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## *Physics Alive*


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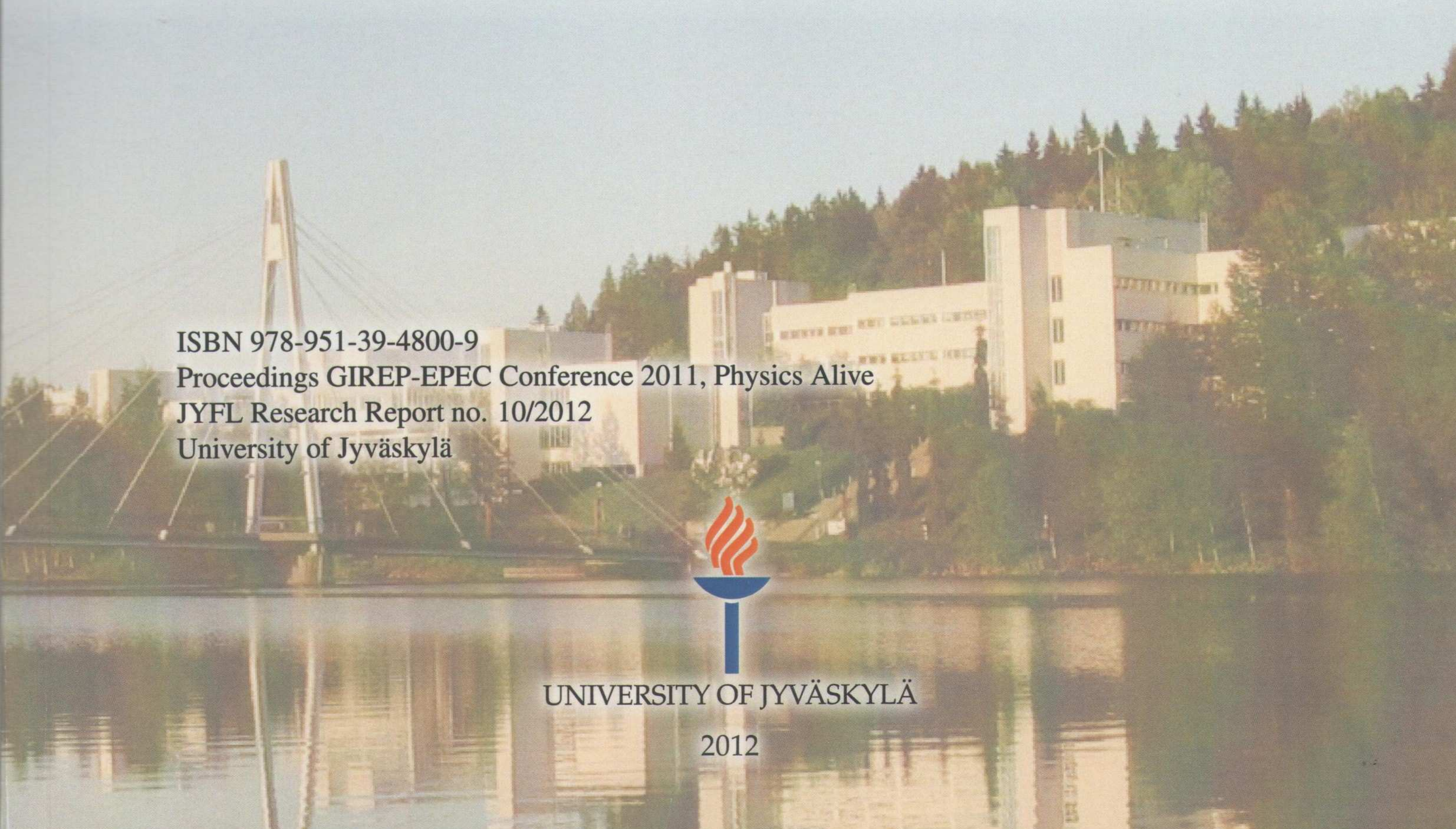


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# Teaching science in early childhood
# – inquiry-based, interactive path on energy

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## Abstract

Declining interest in learning science is observed already in first forms of the elementary school. The advent of the information available at any moment and place makes the traditional, transmission-like ways of teaching inappropriate. As a complementary alternative in several EU countries universities for children are proposed. Interactive lessons, constructed on step-by-step experiments, for early childhood (6-12 years age) show that the concept of energy can be transmitted quite successfully, even starting from null knowledge. Further, any pre-knowledge, for example on gravity, spoils the didactical results. By introducing the concept of energy, we can explain not only falling of objects but also their bouncing-up and, apparently, the spontaneous jumping up of rubber half-balls. In total, almost 2000 children has been trained within Universities for Children (UniKids) lessons on energy all over in Poland. Ways to construct the didactical path and results of teaching are discussed.

