ENERGY IN SCHOOL TEXTBOOKS: A COMPARATIVE STUDY[1]

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Abstract

Energy is a unifying concept that spans all the sciences, and is of fundamental importance in issues of social concern such as the environment and the use of fuel resources. Children have preliminary notion of energy from everyday life, related with the problems of environment and economics (energy production, energy consumption, energy crises). At school, they are confronted with physical idea of 'conserved energy'. In or survey we analyze the introduction of energy concept in Hungarian, Serbian and Polish introductory science textbooks and how that concept is assimilated by pupils We point out some common mistakes and imprecisions occurring in textbooks. We also present how the ways of introducing and explaining the notion of energy was changing over last decades and make some suggestions concerning possible changes for the future.
Key words: *energy, thermodynamics, school textbooks, comparative analysis.*

Introduction

A systematic survey has shown that there are at least six different energy concepts, used in different areas of sciences and human activity (Martinás, 2005).

E1) colloquial "power and ability to be physically and mentally active"

Examples: "Since I started eating more healthily I've got so much more energy. I was going to go out this evening, but I just haven't got the energy. I didn't even have the energy to get out of bed. Her writing is full of passion and energy (= enthusiasm). I'm going to channel all my energies into getting a better job. I tried aerobics but it was too energetic for me. I felt much energized after my holiday.

E2) metaphysical energy: Taking the existence of all these transmutations into account, what remains of the old idea of matter and of substance? The answer is energy. This is the true substance, that which is conserved; only the form in which it appears is changing

E3) the conserved energy of physics

The sound description of E3 energy was given by the Nobel Prize winning physicist, Richard Feynman, who wrote [Feynman 1963]: "There is a fact, or if you wish a law, governing all natural phenomena that are known to date. There is no exception to this law – it is exact so far as is known. The law is called the conservation of energy. It says that there is a certain quantity, which we call energy that does not change in the manifold changes which nature undergoes. That is a most abstract idea because it is a mathematical principle; it says that there is a numerical quantity, which does not change when something happens. It is not a description of a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same."

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Conservation of energy states that the total amount of energy (in mechanics often expressed as the sum of kinetic energy and potential energy) in an isolated system remains constant. In other words, energy can be converted from one form to another, but it cannot be created nor destroyed. In modern physics, all forms of energy exhibit mass and all mass is a form of energy.

E4) a capacity to perform work

In the engineering practice the capacity to perform work is a well–defined concept, and it is called exergy [Ayres at al 98, Daniel and Rosen 2002]. Exergy is the maximum amount of work that can be extracted from a physical system by exchanging matter and energy with large reservoirs in a reference state. This work potential is due to either a potential due to random thermal motion, kinetic energy, potential energy associated with a restoring force, or the concentration of species relative to a reference state. While energy is conserved, exergy can be destroyed. The second law (formulated by exergy) is the principle of exergy dissipation.

In physics the conserved energy and the working ability controversy is "solved" by the statement, that energy is the ability to perform work, but it has available and non–available forms, suggesting that the working ability is always less then the total energy.

E5) useful energy of ecology and economics

The biological (economic) systems are non-equilibrium systems from the point of view of thermodynamics The more developed the system the higher is the distance form equilibrium. To sustain the state we have to feed the system. Nevertheless not only exergy, but exergy in a usable form is needed. The oxygen and hydrogen have more extropy than water, but as Lozada [2005] explained: "But suppose I am dying of thirst on a desert island. If I have hydrogen and oxygen but no catalyst (such as platinum) to make them react, I will die; if I have water, I will live."

As Witt summarized the characteristics of metabolism [2005]: "Consider, for example, the more or less complex metabolism of living organisms. The outcome of that production process is organized living substance. It is maintained by the process not least through the transformations by which energy is made available for use by the organism from carbohydrates, fats, and proteins which have ultimately arisen from the photosynthesis of radiant energy provided by sun light. The latter, together with minerals, water, oxygen, and possibly some other organic compounds, represent the 'inputs' to that production."

As it is emphasized by Witts' summary, in biology and economics only that part of exergy is considered "(free) energy", which is useful. Biological energy comes from solar energy. The energy from the sun is stored and transported in plants and animals as chemical energy in the bonds between atoms in molecules. Some biological energy is stored in phosphate bonds in a molecule called ATP. ATP can release its energy in many useful ways in cells, but it is not very stable, so it is not be a good way to store energy for long periods of time. For transport through an organism, or for longer term storage, biological energy can be stored in chemical bonds between carbon atoms in more stable molecules called carbohydrates.

