Learning physics. The joy of scientific discovery

Grzegorz Karwasz

Abstract

Physics, with Kopernik, Galileo and Newton became first science with a modern methodology: observation – analysis – mathematical model. What is the source of the scientific success of physics is the reason for didactical difficulties – pupils must understand the verbal description, translate it to mathematical formalism and relate it to the real world. Humanistic currents from second half of last century – cognitivism, constructivism and pedagogical perspectives – would facilitate teaching physics. We show how apply these concepts, at different ages of pupils, in an interactive teaching, based on real, simple experiments.

Parole chiave:
physics, didactics, pedagogy, constructivism, cognitivism

La fisica, con Copernico, Galileo e Newton divenne la prima scienza con la metodologia moderna: osservazione, analisi, modello matematico. Quello che è la sorgente del successo scientifico è in contemporanea la ragione delle difficoltà didattiche: gli allievi devono capire la descrizione verbale, tradurla al formalismo matematico e mettere in relazione con il mondo reale. Correnti umanistiche della seconda metà del secolo scorso – cognitivismo, costruttivismo e prospettive pedagogiche – dovrebbero supportare e facilitare l'insegnamento di fisica. Mostriamo come applicare questi concetti a diverse età, in un insegnamento interattivo, basato su semplici ma reali (non virtuali) esperimenti.

Key words:
fisica, didattica, pedagogia, costruttivismo, cognitivismo

ISSN 1722-8395 (print) / ISSN 2035-844X (on line)
Studium Educationis • anno XVII - n. 3 - ottobre 2016

Learning physics.
The joy of scientific discovery

1. Physics – first science of modern ages

Physics, with Galileo, became the first modern science. "Physics came down from heavens to earth along the inclined plane of Galileo" – wrote as a motto in his *Physics for the Inquiring Mind* E. M. Rogers (1960). Galileo's recipe for physics still remains the source of extraordinary successes of this science but also a serious limitation in teaching it.

Great successes of physics come from its reductionism. Galileo, when introducing the accelerated motion, did not consider a complex trajectory, like that of a flying ball that was the source of Aristotle's difficulty. Using a style still resembling somewhat Plato's Dialogues, he wrote: "[…] a body, in the straight-line movement, if starting from rest, covers in the first instant one length of a cannon, in the second – three lengths […]"[1]. In order to force the movement into a linear one, Galileo introduced an external system of reference (the gun), to a great extent an ideal one, and then used a simple, mathematical model.

The other winning element of Galileo's physics is the experiment – a real one (probably at the origin of his observations, like throwing stones from Pisa Tower) and a *gedanken* one. In fact, he does not refer to stones falling from the Tower but makes a deductive analysis – what would happen if a heavier stone were connected with a rope to a lighter one: will they fall with a medium "velocity" or with the sum of two velocities (being together heavier than any of the two components). In his analysis Galileo abstracted from all non important features of the stones, disregarded the air friction etc. Galileo's description of experiments make them repeatable in any place and

1 "Ma questa general cognizione è di niun profitto, quando non si sappia secondo qual proporzione sia fatto questo accrescimento di velocità, conclusione stata sino a i tempi nostri ignota a tutti i filosofi, e primieramente ritrovata e dimostrata dall'Accademico, nostro comun amico: il quale, in alcuni suoi scritti non ancor pubblicati, ma in confidenza mostrati a me e ad alcuni altri amici suoi, dimostra come l'accelerazione del moto retto de i gravi si fa secondo i numeri impari *ab unitate*, cioè che segnati quali e quanti si voglino tempi eguali, se nel primo tempo, partendosi il mobile dalla quiete, averà passato un tale spazio, come, per esempio, una canna, nel secondo tempo passerà tre canne, nel terzo cinque, nel quarto sette, e così conseguentemente secondo i succedenti numeri caffi; che in somma è l'istesso che il dire che gli spazi passati dal mobile, partendosi dalla quiete, hanno tra di loro proporzione duplicata di quella che hanno i tempi ne' quali tali spazi son misurati, o vogliam dire che gli spazi passati son tra di loro come i quadrati de' tempi" (Galileo, 2014, p. 231).

Grzegorz Karwasz

any time: modern physics is a science of modeled, repeatable experiments (and theories that predict experiments checking them).