## 1. Introduction

A falling interest in learning science is observed. Following Osborne *et al.* (2003), in England in the period 1900-2000 the number of students examined at A-level fell by 10% in chemistry and as much as 30% in physics. A dramatic decline of attitudes towards science is observed between the third and fifth form, again the biggest in Physics (see Osborne *et al.*, 2003). New ways of keeping interest of pupils alive and, therefore, new ways of teaching should be sought for.

Energy is one of the most crucial categories in physics didactics, as it results also from discussion groups within GIREP. The very meaning of the name ένεργεια for Aristotle's metaphysics is the "act of being". The XIXth century's definition of energy, as "the ability to perform the work" has been recently criticized by numerous authors. Duit (1987) discussed the meaning of energy as a "substance", Booham and Ogborn (1996) introduced a concept of "energy and change" and the Karlsruhe school (see Hermann 2000) proposed two, different generalizations of energy, based on concepts of flux and changes. Similarly, Papadouris, Kyratsi and Constantinou (2004) used the concept of energy "as a model that accounts for changes in certain physical systems". Various aspects of teaching energy resuming earlier concepts were discussed, among others, by Doménech *et al.* (2007). The literature is vast.

Do these proposal, being internally coherent, *explain* better what the energy is? In the following we present a fully interactive, experiment-based didactical path to teach the energy concept at the level of elementary school (6-12 years, in Poland). The paper is not on the very *concept* of energy but discusses the ways how to *construct* its various (but scientifically correct) meanings in children's minds.

## 2. Need for (hyper)-constructivism

Inflation of information (the internet item "momentum" returns as many as 3,8 mln reference in Polish) and the global availability of knowledge make traditional ways of teaching obsolete. The constructivism, see for ex. (Duitt & Treagust, 1998) starts to dominate teacher attitudes in developed countries. However, in the school practice this constructivistic approach, at least in Poland, is still more a wishful thinking than

the real educational practice. Recently, the Organization for Economic Cooperation and Development (OECD) has developed for years 2011-12 a new system of evaluation of teaching results at the university level (AHELO). The common skills to all students are listed as follows:
- critical thinking
- analytical reasoning
- problem-solving
- written communication.

AHELO recommendations leave little space to traditionally acquired knowledge. Is it possible to base teaching science also at the elementary level on “analytical reasoning”? As we prove by a prototype lesson on energy – yes! if an interactive path is applied and the lecturer “digs-up” correct information from the collective knowledge of the audience. In particular the concept of energy can be reconstructed from a path of carefully chosen experiments. The procedure comes out from “the need to implicate pupils in the (re)construction of scientific knowledge” (Gil-Perez, 2003). This reconstruction does not use external inputs but it is exclusively based on what children see and on their explanations. We call this strategy *“hyper-constructivism”.*

## 3. Elementary-school target group

Universities for children aged 6-12, UnikIds is a phenomenon started some 5 years ago and developing quickly all over Europe, in particular in Austria and Germany. In Poland approximately 50 children universities were born in different cities. Lessons are organized usually by small educational enterprises in collaboration with local university colleges. The participation is subject to fees and the activities run on Saturdays or Sundays. In total about 10,000 children in Poland are involved.

The necessity of integrating experiment to teaching energy has been discussed in numerous papers, see for ex.( Bécu-Robinault and Tiberghien, 1998). In our teaching sequence we use simple objects which can be repeated also at schools. The target group for our activity are mainly 6-10 years-old children, i.e. in the Piagetian terms “a *concrete operational* age” in-between pre-operational and formal operational age (see, Duit, & Treagust, 1998).

The evaluation was done before and after lessons. Two groups of pupils were used: those volunteering to fill the forms at UniKids sessions and 4th and 5th form students from two elementary schools. Questions asked were, among others: i) why objects fall?, ii) why a ball jumps-up? iii) which objects go downhill quicker? light or heavy? Iv) what is the reason that makes objects move? In the pre-test, out of 37 school answers only once the term “energy” was mentioned (in question iv). On i) 20 pupils answered “because of gravitation”, 6 “because they are heavy” and remaining answers were undefined. On iii) 29 answers said “heavier” and 8 “lighter” (no answer was “with equal velocity”). The question iv) was the most troubling; answers were “gravitation, force, muscles, brain” etc. Similar results were obtained in UniKids population. The prevailing answers are i) “gravity, i.e. Earths’ attraction” (90%) and iii) heavier (85%). “Energy” is never nominated by kids till the mid of the lecture.

