strategy for Teaching about Energy", in Energy Education, Proceedings of the International Conference on "Energy Alternatives / Risk Aducation, Lake Balaton 7-13.09. 1989, ed. by G. Marx, National Centre for Education Technology, Veszprem, 1989.

[6] N. Papadouris, Th. Kyratsi and C. P. Constantinou, Student Understanding of Energy as a Model that Accounts for Changes in Physical Systems, Teaching and Learning Physics in New Contents, Proceedings of GIREP 2004 Conference, Ostrava 19-23.07.2004, ed. E. Mechlerova, University of Ostrava, p. 183

[7] R. Trumper, Energy and a constructivist way of teaching, Phys. Educ. 25 (1990) 208-212

[8] Acceleration wrought again, I Lawrence, GIREP 2007, Invited Lecture, in press

[9] G. Karwasz and collaborators, Going downhill - interactive exhibition, Toruń, April 2007 http://dydaktyka.fizyka.umk.pl/pazurki/galileo.html

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