Galileo is a leading figure of modern science also for his audacious promotion of Kopernik's (1473-1543) system. This astronomer, priest, administrator, physician, poet, born in Toru, studied first in Kraków, then in Bologna and Padova, where he did first astronomical observations with his Italian mentors. His treaty, *De revolutionibus*, seems to be a collection of mathematical tables (reporting the observations from the whole life). But, before getting into numbers, Kopernik starts from Greek philosophers asking essential questions – why water does not flow-down from Earth's sphere (with this he anticipated the central-oriented gravity of Newton), and why "Earth which is so big, but for sure nothing if compared to the Universe, should stay immobile and the whole Universe should rotate, that its dimensions we do not know, or probably, we even *can not* know". Einstein, in 1905, with his special theory of relativity confirmed existing of limits on the ever know to us Universe – only as far as the light have travelled from the beginning of cosmos (13.78 billion years).

Descartes in his *Discourse on the method of guiding the reason*, applied to optics (1668) formulated four scientific principles[2]:

> "The first was never to accept anything for true which I did not clearly know to be such; that is to say, carefully to avoid precipitancy and prejudice, and to comprise nothing more in my judgment than what was presented to my mind so clearly and distinctly as to exclude all ground of doubt.
> The second, to divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solution.
> The third, to conduct my thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend by little and little, and, as it were, step by step, to the knowledge of the more complex; assigning in thought a certain order even to those objects which in their own nature do not stand in a relation of antecedence and sequence.
> And the last, in every case to make enumerations so complete, and reviews so general, that I might be assured that nothing was omitted."

2 Le premier était de ne recevoir jamais aucune chose pour vraie que je ne la connusse évidemment être telle, C'est-à-dire d'éviter soignousement la précipitation et la prévention, et de ne comprendre rien de plus en mes jugements que ce qui de présenterait si clairment et si discinctement à mon esprit que je n'eusse aucune occasion de la mettre en doute. La second, de deiviser chacune des difficultés que j'axaminerais et autant de parcelles qu'il se pourrait et qu'il serait requis pour les mieux résoudre. Le troisième, de conduire par ordre mes pensées, en commençant par les objets les plus simples et les plus simples et les plus aisés à connaître, pour monter peu à peu comme par degrés jusques à la connaissance des plus composés, et supposant même de l'ordre entre ceux qui ne se précèdent point naturellement les uns les autres. Et, le dernier, de faire partout des dénombrements si entriers et des revues génerale que je fusse assuré de ne rien omettre. (Descartes, 1668, pp. 20-21).

Newton, in his *Principia matematicae* shaped physics into a rigid, mathematical discipline. In order to prove the phenomenological dependences of planets' orbits (Kepler laws) he needed to derive the dependence for the centrifugal force. – he derived the motion on a circle as a consecutive series of squares. The result permitted to explain the fall of the objects, the movement of planets and moons (including Galileo's satellites of Jupiter) and the flight of comets: a single result that explained apparently different phenomena. And a series of approximations from a square to a circle led to new mathematics: differential calculus.

Immanuel Kant brought a substantial revolution into modern philosophy, but he contributed also to physical geography, physics of atmosphere, mechanics of Solar system and its origin. The essential influence of Kant on the methodology of science stays in stressing the importance of the observer: we discover the nature only via our perception. This statement can be described in a complementary way – a scientists formulates questions to the nature, but not like a child asking "what is this?" but like a judge to the suspect: "Is it truth that on Monday 1st May at 8 pm in Gower Street you have stubbed Ms Stevenson?" The scientific discovery is a kind of *distillation* of the nature – not only a well prepared experiment like Galileo did but, first, a well prepared question. i.e. a working hypothesis.

A set of four equations on electricity and magnetism by Maxwell (about 1865), in which he predicted electromagnetic waves, are example of Kant's *synthetic a-priori preposition*. Another example of such a genial reasoning is Einstein's general theory of relativity (about 1915) in which from the mathematical conciseness of one single equation such strange phenomena arise as the sliding of a space-time around a rotating Earth or gravitational waves.

XX-th century physics brought unexpected discoveries, like Quantum Mechanics, that led to great philosophical consequences: the nature can not be predicted in its all details – measuring one notion excludes another. This is important information to be transmitted by physics to young people: not only our minds have limits, but the very nature is unpredictable.