The lesson starts from Aristotle’s question, why objects fall. If the reason is that they tend to the natural place, the centre of Earth, they would never jump-up after falling to the floor. If stated directly in this way, the inquiring path would be destroyed, as the answer is given in the question. In experiments constructed correctly, kids notice themselves that *not-jumping* up is an *unusual* behaviour of objects falling down.

A crucial experiment is with a simple curved guide on which a ball rolls down and climbs up on the opposite slope. Explosion of laugh follows “the training of the ball, to do this”. Introducing the concept of energy, one can also explain bouncing of objects and, apparently, the spontaneous jumping up of rubber half-ball, dropper-popper. When wooden birds move, we feed them not with glass balls, which are re-collected at the end, but with the *energy* (the potential energy, in this case).

1º Prof: - Why objects fall? Audience: - *Because the gravity acts*
Prof.: - OK! And what gravity is? Audience: That is the attracting of objects by Earth.
Prof. – And what is the *reason* for this attraction? Audience: Gravity.
Prof. You see that this explanation does not say much. Let’s try another one.
Prof.: - Once upon a time there was a philosopher called Aristotle who maintained that objects fall because they are have and the natural place for heavy objects is the centre of Earth.
[In the meantime I take-out the jacket, apparently for being more comfortable, place it on the table and I make the ball fall on the jacket.]
Prof.: - As you see that’s truth. The ball tried to fly to centre of Earth and only the table prevented it.
2º Prof: What do you think – can objects bounce up spontaneously? [And now, with everybody concentrated on the ball we try the telekinesis]
Prof: So, look now on that other experiment.
[the sequence with the double curved guide follows. In the first instance I stop the ball in the middle of the path, i.e. in the lowest point]
Prof: - Did you like this experiment?
Audience: *they unwillingly disapprove but we do not allow to articulate it openly!!*
Prof: - Now, I will show you that the ball can be trained [Then the magic sequence of a wizard follows, to rise the attention]
Prof.:- I tell you, ball, go! [now we do not stop the ball in the middle of the guide bur when the balls climb the opposite slope we say] – and now, come back!
[Everyone laughs, sometimes they shout: “- because you stopped it before!”] [1]
3º Prof.: - you see? Now we have a new way for making the ball well trained.
[ Now we make the ball fall on the floor. Obviously, it bounces up.]
4º [Next is the sequence with two balls, falling one on the other, with the upper one, lighter, bouncing up to the ceiling. (Karwasz *et al.* 2005)] Children, spontaneously, after 2-3 trial comment : *Because the lower one has transferred the* ***energy*** *to the upper one!***.**
[And that’s practically the end of the lesson: the aims has been reached: the energy is the reason making objects move. Even if ona a higher level we should discuss it carefully, at 6-8 yrs age that’s quite good explanation. Some 20 experiments follow but they are less important.]

**Fot. 1.** The interactive lecture “Going downhill” faces a serious didactical task – how in teaching kinematics go beyond the tautology “objects fall because the gravity acts”. The experimental set-up consists of approximately 30 objects, all of them illustrating the concept of potential and kinetic energy. First to the left, a double curved guide for “training” balls which come back after climbing on the opposite slope of the guide.

The lessons are fully interactive, i.e. experiments are performed on the stage by volunteers. Additionally, as lessons are run in big groups (100-200 children) all kids should feel involved in the activity. Therefore elements of competition (“- Which duck is quicker on the slope”, “Lets’ vote if the heavier cart will arrive first?” etc.) are introduced. Some experiments, like listening to a uniform walk are performed with eyes closed, some are quite involving, like an (unsuccessful) trial of telekinesis to make the ball jump up.

[1] Children are surprised by hat they have accepted the previous experiment with the ball stopped in the middle of the guide and that they have agreed on the explanation by Aristotle: following that explanation the ball should not climb on the other side of the inclined plane.

**Fot. 2.** Spontaneous playing after the lecture: "-What happens if...?" Full invention and children's initiative, satisfactions from an experiment planned independently. a) Does the heavier cart roll down quicker than the light one? b) What is the shortest-time path and why? c) Which duck is quicker?

## 4. Free-hand impressions

Obviously, interactive teaching physics in a non-homogenous group, with different cultural a knowledge background is an ambitious task. Didactical results have been evaluated on the open basis. At the distance of five months, before another lesson in physics, children have been asked to draw a single experiment that they remember form the previous lecture. About 40 drawings have been collected.

