Teaching physics in XXI century. Why and how

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Fifty years ago, when GIREP was founded, our civilization was very different from that we are now living in and which we are trying to comprehend in order to provide at least some guidance to the future generations. The guidance which in the past we would have called education.

Fifty years ago our civilization was that of vinyl records, Walkman and MP3 era was yet to come, electronic watches and wireless phones were only in the Dick Tracy cartoons and the James Bond movies. Computers were behemoths hidden behind doors of military, industrial and selected research institutions. CERN an Arecibo were in their infancy and so were preparations to the moon landing. Satellites were launched but they have served mostly military purposes with very limited though often important scientific output.

Fifty years ago the world was heavily breathing under the weight of the Cold War, regaining semi-balance after the President Kennedy assassination and the Chairman Khrushtschev forced resignation. France was struggling with relocation of almost 900 thousands of “migrants” from Algeria and mopping out the rest of OAS. The new seeds of terror cancer were growing in Germany and Italy. The sounds of guns from Vietnam were not yet bothering us too much.

In spite of all that “the West” was rich and happy but soon this state of illusionary tranquility was shattered on streets of Paris with student revolt which had derailed education system of those times. The system which was essentially the continuation of “the business as usual” inherited from the pre-war Europe. Major consequence of that Paris spring was that the era of experiments in education based upon preconceived ideological “principles” has begun. The best description of those attempts to invent new education was ridiculed by comedian and mathematician Tom Lehrer in his song “New Math”\(^1\) – “the important thing is to know what are you doing rather than to get right answer”. Politically motivated system of tests was slowly but persistently taking over, first schools and later, universities. That was, basically the educational systems which XXI century generations have inherited.

The beginning of XXI century was marked by the first sign that our society is not prepared to face reality of the technological changes, which throughout the last years of the previous century were already slowly and quietly reshaping the future of the mankind. The bogus Y2K catastrophe, predicted for the 2000-2001 night, was quickly forgotten and the lesson from it has never been learned. Meanwhile, progressing like the bushfire, the process of moving all our essential activities on-line resulted in the situation that serious collapse of the information network in any country, but especially in the most developed ones, would be an effective Armageddon.

On various occasions I have been showing the picture, taken by my nephew, during the New York hurricane Sandy blackout in 2012, of people on the street lining up to the stand providing the charge to their mobile devices. Access to the Net was equally important as food or water.

Today’s family, with two junior-high age kids, is typically using four smartphones. A rather conservative estimate of yearly electric energy share of the smartphone, in support of the network and world cloud system – we can neglect minor energy use for charging – is roughly the same as that of

\(^1\) Tom Lehrer. New Math. https://www.youtube.com/watch?v=UIKGV2cTgqA.
a modern refrigerator. That family is surely completely unaware of that although it will be unable to exist, socially and professionally, without access to the Net. Imagine what will happen when, eventually, someone will ask them to pay the bill? In spite of taking hours of physics in high schools and possibly in college they were never properly thought to understand the energy flow in the contemporary society.

In that completely different civilization our educational system is trying to provide the guidance to our youth using essentially the same language and ideas as fifty years ago. We are as physicists on the turn of XIX and XX century trying to explain various, discovered at that time phenomena with classical physics. They failed since what was needed was a different science and a different language. Eventually that new science – quantum mechanics and relativity theory were established changing world forever. That is precisely what we need now in education.

Since the civilization, we lived in, was changed by the proliferation of the discoveries of physics, we are obliged to start the invention of new education, education of the XXI century, from changing the way we teach physics. Physics is understood here in a broad sense as what used to be called natural sciences, mathematics and applications in some basic social sciences like economy. That is the definition of physics given in the seminal lecture of great mathematician Vladimir Arnold back in the XX century.

We should base our future educational system, or systems, on problem solving. The problems are all around us. Thomas Jefferson formulated the basic ideas of science and civilization progress, which Gerald Holton called Jeffersonian Research Program. It assumes that problems to be solved are picked by active individuals depending on his/her interest from the pool of issues provided by natural and social, cultural and political environment. That program, applied to education, reverberates XVIII century Johann Pestalotzzi “teaching child not a subject” program. We should allow a pupil to pick up problems according to his or her talents and interest and then use that knowledge wisely to steer that person throughout the long process of education. That requires individualization of education, not possible in the past but achievable now due to phenomenal development of technology. We no longer need to provide the same chunk of knowledge to everybody, for whatever knowledge of facts, data, methods, is necessary it is available in that sea of information provided by the global network. What we have to provide in education is how that knowledge should be effectively filtered out from the peta-bytes of information and noise of the Network. Because effective filtering of information is exactly what we do in physics and since most of the problems of today are physics-related that is why we need to teach physics in XXI century. The question is now how.