2. Physics: cultural impact

Examples of Kopernik, Newton, Einstein, who were not "professional" scientists (the first was a priest, the second – the head of English mint and the last – a patent clerk) show clearly that physics (and other sciences also) is in the first place a *heuristic* adventure[3]. On the other hand, mental procedures introduced by Galileo, Descartes and Newton – inductive reasoning, synthetic comparison, common interpretation of different phenomena, remain till today the characteristic features of physics as compared to other sciences. As

3 Here we do not agree with Thomas Kuhn who states that scientific revolutions come from historical necessities.

an answer "What is physics?" Steve Chapman (2015, p. 102) enumerates, in the following order, "big ideas" staying behind this science:

- Reductionism – physics uses few laws; moreover, at higher level of generalization, different phenomena can be explained by the same *principles*; for examplee refraction of light in lenses and the pathway of a stone thrown in the gravitational field are governed by the same principle "of the least action".
- Causality – in spite of indeterminism of Quantum Mechanics and the relativity of space-time, no phenomena can occur without their prior *causes*.
- Universality – laws of "Earth's" physics prove to be valid at the most remote limits of the Universe; this means also that laws of physics are fixed once for ever.
- Mathematical modeling – "we can use calculations to predict what real objects and systems will do".

Physics, thanks to reductionism, mathematical description and frequent symmetries in different phenomena could be an example of a science with a clear, simple structure. This is for example of Maxwell laws, which with four laconic equations describe as different phenomena as attracting magnets, thunder storms and propagation of light. The mathematical synthesis of the general relativity is just a single equation, with two terms, but leading to some ten thousand phenomena, out of which we know just 3-4 most evident, like the non-elliptic orbit of Mercury and curving the light of stars by nearby Sun.

Physics is also a good example of working by concepts, adopted into Italian didactics by E. Damiano (1994, p. 36). The competences that E. Damiano derived contain, among other: – reduction of single phenomena to one concept (generalization), – defining the properties of a concept, – select pertinent or non-pertinent elements of the concept (discrimination), – applying concepts to solving phenomena, – applying concepts to other phenomena (extension). Physics reserves certain words as "registered": force, energy, power – all belong to mechanics, but have exclusive, non changeable meanings. As stated P. Crispiani describing concepts and the methodology of Galileo, "From the concept starts the first systematics of the epistemic process, hence the knowledge of the reality and the construction of theories" (Crispiani, 2004, p. 97).

As compared to some other academic disciplines, physics offers vast professional possibilities. As written on a leaflet from Nottingham University (2016), physicists can work not only in research but also as experts in market analysis, as engineers in electronics and informatics, as light and sound directors in theatres, as managers in industry etc. 84% of graduates find job within six months and the average starting salary is 21.500 £.

Unfortunately, school teaching of physics usually concentrates on the final phenomena and formula, disregarding the beauty of physics: as a intellectual adventure (like it prospects from texts of Galileo) or a modeling and subsequent exploration of the (simplified) nature, like it was methodologically stressed by Kant.

3. Overcoming didactical difficulties

The same features that allowed physics to obtain great scientific results constitute the source of didactical problems. The objection of pupils (and ex-pupils, i.e. adults), against physics are the same all around the globe, from Seoul to Sao Paolo. Physics is difficult, it has little to do with the real world, it contains mathematical equations impossible to learn.

Physics, *par excellence* is a model of *forma-mentis* science: take a real situation, reduce it to a model, plan an experiment, perform it and apply a mathematical model to it. So, in didactics of physics, as it is constructed traditionally, pupils have to posses: i) good language comprehension, ii) imagination – how to translate a written description into a real situation, iii) capacity of abstraction – which elements can be removed from a real world in order to prepare a model, iv) mathematical skills – how to describe and solve this model.

Conjunction of different elements – from linguistic to mathematical ones – makes physics a real "burden" for pupils, in any time and any place. Pupils usually miss just one of the elements in the chain from wording to mathematical solving and this is enough to impede successful learning. The worst that can be done in this situation is to attribute the fault to pupils: this is simply a wrong way of teaching physics as a "cultural" subject for the whole population, like it is required in the contemporary, democratic school.

Possible solutions should come from tackling single elements of the chain above. For instance, Internet-based, interactive solving of problems proposed by Karlovy University in Prague (Koupilová, 2016) is an example helping pupils to translate a verbal description info schemes and symbols. The advantage of the computer-based technique is that successive question, suggestions and solutions are shown only when the student explicitly asks for it. Additionally, the collection is divided according to the skills to be developed: mathematical solutions, graphs, qualitative tasks, unusual solutions etc..