Definition given by BEIng (Biological Energy Interest group) [BEIng][2]: "We use the phrase 'biological energy' as a convention to refer to a specific social and technological endeavour: to use the metabolic capacities of organisms to convert some combination of light, biomass, organic compounds, gases and water into useful chemical-bond energy; i.e. storable, transportable, energy yielding molecules as well as industrially useful materials. Examples include hydrogen, methane, alcohols, ammonia and bioplastics."

Nowadays in economics the energy is considered as fuel. A substance used as a source of energy, usually by the heat produced in combustion. The modern economic energy concept becomes popular with the energy crises, which is a great shortfall (or price rise) in the supply of energy to an economy. All living organisms including humans dissipate exergy. In any

[2] http:// web.mit.edu/~pweigele/www/being/content/what.htm

production process an important factors of production can then trivially identified: the matter or materials, i.e. substances of a certain chemical or molecular composition, which are non–equilibrium systems. This inputs are transformed. The production is the transformation of exergy from a less useful to more useful form. The energy term in economics is not simply the useful part of exergy, but it contains a valuation, too.

E6) pseudoscientific energy

"What made it appealing was that energy is always conserved, never created or destroyed." Davies (84) goes on to say, "When an abstract concept becomes so successful that it permeates through to the general public, the distinction between real and imaginary becomes blurred... This is what happened in the case of energy... Energy is... an imaginary, abstract concept which nevertheless has become so much a part of our everyday vocabulary that we imbue it with concrete existence."

Sometimes these mystic energy followers consider these energies as the real generalisation of the energy of the science. For them the secondary school education in physics, that is the Newtonian energy concept – gives the basis to understand these "mystic" energy. According to a 2005 Gallup poll, 55 % of Americans believe in psychic or spiritual healing, based on this New Age energy. That is the point where we have to mention the "Free energy" cult [3], or with other words, the perpetual mobile constructors. In the last 150 years at least 1400 "free energy" machines were patented in USA. They claim that certain special interest groups are suppressing technologies that would or could provide energy at reduced costs, reduced pollution output, or would or could reduce the energy consumption of various devices. The knowledge given by the education is not sufficient to avoid investments into this "miracle machines". United States Patent and Trademark Office (USPTO) has made an official policy of refusing to grant patents for perpetual motion machines without a working model. One reason for this concern is that a few "inventors" have waved a patent in front of potential investors, who may believe that said patent proves the machine works.

Energy in school

Our aim is to investigate the books on physics, whether they can help to understand the problem of energy? Before entering science classes, children have preliminary notion of energy from everyday life, related with the problems of environment and economics (energy production, energy consumption, energy crises), corresponding to "E1" and "E6" in our classification; At school, they are confronted mainly with physical idea of 'conserved energy'.

In many countries, science teaching is still divided into classes of physics, chemistry and biology, often without correlations between relevant curricula. The notion of energy is discussed mainly in physics classes (as "E3" and "E4" in our classification), it also appears in biology (mainly in the context of environmental problems) and (rarely) in chemistry, usually in senior classes of secondary school, e.g. "exoenergetic" and "endoenergetic" chemical reactions (Orzechowski [2004]).

Additional confusion in due to different energy units (J, cal, kWh, eV etc.) used in different contexts.

In our survey we analyze the introduction of energy concept in Hungarian, Serbian and Polish introductory science textbooks and how that concept is assimilated by pupils. Interviews and tests for understanding have been used (Nahalka et al., 2002). While it is often declared that programs for lower secondary/upper primary physics classes are based on the "development of notion of energy and understanding of energetic transformations/the notion of energy, its different forms, mutual transformations and its utilization by humans", there are still

[3] http://en.wikipedia.org/wiki/Free_energy_suppression

many common mistakes and inaccuracies occurring in textbooks. Moreover, most of “extensions” of the basic program still base on the physics of ideal gases.

Trumper and Gorsky (93) investigated the energy concept of children. They identified nine distinct conceptual frameworks, cited by Sefton (98). Characteristics of these broad conceptions what they found that refer to capacity to perform actions. It is clear, that in spite of all the efforts of education of physics the conserved energy concept is far from the students.

Gregg Swackhamer in 2005 gave a very concise summary of the problem, in his draft “Cognitive Resources for Understanding Energy” [4]. Here are some important statements:

“One hundred and sixty years after its advent energy has become an indispensable concept for describing and explaining our world scientifically. Therefore it is now ubiquitous in school science curricula worldwide and regarded as of first importance universally by scientists and educators alike. Nonetheless, energy is not well understood by our students. Students graduating from secondary schools generally cannot use energy to describe or explain even basic, everyday phenomena.”