Since physics is to serve as a tool of education rather than just one of many subjects included in the school curricula the way we teach it should change. I have already mentioned conservation of energy. Probably every program of high school physics contains exposition to the conservation of energy and basis of thermodynamics. In spite of that, the concept “renewable energy” is used permanently in the important debate about the mankind energy and/or climate future. The fact that in Europe solar energy per square meter per day only implies 0.5 l of 95 octane gasoline and that this tiny amount is further

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2 V. Arnold. On Teaching Mathematics cf for example http://pauli.uni-muenster.de/~munsteg/arnold.html.
3 Gerald Holton. Science and Anti-Science Harvard University Press, Boston 1993 see also http://issues.org/16-1/holton/.
partially lost by whatever devices we invent to use it, because thermodynamics laws are so “cruel” is not generally understood, not only by politicians.

A brief check of the Tesla cars add page\(^4\) provide information, given by the producer, on how much electricity we need to produce and to deliver to the electric outlet in the Tesla owner garage in order to provide the juice for a one kilometer ride. Multiplying that by the number of cars registered in a country and then by averaged mileage covered we can easily estimate that switching to Teslas would require increase of electricity production of a country by huge percentage (in Poland about 15 to 30%). That would be a disaster to a country electric grid, unless it will be considerably improved.

We cannot prepare the future generations for the „all electric” world unless we will teach them science, particularly physics, differently than today. The founding father of the electric revolution of previous century, Carl Proteus Steinmetz, was aware of that when he was preparing courses for his students in Union College. His ideas echo in words of Thomas Friedman and Michael Mandelbaum\(^5\).

*Learning to repair the engine of an electric car, or a robotic cutting tool, or a new gas-powered vehicle that has more computing power that the Apollo space capsule – these are no skills you can pick up in a semester of high school class.*

Staying with my example of the science of electricity, that implies that in addition to fundamental facts like Coulomb interaction, Kirchhoff’s and Ohm’s laws we have finally to include into high-school curricula Maxwell equations. For in the world which is now immersed in the electromagnetic radiation, form the sun light to Bluetooth generated waves connecting all the smartphones, laptops etc. in this lecture hall, knowledge of the properties of the electromagnetic waves is of predominant importance.

To teach the properties of the electromagnetic fields and their interaction with matter we also have to teach how the mankind progressed by developing the means of generating electric energy including the fact that electricity is a fantastic tool to transport energy and extremely ineffective way of storing it. The knowledge of that is required for all citizens of XXI century who have make a decision on how in the future we will generate electric energy. Otherwise various activists will continue to win debates for and against nuclear energy using solar energy as panacea for our energetic dilemmas. The modern teaching of electricity and magnetism will have to abandon beautiful and pretty useless, for today discussion, XIX century experiments, they have to be replaced by modern experiments showing all the same properties of the electromagnetic field. The ghost of a one Farad, a giant metal sphere, should be either replaced with the capacitor Earth ionosphere – ground or be buried with all required honors. I would like to ask this conference how many students, you teach, know how the super-capacitor, in my few dollars’ worth watch, works. Just the basic principle.

The return of physics teaching to its usefulness begins in the school laboratory. Only by giving students the chance of doing lots of modern experiments we will be able to show them, that it is impossible to do those experiments and subsequently build “things” we use daily, without thorough knowledge of the fundamental laws, like the conservation of energy I was just talking about.

We should also renew the pool of experiments we do in schools. We have to stop fearing experiment with radioactivity in schools. Knowledge of radioactivity is an anathema in today’s curricula, an absurd in the time when our medical colleagues are using antimatter in every day practice (PET devices). Irresponsible choice of the radioactivity units result in the fact that seven or so kilo-becquerels of radioactive decays in our body and even the radioactivity of common banana might stir a profound feeling of fear between most of the college educated individuals. How many radiologist attendants can explain the crucial difference between the Gray and Sievert units. That difference is important in explaining why beaches of Brazilian resort Guarapari are open to the public.

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\(^4\) [https://www.tesla.com](https://www.tesla.com).

\(^5\) T.L. Friedman & M. Mandelbaum. That Used to Be Us How America Fell Behind in the World It Invented and How We Can Come Back Picador New York (Kindle edition).
There are many areas of classical physics, whatever that means in the XXI century, which are wrongly presented in schools. For example the notion of entropy is so crucial in understanding contemporary informatics, how the MP3 or other compressing algorithms work etc. I do not even mention the basis of quantum information processing. That last idea might revolutionize the world beyond the common tale about Schrödinger cat. Do we teach that at all?

Most of mechanical devices function because of friction. How many thousands of students are finishing their school or college education with the wrong „conviction” that friction force $T$ is always equal of $\eta N$, where $N$ is the force exerted perpendicularly to the surface and $\eta$ is the friction coefficient?

Essentially all the facts about things I have mentioned can be found in the Net. Most are there to find using ways of searching we have to explain to students, particularly explaining that what is on the Web is not necessarily true. Wikipedia, unfortunately, is not as dependable source of information as the Wolfram Alpha. Not all the e-education materials are of the quality of Khan Academy.