An important role in linking concepts to the real world is played by experiments. Unfortunately, they are usually prepared by the teacher, in a procedure called SPEA (Michelini, 2004): - situation, - predictions, - experiment, - analysis. "A wire is placed in the magnetic field. What will happen if an electric current goes through the wire?" This is clear – it will move. Only the direction of this movement is to be guessed. SPEA, although being a step forward in translating physics into the real world, deprives students of a part of the Descartes' logical procedures: they find experiments (and implicitly also explanations) ready - no place is left for their own *constructing* of the discovery path. Interactive, constructivistic teaching, as described later is different: pupils have to organize independently their own experimental procedures. They need not to follow that invented by "professional" scientists. What is important is to trigger pupils own creativity (see fig. 1a from workshops on electricity for children aged 6 11).

Insisting on the mathematical side of physics brings a risk of loosing the simplicity. In Newton's cradle, see fig. 1c, surprising for the player is that the same number of balls is ejected as it impinged. A mathematical solution requires solving of a set of equations for energy and momentum conservations, see (Zanetti, 1994). A verbal explanation is easy: "Only two balls participate in the collision – the first and the last one. Other serve solely to transmit the initial impact" (Karwasz, 2005a). Children's attention is pinned down for long minutes, see fig. 1b. The same astonishment experiments exercise on adult students, fig. 1c. But experiments and interactive exercises are only few examples of broader methodologies that await to be introduced into didactics of physics.

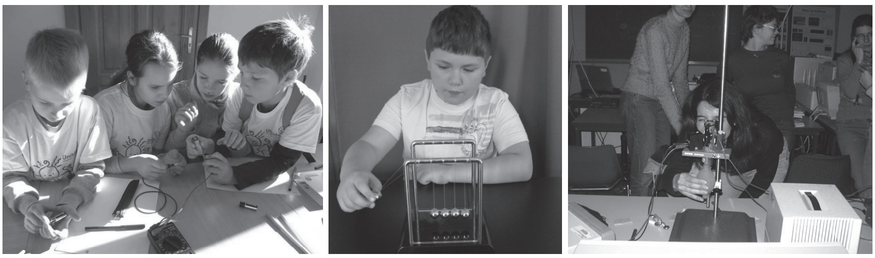

Fig.1. Free-run experiments as a method for triggering interest and creativity: a) Kids interactive laboratories with self-organizing: electrical measurements, UniKids, Głogów, 2012. b) Newton's cradle – a simple object, that does not require complex mathematics for explanation but attracts attention. c) Discovering atomic physics (Millikan's measurement of the charge of electron) – workshop with teachers at Udine University (SSIS) 2006. Experiments and photos by author.

4. Cognitivism, Constructivism, Pedagogical Contents

Half a century ago, in parallel to the acceleration of technological progress, three important currents in-between didactics, pedagogy and philosophy were developed. The first one, cognitivism, in words of one of the founderswas born as a "paradigm shift" in human sciences, from "biological side of psychology to a vineyard of perception, memory, thinking. All of these now conceived as information processing" (Bruner, 1991, p.X). Not the final information but all cultural linking to history, philosophy, psychology, theory of information is important in acquiring knowledge. "A mind well-done" (Morin, 1999) and not well-filled.

The second current, constructivism, brings back to pupils the possibility of their own scientific discovery; in EU naming it is called inquiry-based teaching. Constructivism broke the barrier of implementation only at the end of last century: "For most of this century, our educational system served only the elite in thinking-centered classrooms. The majority of students received an education aimed to the acquisition of basic skills and routine knowledge." (Goldman, 1998, p. 258). Italian teachers, as shown by OECD studies, still declare mostly "direct transmission believes", being at the end of OECD (TALIS, 2009, p. 95).

Third cultural current born several decades ago is the "Pedagogical Contents Knowledge" (Shulman, 1982). The teacher has to relate won tasks to what the student already knows; teaching should also take into account pedagogical outcomes that can result from a particular, sectorial knowledge. In didactics of physics PCK is particularly important as, among others, it aims to identify wrong pre-concept, possessed by pupils, that impede a correct learning (like that of Aristotle on falling stones).

Unfortunately, as reviewed by Abell (2008), in spite of extremely vast referring to the work of Schulman, the didactical practice took little advantage of PCK: in didactics of physics have been identified but a remedy on them is just to declare "that they are wrong". For instance, children show many different intuitions on the nature of the electric current – moving atoms, special carriers, vibrating waves inside the conductor etc. But textbooks state only that "electrons carry the current". This is wrong from three points of view: physics, didactics and pedagogy. In physics – because electrons are the exclusive carriers only in metals, like copper or gold; the carriers in metals, like tin and bismuth, are both negative electrons and positive holes (lack of an electron in the metal structure). In plasmas (the "fire" for Aristotle) and liquids (like water) the carriers are both electrons and ions. Didactically – because carriers itself do not explain the propagation of signals through conductors: these are waves. Pedagogically, because criticizing free-hand concepts kills pupils' imagination.