“Energy as presented in school science is not a single, coherent concept, and it is not always consistent with the scientific energy concept. Furthermore the energy concept in the professional science education literature is not even unitary. As a result energy is not treated in consistent ways from year to year and from discipline to discipline in our schools. Today’s school science energy concept has retained and acquired connotations that contradict the modern scientific energy concept and that hinder its comprehension by teachers and students alike.“

The problem of the different connotations was already mentioned in 1914 by a Hungarian writer – Ferenc Móra (1914). Mora wrote a short article in a newspaper about Robert Mayer, with a good introduction of the First Law of Thermodynamics. He stated the grave conceptual problem as: “If I say that I do not believe in the conservation of energy than the Professors of

Physics will say that I am asinine, as I am a layman. If I say that I do believe in the conservation of energy than the Reader of this Journal will say that He is asinine, as he is a scientist.”

Móra said, that he does not believe in the conservation of energy, as his energy disappeared: “Where is that Robert Mayer who can tell me where is my childhood’s energy?”

This problem of understanding of energy is a problem of the schools. It is a grave problem, as the majority after the secondary school stops the education in natural sciences.. The majority of non-natural scientists do not feel the energy concept, and the only understandable version for them is the E6.

Thermodynamics in primary/lower secondary schools

We compared the primary/lower secondary school books on thermodynamics in 3 different countries, Hungary, Serbia and Poland. Here we present the detailed description of the Polish system.

Up to 1999/2000 there was a „8+4” system, similar to SR and HU. At primary level, physics was taught in classes 6–8. Thermal phenomena were taught in 7th class, after mechanics (Ginter 1985); the course included the notion of internal energy and first law of thermodynamics. At secondary level, physics was taught in classes 9–12. The course encompassed ideal and real gases, first and second law of thermodynamics, heat engines and Carnot cycle, notion of entropy, statistical interpretation of entropy (Salach 2006).

After the reform of 1999/2000, we have a kind of 'recurrent' teaching, starting from integrated science (primary school, classes 4–6), based on everyday experience: inter alia –

[4] modeling.asu.edu/modeling/CognitiveResources–Energy.pdf

states of matter, kinds of energy, thermal processes etc. The main stress in on showing mutual relationships between various natural phenomena (Hoppe 2001).

In 3-year lower secondary school there is a large variety of approved textbooks – they have to cover curricular framework, but there is a freedom of choice of sequence of material. Energy and thermal phenomena are discussed in Class 1 or 2 (Ginter 1999, Rozenbajgier 2006a,b). In (Rozenbajgier 2006a,b), evaluated as the best gymnasium physics textbook by the Polish Academy of Arts and Sciences there are many examples from real life, describing (among others) various energy transformations. There are also rather extensive and illustrative description of phase transitions and related thermal effects.

Compulsory education ends after 'gymnasium' (class 9); so in compulsory 9-year education cycle Second Law does not appear. On the other hand, there is extensive discussion of energy forms and energy transformations. In book for primary school it is even mentioned that colloquial notion 'energy is consumed' is not related with physical energy. Integrated approach at early stages is probably a good way to introduce basic notions to kids (for example; they learn about water, volcanoes, human organism etc. and on that occasions they learn new physical, biological and chemical notions).

In Lyceum (class 10–12) there is also a large variety of various textbooks realizing common curricular framework in different ways. Some of them are 'classical' (centered on Carnot cycle, ideal gases etc), but there are also other ones which even introduce elements of 'new science': chaos theory, thermodynamic time arrow etc. (Chyla 2003).

Results

All the text books investigated are very high quality texts. Experiments, relation with real word problems are present. Naturally some of the simplification needed, are questionable, but there no text book which is not acceptable from scientific point of view. The structure of the text books is different, but all of them have their own logic, and they are good.

There are in every country efforts, which are promising. The "Polish way of "recurrent teaching", i.e. introducing basic notions two times during compulsory education (age 10–12 and age 13–14) seems to be promising, First time teaching is based on children everyday experience and the notions are presented in integrated learning environment. In Polish upper secondary school there is also place to introduce some notions of 'new physics' (chaos theory etc.) and to discuss more deeply issue of irreversibility. Great flexibility of PL primary and secondary school programs (inter alia: the sequences of teaching basic notions can significantly differ) can be a good basis for further investigation in coming years (efficiency of teaching physics along various paths). Similar trends are characteristics for Hungary and Serbia.

Nevertheless the basic problem of teaching of thermodynamics and thermal phenomena, that the phenomena are everyday experience, the physical concepts are abstract. In primary school, about 40 thermodynamics-related terms are introduced (mentioned). In the thermodynamic part (in the lower secondary school in Poland or in the 7^{th} class in Hungary and in Serbia) , most of them are re-introduced and explained in more detail. But there is no clear distinction of the different meanings of energy – the books handle it as a unique, well-defined concept.