IT proliferation had changed our life. One of the area of education where, I believe, the use of the IT should be restricted, is the school laboratory. I strongly oppose the replacement of real experiments with the beautiful computer simulations and/or YT presentations. Computers can and should help us to do experiments better and analyze their results but should never replace the experiment. I repeat here again that the only use of laptop, tablet or whatever, in teaching gravity is to drop it from the table to show which direction the earth gravity works. A few dollars’ worth tools available in the Raspberry Pi project, together with that computer by itself, are excellent in helping students to build their own experimental apparatus required to precisely measure the gravity acceleration. However, that would require an active participation of a student in a real experiment and offers them the chance to face difficulties of the real experiment—that means world, not beautiful computer graphics occasionally massaged for the purpose of better visualization as the laws of the mechanics used in shooting fighting scenes in the movie Matrix.

I believe knowledge of physics is important as a basic tool for understanding the world. Three years ago my 10 years old grandson took with him for vacation, we were spending together, the book suggested by his teacher – The Adventures of Tom Sawyer. I noticed that he did whatever possible to avoid reading it. He confessed that he found that book dull. He was reading the paper edition of the book. I promptly provided an electronic version of it and we started to read it using the quality book-reader on one of our tablets. The book had „opened up”. I found that the children, here in Poland, asked to read that book are unaware from where it comes, and what is the meaning of, the Samuel Clemens literary pseudonym – Mark Twain. So we used the ability of the reader to search the Web for notions marked in the text and we started to explore first the notion – Mississippi. Soon were investigating the details of that river hydrology, then the engineering of the famous Mississippi boats and ships. For example why those boats have the paddle-wheel on the back in contrast to the boats, say on the Vistula or Rhine. Soon the question of the positioning of the boilers on those boats became an issue of discussion and simple experiments we did with breakfast frankfurters, etc. We also had to resolve the problem of the book translation into Polish, particularly the question of some politically incorrect words used by Twain, which have been translated into Polish in a completely ridiculous fashion. As you see I used the book from the primary-school children bookshelf as the tool to teach several “subjects”\(^6\). A few days ago, during the yearly conference for teachers, that was held at the Copernicus Science Center, jointly with the one of the leading Polish and French actor Andrzej Seweryn, we run the workshop devoted to the physics way of reading books. This time we used one of the rhymes for children by Polish poet Jan Brzechwa “The Nut” in which a lawyer from a little town next to Warsaw gets a particularly tough nut and tries to crush it by many means which all fail, eventually a squirrel

\[^6\] L.A. Turski Lecture on the 60 anniversary of the Institute of Literature of the Polish Academy of Sciences 2013. Computer presentation available from the author. Fragments included in the interview with Anita Czupryn in Polska the Times, http://www.polskatimes.pl/artykul/1074970,prof-turski-bez-pana-tadeusza-nie-mozna-zrozumiec-tego-co-sie-w-polsce-dzialo-i-dzieje,id,t.html.
enters through the window and crushes the nut shell and eats the kernel. All those unsuccessful attempts to crush the nuts can be used to introduce the meaning of the word hard, the method of measuring hardness of materials (one of the attempts to crush the nut by a blacksmith using the heavy hammer fits beautifully the Leeb method of measuring the hardness by rebounding a tester head from a tested material) and finally the fascinating story of rodent’s bite power. That last issue allows to introduce the concept of allometric relation, basic in nature but not mentioned in school education (the strength of rodent bite is related to the body mass of rodent by power law with the same exponent for hundreds of rodents investigated).

I believe I have made my points pretty clear. I would like to close with one quotation to support my way of thinking about the physics education of XXI century which is that from the book which has been my guidance in thinking about the education from the day I have got it, John Dewey *Democracy and Education: an Introduction to the philosophy of education*. It says:

> Pupils begin their study of science with texts in which the subject is organized into topics according to the order of the specialist. Technical concepts, with their definitions, are introduced at the outset. Laws are introduced at a very early stage, with at best few indications of the way in which they were arrived at. The pupils learn „science” instead of learning the scientific way of treating the familiar material of ordinary experience.

After fifty years of GIREP existence the world civilization is on a turning point. We have a fantastic progress in the technology, medicine, agriculture, biology—including that of our own genome structure and have possibility of making this world a place of plenty and as peaceful as possible. Nevertheless we are facing the migrants problem, on the scale similar to that fifty years ago, which we cannot handle with our technical means surpassing anything available to our predecessors. We are facing the terrorist treat which again we cannot contain in spite of employing technology no one even dreamed about when Red Brigades were rooming the streets of Rome. We face the world energy crisis and possible consequences of whatever changes in climate are ahead of us. I believe that all this is strongly related to the failure of the world educational system.

That Education system we have now failed us. The point is to build a new one. In that new system the main goal should be a better understanding of nature surrounding us, for the changes in it, irrespectively anthropogenic or caused by natural phenomena, will soon influence the way we live on a scale we had not envisage when the atomic energy was harnessed and transistor were build. This goal cannot be achieved without improving the understanding of basic rules the nature works according to and the basic rules through which we can use the nature in a sensible way. And that means physics. With improved physics education we can create truly educated society and the society of educated people, as Thomas Jefferson said, is the only one which can guarantee the preservation of the most precious value in human live-the freedom.