Generally, great ideas of Cognitivism, Constructivism and Pedagogical Contents still await detailed implementations in didactics of physics.

5. Physics is Fun

One of the proposed (successfully) solutions is to make reference to every-day physical phenomena. In Italy it was introduced by V. Zanetti (1994); in Poland the idea of simple physical objects (Karwasz, 2000) triggered a huge success of science centers, born practically in every academic center. Pedagogical importance of such a learning by "playing" is that the same objects and collections can be used for constructing individual activities for different ages and interests, being complementary to textbook teaching(Falchetti, 2011).

Referring to every-day phenomena is not new (Perel'man, 2008), it was done by greatest scientists (Landau, 2014), at all levels (Parker, 2005), and in all languages (Frova, 2001). An entire para-academic course of physics by P. Hewitt (2015) has been constructed from every-day observations. However, in spite of their great importance for triggering interest in the subject, textbooks based exclusively on the phenomenology and not reflecting the conceptual (and historical) development of physics hardly can constitute a basis for a systematic didactics – the very course of Hewitt (2015) has also evolved in this direction.

In the EU Science & Society Project "Physics is Fun" (Karwasz, 2005a) we proposed to extend the use of simple objects from their mere phenomenology to a planned didactical implementations, particularly in modern physics. For instance, gravitational lenses, predicted that deviate the light of remote galaxies. In optics any strange shape, including a bottom of a glass, makes the same effect(see fig. 2a). A hyperbolic funnel is used to show closed orbits of planets and Kepler's laws; a spherical-like funnel gives open orbits, like predicted by General Relativity (fig. 2b). A gondolier rows from one side only because the gondola is slightly asymmetric; the times goes only forward, as for some (unknown) reasons elementary particles (strange quarks) "recognize" the time-arrow (Karwasz, 2005b).

Fig.2. "Physics id Fun" – simple objects for complex ideas. a) gravitational lenses multiply objects - in this case the ladder in neighbor's garden is seen by multi facets piece of glass. b) Kitchen funnels and a "gravitational" funnel used to explain Kepler's laws ("Physics is Fun" exhibition, Gda sk, 2005). c) Venetian gondola, slightly asymmetric (and therefore allowing rowing from one side) illustrates an asymmetry of the time-arrow: only heavier quarks, like *strange* show the asymmetry.

6. Hyper-constructivism and neo-realism

The difficulty in learning (and teaching) physics, clearly comes from the lack of linking between the two approaches presented above - a pure, mathematical model vs the real, phenomenological observation of the world. Such linking can be done using the mutually complementary methodologies proposed: hyper-constructivism and neo-realism (Karwasz, 2012). Hyper-constructivism (HC) uses to some extent the concepts of social constructivism, in which the knowledge is constructed in a sub-society as a common compromise (Berger, 1966), However, we reject the idea that science is historically and socially dependent – it would lead to relativism, denying the very basis of physics. HC uses the wisdom coming from PCK in identifying pre-concepts, but differently than other approaches, does not reject them as wrong: there must be always some correct *reasoning* or external evidence that induce pupils into these pre-concepts. It is enough to recall this reasoning and falsify the wrong evidence by experiments prepared in advance or *ad hoc* as answers to pre-concept. The extensive use of conceptual, but simple experiments we call neo-realism.

Let's consider a problem classical for the whole physics, i.e. motion. A key to the efficient teaching is an extra knowledge of the teacher, beyond that to be transmitted to the student. Humanistic – philosophical, historical, linguistic aspects are part of this extra knowledge. In the case of motion the necessary starting point is Aristotle. His *Fisica* almost entirely is dedicated to the definition of motion, as a change of the state. But our knowledge on Aristotle comes from his critics – that all heavy objects *tend* to go to Earth's center, that light objects like air tend to ascend and that the air pushes moving objects. Why Aristotle (and children today) think that objects are pushed by air and that heavier objects fall in a shorter time than lighter ones?

Fig.3. Hyper-constuctivistic path on the free-fall. a) "What is the difference between the two balls (or carts) ?" – One is heavier! b) "Close eyes and listen carefully! Do they fall together?" – a teacher must perform this part personally. c) "Now check it again with a piece of paper! You see that this is the air friction which makes the difference". d) The final, checking experiment uses a glass tube without air and two objects inside – a coin and a feather; they fall together. Experiments by GK.