That is not only problem with energy. The teaching of physics does not reflect the connotation of words outside the physics discipline.

The concept of force is a grave problem too, and similarly the concept of work.

In the thermal part heat and temperature are considered as known, trivial concepts. As for instance, the zeroth law of thermodynamics, namely that in equilibrium the temperature is constant is not mentioned. We do not miss the name, zeroth law, but that law.

Distinction of the different meanings of work is neglected. Work is a purposeful action to produce changes, but in physics effort needed to produce certain changes or displacement times the force.

Conclusions

In the following table we present the number of new concepts introduced in the text books – The new concepts were defined – where it is an unknown word for the majority, or there is a difference between the colloquial and the physical usage)

Table 1. New concepts related with thermal physics.

	HU	SR	PL
Primary/ Lower secondary	Csákány 58 Zátonyi 48 Gulyás 45	Milan 33 Jovan 37	38 (lower secondary)
Secondary	Pászli 59 Karácsonyi 32	Raspopovic 28	35 (upper secondary); 16 of them new

There is a significant difference between the countries; The Hungarian books talk also about the heat engines, and the efficiency. The smaller number of Secondary school concepts is explained by the fact that the books assume that concepts mentioned on the elementary level are already (or yet) well-known.

In the surveyed books we did not find reflections for the different connotations of energy.

Appendix: List of textbooks

Hungarian: text books:

Gulyás János–Honyek Gyula–Markovits Tibor–Szalóki Dezső–Tomcsányi Péter–Varga Antal: *Fizika 7* Műszaki Tankönyvkiadó, Budapest 2003 2. kiadás (143 pages, thermodynamics – 38 pages).

Dr. Zátonyi Sándor: *Fizika az általános iskolák 7. osztálya számára*. Nemzeti Tankönyvkiadó, Budapest, 2006 3. kiadás (195 pages, thermodynamics – 57 pages).

Csákány Antalné–Károlyházy Frigyes: *Fizika 7*, Nemzeti Tankönyvkiadó, Budapest, 2006 2. kiadás (155 pages, thermodynamics – 51 pages).

Dr. Karácsonyi Rezső: *Fizika a gimnáziumok 10. évfolyama számára*, hőtan, elektromágnességtan (humán érdeklődésű középiskolások számára) Nemzeti Tankönyvkiadó, Budapest, 2003 2. kiadás (239 pages, thermodynamics – 85 pages).

Dr. Paál Tamás – Dr. Pászli István – Venczel Ottó: *Fizika szakközépiskola 10. évfol*yama. Nemzeti Tankönyvkiadó, Budapest, 2006 3. kiadás (211 pages, thermodynamics – 70 pages).

Polish textbooks

Chyla K., et al., (2003). *Physics with Astronomy*. Bielsko Biala: Debit. (in Polish).

Ginter, J., (1985). *Physics, 7th class of primary school*. Warsaw: WSiP. (in Polish).

Ginter, J., (1999). *Physics, 1st class of gymnasium*. Warsaw: WSiP. (in Polish).

Hoppe, L., et al., (2004) *Science, 4th class of primary school*. Gdynia: Operon. (in Polish).

Hoppe, L., et al., (2001) *Science, 6th class of primary school*. Rumia: Operon. (in Polish).

Rozenbajgier, M., & Rozenbajgier, R., (2006a). *Physics for Gymnasium, Part 1*. Krakow: ZamKor. (in Polish).

Rozenbajgier, M., & Rozenbajgier, R., (2006b). *Physics for Gymnasium, Part 2*. Krakow: ZamKor. (in Polish).

Salach, J., (2006). *Thermodynamics*. Krakow: ZamKor. (in Polish).

Serbian textbooks

Raspopovic, M., Bozin S., Danilovic E., (1994). *Physics for 2^{nd} class of secondary school (mathematical profile*). Beograd: Zavod za udzbenike i nastavna sredstva (197 pages, thermodynamics – 96 pages).

Raspopovic, M., Nikic, B., Ivanovic, D., Tomic, J., Krpic, D., (2002). *Physics 7^{th} class of primary school.* Beograd: Zavod za udzbenike i nastavna srestva (121 pages, thermodynamics – 25 pages).

Setrajcic, J.P., Kapor, D.V., *Physics 7^{th} class of primary school.* Beograd: Zavod za udzbenike i nastavna sredstva, (108 pages, thermodynamics – 10 pages).

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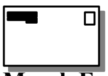

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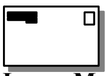

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