Is the second law of thermodynamics easier to understand than the first law

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Dit artikel stelt een, ook voor de nederlandse situatie, interessante en actuele vraag. Het is overgenomen uit: 'Entropy in the School', Proceedings of the 6th Danube Seminar on Physics Education, ed. George Marx, Roland Eötvös Physical Society, Budapest 1983.

Am I posing a strange question in this paper ? It seems so. Usually the first law comes first in physics instruction. The second law comes late. In many introductory physics courses for 10- to 15-year olds this law is completely disregarded. In the Federal Republic of Germany, for instance, the great majority of students leave school with almost no knowledge of the second law.

Is the second law too difficult a topic for most of the students ? Or is an uneasy feeling among teachers and members of syllabus committees concerning the concept of entropy responsible for the minor role the second law plays in physics instruction ?

The latter seems to be more likely. The following sections of this paper will present arguments to the effect that some aspects of the second law are easier to understand than others of the first law.

1. Remarks on the historical development

On the one hand, the second law may be regarded as older than the first law. Sadi Carnot worked out his famous theory of the steam engine in 1824. The second law was already contained in this theory. The idea of the first law arose about 20 years later in the work of a couple of researchers, predominantly independently of each other (Mayer, Helmholtz, Joule, Colding and others, see Kuhn, 1959).

On the other hand, the first law may be taken as the older one. Roots of this law were already developed by Leibniz. The principle of conservation of vis viva was already well known in the mechanics of the 18th century (see e.g. Hiebert, 1962).

In connection with the question posed in this paper a short look at the development of the two laws in the 19th century could be of interest.

Ideas of the first law arose about 1842. The fathers of this law, namely Mayer, Joule, Helmholtz and Colding, did not infer it from empirical evidence. The contrary seems to be true. They were already convinced of the idea of (energy) conservation. This conviction was not only rooted in rational belief but in metaphysical or religious speculations too. This is also true for Joule. His empirical findings were so weak in the beginning of his work that only a person with a strong belief in the conservation idea could accept the results as empirical proof. In general, empirical evidence for the principle of energy conservation was still rather weak, even after it had been accepted by the scientific community (Meyerson, 1930, 199 ff).[1]

The new idea of energy conservation was greeted with distrust by the physicists in the very beginning. The first papers of Mayer and Helmholtz, for instance, were rejected by the scientific community for several reasons. But it took only a short period of time for the principle of energy conservation to ascend to an unquestionable truth. By about 1860 the struggle for the acknowledgement of this principle was finished (Planck, 1913). In 1870, the principle was used in the discussion of Weber's theory of electrodynamics as proof of this theory (Helm, 1887, 47).

The second law had its origin in Sadi Carnot's theory of the steam engine. It was based on experiences with the transformation of heat into work. This law did not become part of physics until the first law had been accepted by some of the scientific community. Clausius formalized the second law in 1850 by introducing the concept of entropy. About 16 years later Boltzmann gave an interpretation of entropy in the particle model of statistical mechanics. Although the second law became one of the cornerstones of physics an uneasy feeling - especially with the concept of entropy - still remained.

There are several reasons for this. Firstly, the mathematical form Clausius gave to the second law is considered as a source of misunderstandings (Ostwald, 1908, 110). Truesdell (1980) voices the following accusation:
"Hitherto thermodynamics had been, like any other theory in mathematical physics, pretty largely a model for the way things are. In Clausius hands it now begins to change into a model for the way things are not (337)."
" ... thermodynamics turned its back on the real world (338)."

Secondly, the notion of conservation seems to be accepted much easier than the idea of irreversibility (see Helm, 1887, 53).[2] Meyerson (1930) has dealt with this aspect in some detail. The pivot of Meyersons philosophy is the idea that the search for identity in the midst of change is inherent in human thinking. Therefore, conservation principles are very 'attractive' to the human mind. Human thinking has the tendency to look for something that does not change in time, something that can be reidentified.[3] There seems to be no such tendency for thinking within the framework of irreversibility.

Meyerson (1930, 272) points out, that the second law is presupposed implicitly at the beginning of most textbooks on heat. Poincaré's definition of temperature (the temperature of two bodies is the same, if neither expands when brought into contact), for instance, already makes use of the second law. Therefore, the second law seems to be a self-evident idea whenever dealing with heat phenomena.