As a working hypothesis we adopt the pre-concept: heavier objects fall quicker than light ones. An inclined plane with two identical (apparently) carts is used to check this hypothesis (see fig. 4b). One of the carts is made heavier, by adding two brass weights inserted into the wood, in an invisible way. A children, (see fig. 3) a is asked to discover, what the difference between the carts is. (A SPEA-like question "Which one is the heavier would spoil the HC path). The answer is immediate: "This one is heavier". The next step is to allow children to declare themselves on one of the hypothesis – the heavier (or lighter) is the quicker. We do it by voting. To verify experimentally the answer, two children launch carts in a precise order: "So the heavier should join the lighter before the end of the track, shouldn't it?" We repeat the experiment, with an (apparent) excuse that the launch of the second cart was not enough prompt, but the results is the same. So we proceed with a *cross-check* experiment: the lighter cart is launched after the heavier. At this point we stop the experiment; as a great Polish pedagogist, K. So nicki used to say – the excess of exemplification is infantile. Children, without further experiment, are ready to correct their previous working hypothesis: all objects, independently of their mass fall with the same speed.

We have to reward pupils for the correct answer, confirming it experimentally. Again two similar balls are chosen – a ping-pong one and a caoutchouc one. We make the two balls fall (now, to be quicker and more precise by ourselves) from a heights of about 60-70 cm, fig. 3b. Again, in the view of abstracting from non important details, we teach children the sound of the two balls jumping from the table – it is easy to be distinguished. At that point pupils *listen* (not watch) the two balls falling: "Clear! They fall together. Let's have a vision of it!" (again, the experiment repeated as a heuristic reward for the correct reasoning). Once the precise rule is fixed (all objects fall with same velocity) and within the same temporary window of the affective attention of children, we falsify this hypothesis: with the same two balls we climb to the stairs (or table, see fig. 3c) and launch the balls not into the table but to the floor (a distance for the free fall of about 2 meters). Now the balls hit the floor in two instants that can be easily distinguished. Why? Let's do it with two pieces of paper - a flat sheet and the same pieces rounded into a ball. The difference is enormous: "This is air friction which makes the difference!"

Note that our hyper-constructivism is exactly Descartes methodology of reasoning: first – start from a well acquired knowledge of pupils, that a consensus is obvious; second – define small steps towards the chosen cognitive goal; third – organize the reasoning from simplest cases (first experiments on the free fall confirming Galileo's law) to more complex (experiment with air friction); finally – re-examine the consistency of the results, by cross-checking experiments (in the case of free fall – the experiment with a coin and a feather falling in a glass tube from which the air was evacuated (fig. 3d) and additionally the film on the fall of a hammer and a feather from Apollo's 17 experiment on Moon.

Experiments for pupils should be organized as simple as possible; in other words, in a way that pupils can repeat them at home without difficulties. Note that Galileo did not describe the fall of objects from the tower of Pisa (which is unique) but formulated the law in a general manner: no particular gun is needed for a special unit of time or distance.

7. Pedagogical aspects

Physics, with all its experimental and mathematical contents, as summarized in 1st and 2nd chapter, remains a heavy charge for pupils and teachers. The latter, frequently suffer from gaps in their knowledge of physics, and organize their personal (anti)pedagogical behavior in a way to hide these gaps. But even if the teacher of physics shows good knowledge of his subject, she/he rarely pays attention to the pedagogical *impact* of her/his educational action. Where, in all complex teaching of physics, is the place for the educational imprinting?

Today's school, with the arrival of international comparative tests like PISA by OECD and ranking schedules performed not only by educational authorities like the ministry by also by a myriad of bigger or smaller journals, became oriented towards "efficiency". That can be highly misleading (Milan, 2014). In the case of Poland, well scored by PISA, other OECD studies (TALIS, 2009, p. 145) comparing the criteria for school evaluation (students scoring, subject olympiads, other tests) placed that this country is on the top of *formal* school management, just after Malaysia. Italy is in the middle of OECD countries: the school is more democratic and pays more attention to the individual student. This is to be attributed not only to different ways of preparing teachers, but mainly to the whole cultural *entourage* around the education that starts from the family and continues in local communities – village, condominium, parish, oratory, youth association, scouts etc.: a single person is the final addressee of pedagogical and educative actions.