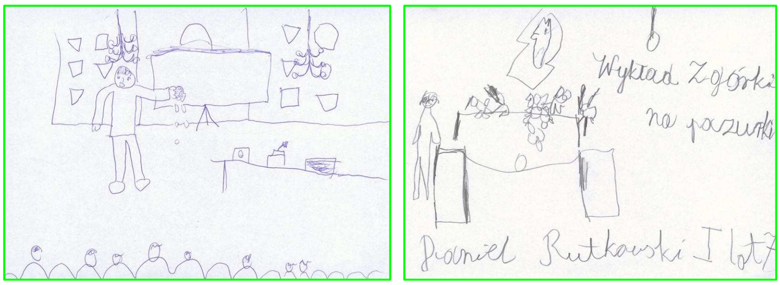


**Fig. 3.** Evaluation of the didactical results – children's reports after 5 month from the lesson. The first type of drawings, in clear minority are "collective photos" but also here it's clear that children noted the *key* experiments like that with a double, curved guide.

Much to our surprise only few of them reported the lesson as a photographic shot. The majority of "reports" showed crucial experiments and some of them just drawings of the *physical* processes, like schemes for collisions of balls. Very few drawings reported the pre-concept "- Objects fall because the gravity acts".

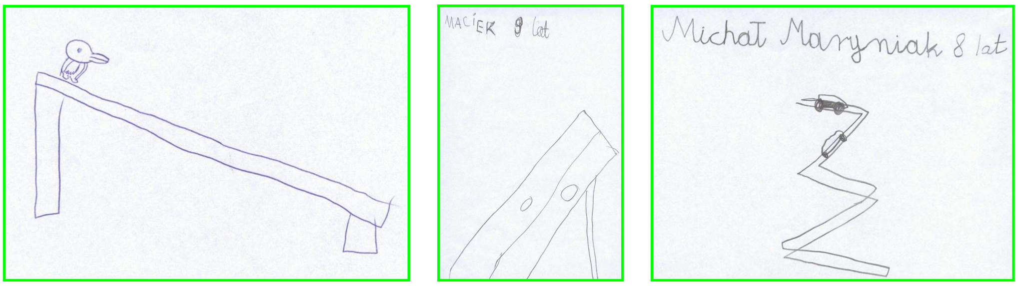


**Fig. 4.** A second group of drawings reported the *key* experiments. a) A duck descending the plane illustrates the concept of the uniform motion; b) rolling down balls explain the accelerated motion; c) experiment with two carts with different masses shows the independence of acceleration on the mass.

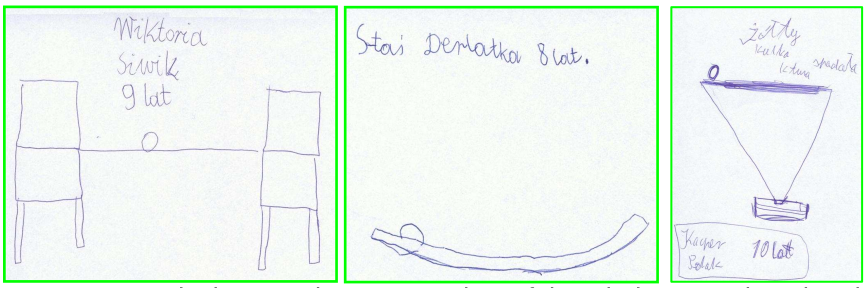


**Fig. 5.** It is surprising in this *ad hoc* check that some children reproduce *exclusively* the crucial points of reasoning – like the experiment with the curved guide or the "gravitational" funnel. These were exactly the most important points of the whole reasoning: the objects fall when the potential energy changes into the kinetic one and rise if it happens *vice versa*."

We stress that children were not advised on the didactical check and they draw the graphical reports *ad hoc* while waiting for the new lesson. The only hint given was "-Please, draw what you remember!"

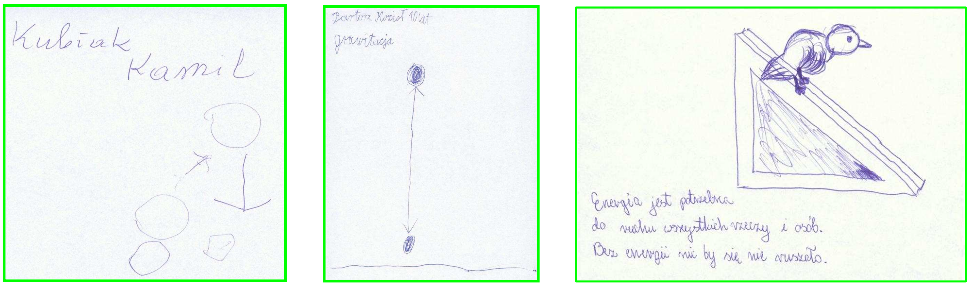


**Fig. 6.** Evaluation of the didactical results. The highest score, for the capacity of resuming the laws of physics received these three drawings – the first one of a boy hardly capable of writing. Experiment with two falling balls placed one above another is just the one after which children find the "magic" formula: "-The energy has been transferred!" The last one, of 12 yrs old girls says: "-The energy is needed for the movement of all objects and persons. Without energy nothing would move".

Test performs in the same groups after experiments show 40% pupils answering "objects fall because they posses *energy*" (remaining pupils maintain their pre-answer "gravity"); 65% say "objects jump because they posses energy"; above 80% say "light and heavy descend with the same velocity".

## 5. Conclusions

Constructivism in modern pedagogy has two meanings, one being more social and the second one, concerning didactics and coming from Piaget and Vygotsky. However, also this second approach underlines social aspects of the process of constructing knowledge (see, Duit & Treagust, 1998). We note that as far as the presented teaching sequence is based on the knowledge of the audience (i.e. of single children asked one by one), there are no social aspects in this procedure. The whole teaching path aims rather to *changing* social aspects, like common understanding, pre-concepts, social erroneous sensibility etc. Children do not discuss science among themselves but perform individual *analytical reasoning.*

Secondly, these are carefully planned experiments which turn out to be decisive in early childhood perception of science. The whole reasoning path must be based *didactically* correct questions and experiments which give clear, not-questionable answers and are carefully planned to avoid any "collateral" answers. The trainer must know what he *wants* to teach. Asking *any* question, not the right-at-the-moment one gives usually a wrong answer. This is usually *scientifically* correct answer but pulling the reasoning in didactically wrong direction.

A crucial problem, especially in a group containing also children aged 11-12 are pre-concepts. They already use the concept of *gravitation* what hinders them to follow the reasoning with the rest of the audience. We do not perform merging of pre-conceptions and *scientific* concepts into a kind of hybrid *beliefs* but propose well-defined experiments to dismantle misconceptions. Those were only *thought* (gedanken) experiments in times of Galileo and Einstein, now these experiments:
- have been checked in scientific laboratories (i.e. the fall in vacuum)
- can be shown in simplified versions (two carts with different masses)
- have practical, measurable consequences (going downhill by bicycle is dangerous!)
- have *YouTube* or similar ocular versions, which are always "on hand" if the real experiment fails (Karwasz, 2006).

Recently we have extended the concept of *hyper-constructivism* into lower secondary school (gymnasium), writing an “easy-book” in Mechanics (Karwasz, Sadowska, Rochowicz, 2009). This book follows the same line as the experiments shown above: nothing is given as granted and pupils must get convinced that some terms (energy, force, momentum, vector) are useful for *their* own reasoning about the world. Didactical testing is encouraging: we see a shift from “insufficient” results to a more equal distribution of votes, see fig. 7.

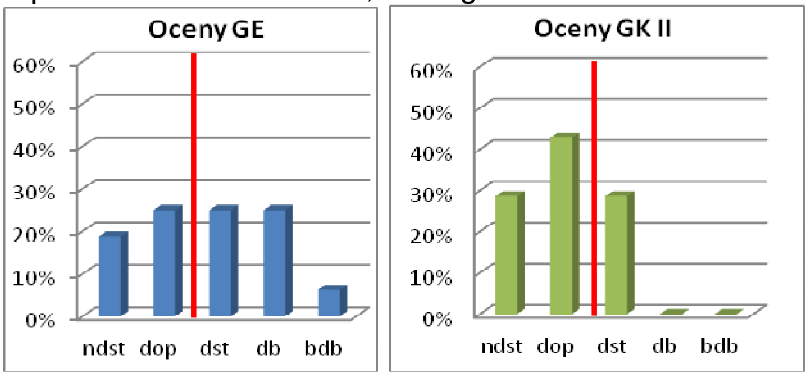


**Fig. 7.** Test of the didactical efficiency of the hyper-constructivistic text-book for lower secondary school. The experimental group (GE) shows more equally-distributed results than the control (GK II) group. Positive votes are on the right side of the red line. Source: Sadowska (2011)

Finally, we stress again the didactical/ pedagogical aim of the proposed methodology and scenarios: not to establish the fixed knowledge or the definition of “energy” but to open children’s minds for *experimental reasoning.*

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