As discussed by Macchietti (2012) the Italian concept of a "person" goes beyond the Greek meaning of an actor and with millennia of Christian tradition acquired the attributes of the liberty, responsibility, spirituality. An essential part of the Italian educational chain is also the "kindergarten", i.e. "mother's school" in Italian wording. It derives from a long cultural tradition, summed with the extraordinary pedagogical (and affection) attention paid to the children as it was introduced by M. Montessori. Using her language, the attention paid to the child and the liberty left to him/ her "transforms the child into thoughtful and diligent little man, who makes, in the secrecy of his heart, decisions and selections very different from what we would have expected […]"[4] (Montessori, 1968, p. 119).

Fig.4. Pedagogical aspects of hyper-constructivism: a) *ad-hoc* lesson in "Hewelianum" Science Center in Gda sk, Poland, for Pedagogical Lyceum from Trento: "There are no wrong answers of students, but only wrong questions posed by teacher." b) Enhancing the personality of a child by his own experiments: "Does heavier cart slide down more quickly than the light one? Try it as long as you want!" c) Collective construction of knowledge at the lesson for children 6-12 yrs, on the free fall (with the energy as the goal concept): "If we all together try mentally the telekinesis, the ball will jump up!" But one boy does not believe it. Lessons & experiments by GK, photos Maria Karwasz.

4 "È questo che trasforma il bambino in quel piccolo uomo pensante e diligente, che prende nel segreto del suo cuore decisioni e fa scelte così diverse da quelle che avremmo supposto […]" (Montessori, 1968, p. 104).

How does it translate to teaching physics? The feeling of the child to be free in responses, i.e. receiving a reward independently from the correctness/incorrectness of the answer[5] can be felt unjustified, but for sure stimulates pupil's self-confidence. As proved by neurological studies (Chiarenza, 1991), a positive pre-attention and an immediate post-prize stimulates by a factor of ten the mental capacity. A negative and, moreover, frequently public comments by the teacher, hinders further activity of the pupil.

In physics, any experiment that the pupil performs independently "goes correctly": never an experiment goes wrong, it only gives a different result than we predicted. It is the task of the teacher/trainer to fix experiments in a way that a positive result can be possibly reached: experiments can not be to complicated or uncertain. Unless, the teacher wants to stimulate a kind of competition, for example in manual capacities. Also SPEA procedures can be pedagogically useful: let pupils to have a brain-storm, followed by a panel discussion and by voting on the possible outcome of the experiment prepared. The joy of getting an *own* result is, pedagogically, more important than getting "correct" physically data.

8. Conclusions

Educational aspects of teaching physics in school should enhance the scientific features of this science, as an example of the step-by-step deduction on the external world. If this procedure is omitted (or shortened) then physics becomes a dogmatic discipline: "First, second and third law, now learn it by heart and I will check it at the next lesson!"

Properly executed constructivistic (and experimental) path should teach, somewhat differently than other natural and humanistic sciences:
- the capacity of observation of phenomena in their complexity;
- detecting crucial features of phenomena;
- forming own *working* hypothesis;
- designing opportune experiments with only selected, indispensable elements of the reality;
- correcting the initial hypothesis;
- formulating laws;
- confirming formulated laws;
- cross checking of the laws, to obtain their (apparent) falsification and in this way determining the *limits* of the validity.

Such a process, called by us hyper-constructivistic develops various skills that are desirable in school education:

5 We paraphrase this statement to a joyful extreme: there are no incorrect answers of the student, but only incorrect questions as posed by teachers (see fig. 4a).

- capacity of personal expressing;
- collaboration in the group;
- individual division of tasks, that can enhance specific talents (even apparently harmful like being noisy) of each pupil.

Frequently evoked today social competences that physics can produce in young minds, can be ordered in following manner:
- capacity of critical evaluation of the external reality (or theories);
- capacity of detailed planning of experimental procedures;
- capacity of extracting crucial information, with coarse confidence error bars;
- capacity of synthesis of different phenomena;
- insistence on practical implementation of correct ideas on the external reality.

Resuming: leaving the detailed definition of Newton laws to internet, the learning and teaching physics can re-acquire their *forma-mentis* importance, once the teacher (and school programmes and equipment) allow a heuristic adventure rather than gaining PISA scores.

References

Abell S. K. (2008). Twenty Years Later: Does pedagogical content knowledge remain a useful idea? *International Journal of Science Education*, 30, *10*, pp. 1405-1416.

Aristotele (2011). *Fisica*. Milano: Bompiani.

Berger, P. L. and Luckmann T. (1966). *The Social Construction of Reality. A Treatise in the Sociology of Knowledge*. Garden City, NY: Doubleday.

Bruner J. S. (1991). *Acts of Meaning*. Cambridge: Harvard University Press.

Chapman S. (2015). Physics and Astronomy. In R. Toplis (edited by), *Learning to Teach Science in the Secondary School. A companion to school experience*. London-New York, Routledge, Taylor & Francis Group.

Chiarenza G. A. (1991). A critical review of psychological and clinical aspects of movement related brain macropotential in humans. *Italian Journal of Neurological Sciences*, *12*, pp. 17-30.

Crispiani P. (2004) *Didattica cognitivista*. Roma: Armando.

Damiano E. (1994). *Insegnare con i concetti*. Torino: SEI.

Descartes R. (1668). *Discours de la methode pour bien conduire sa raison et chercher la verite' dans les sciences plus la Dioptrique et le meteores, qui font des effais de cette Methode*. Paris: Girard.

Falchetti E. (2011). I musei scientifici incontrano i giovani. *Studium Educationis, 3*, pp. 97-111.

Frova A. (2001). *La fisica sotto il naso*. Milano: RCS Libri.

Galileo G. (2014). *Dialogo dei Massimi Sistemi*. Milano: Oscar Mondadori.

Goldman S. (1998). Researching the Thinking-Centered Classroom. In J. G. Greeno, S. V. Goldmanw (edited by). *Thinking practices in mathematics and science learning*. Mahwah, NJ: Lawrence Erlbaum Associates.

Hewitt P. G. (2015). *Conceptual Physics*, 12th ed., Harlow: Pearson.

Karwasz G. P. (2000). Czy wiat kr ci si w prawo? Fizyka i zabawki, (Does the world turn right? Physics and toys), *Post py Fizyki, (Progress in Physics)*, 51, Supplement.
Karwasz G. et al. (2005a). *Physics and Toys*, CD-ROM. Sopot: Soliton.
Karwasz G. (2012). Teaching science in early childhood – inquiry-based, interactive path on energy. In Lindell, A.- Kähkönen L., Viiri J., editors, *Physics Alive, Proceedings GIREP-EPEC Conference 2011*, JYFL Research Report no.10/2012, University of Jyväskylä.
Landau L. D., Kitaigorodskij A. I. (2014) *La fisica per tutti*. Roma: Editori Riuniti.
Macchietti S. S. (2012). Persona. *Studium Educationis, 3*, pp. 135-138.
Michelini M., Vercellati S. (2012). Pupils explore magnetic and electromagnetic phenomena in CLOE labs. *Latin-American Journal of Physics Education*, 6, Suppl. I, August 2012, pp. 10-15.
Milan G. (2014). Le "pagelle" OCSE: risultati in chiaroscuro. *Studium Educationis, 1* , p. 115-116.
Montessori M. (1968). *La scoperta del bambino.* Milano: Garzanti.
Morin E. (1999). *La tête bien faite*. Paris: Éd. du Seuil.
Parker S. (2005). *The Science of Electricity & Magnetism*. London: David West Children's Books.
Perel'man Ya. I. (2008). *Physics for Entertainment*. New York: Hyperion Books.
Rogers E. M. (1960). *Physics for the Inquiring Mind*. Princeton: Princeton University Press; London: Oxford University Press.
Shulman L.S. (1987). Knowledge and Teaching. Foundation of the New Reform. *Harvard Educational Review*, 57, *1*, pp. 1-21.
Zanetti V. (1994). I giocattoli e la scienza. Schede per una diversa didattica della fisica. *La fisica nella scuola*, 26, *4* (supplemento).

Website citations

Karwasz G. *et al.* (2005b). *Physics is Fun*. EU Science & Society 020772 Project,
http://www.2020-horizon.com/PHYSFUN-Physics-is-Fun(PHYSFUN)-s26601.html
http://dydaktyka.fizyka.umk.pl/Physics_is_fun/ (accessed 13/08/2016)
Koupilová Z. *et al.* (2016) *Collection of Solved Problems in Physics,* Univerzita Karlova, Prague, http://physicstasks.eu/ (accessed 13/08/2106)
TALIS (2009) *Creating Effective Teaching and Learning Environments. First Results from TALIS,* OECD Teaching And Learning International Survey http://www.-oecd.org/dataoecd/17/51/43023606.pdf (accessed 08.08.2016).

SE