Meyerson points out further that the principle of the conservation of substance (material), the principle of inertia and the principle of energy conservation are in contradiction with everyday experiences much more than the common experience that heat travels only from hot to cold.

Meyersons point of view may be summarized as follows. The second law stems from experiences with heat phenomena. It is implicitly presupposed whenever dealing with such phenomena and it is much more in accordance with everyday experiences than the first law.

The first law has its origin mainly in the tendency of human thinking to look for constancy amidst change. It is, therefore, more 'attractive' for the human mind than the second law.

It may be interesting to mention that J.Piaget (1973, 205) gave a very similar interpretation of the difference between the first and the second law. From the standpoint of his genetic epistemology the main difference is the following. The first law was postulated by rational belief before it could be accomodated to experiences. The second law was revealed by experiences before it could be assimilated to rational thinking.

2. Empirical studies on understanding the first and second laws

Lessons learned from the history of science may provide us with some ideas and hypotheses about learning difficulties in physics instruction. But if we want to get information about learning the first and second laws by our students in school, empirical research is needed.

Unfortunately, only a small number of empirical studies is available in this area.

This is true especially for studies concerning the second law. The purpose of the following section is, therefore, twofold. On the one hand, I wish to present an overview of the body of knowledge available (as far as I know of it, of course). On the other hand I wish to mention areas where research seems to be necessary.

2.1. Empirical studies concerning the first law

The formation of notions of conservation during cognitive development has been investigated by Jean Piaget and his co-workers in Geneva as well as by many 'Piagetian researchers' all over the world.

According to genetic epistemology, the following three logical operations lead to conservation ideas: identity, reversibility and compensation (Piaget, 1973, 125). The idea of conservation of substance (material) can already be found among 7 to 8 year olds. The idea of the conservation of weight follows about two years later, conservation of volume about a further two years later. The roots of 'conservation ideas', therefore, crop up early in cognitive development. But the logical operations are applicable only to rather simple cases. They also cause severe difficulties for much older students (see e.g. Lovell, 1966).

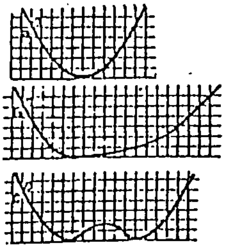
There is only a small number of studies within Piagetian research which deal with the conservation of energy (Piaget, de Lannoy, 1973; Dahncke, 1973; Jenelten-Allkofer, 1979).

Explaining simple processes of mechanics (e.g. the coupled pendulum or the frictionless motion of bodies) even older students (about 16 years old) only seldom employed a type of thinking we would call thinking within the framework of energy conservation. It seems that an idea of energy conservation which is applicable to processes in mechanics is not formed during cognitive development.

It is precisely these processes of mechanics that play an important role in many paths to the energy concept in school. Normally, the principle of energy conservation is not simply introduced as an axiom. Many empirical evidence is compiled to convince the students that this principle is true (see e.g. PS II 1969; Rogers, 1965, 1971; IPN, 1978). Processes of mechanics are prefered for this purpose because the same state (e.g. the same height or the same speed) is present at the beginning and the end of a period of observation.

Such teaching efforts seem not to be very successful. Emperical studies point out that only a minority of students in grades 6 to 10 employs the principle of energy conservation when explaining such mechanical processes. The majority of students prefers notions stemming from everyday experiences and words from everyday language. This is true even for students who have had some years of physics instruction in which the principle of energy conservation was given considerable attention (see Jung et al., 1977; Duit, 1981a, 1981b, 1983; Duit, Talisayon, 1981).

I would like to give one example for the mentioned learning problems of students in some more detail (see fig. 1).



The ball is released at the marked spot and rolls with no drive of its own. We will pretend that there is no friction.

	a	b	c
Prediction of correct height	47	26	33
Use of energy for explanation	35	26	22
Use of energy conservation for explanation	26	18	15

171 students, grade 10, after physics instruction in grades 7 to 10

fig. 1: The motion of a ball in curved paths.
Figures give percentages.
The idea for this task stems from DAHNCKE (1973).

The number of students who predict the correct height of the ball on paths b and c is substantially smaller than on path a. The word 'energy' is used only by a minority of students when explaining the prediction. Most students use words from their everyday language like swing (Schwung). A rather small number of students argues with the principle of energy conservation. Most explanations follow notions and ideas stemming from everyday experiences or mention geometrical qualities of the paths (e.g. the symmetry of path a).

In a study on misconceptions in school thermodynamics (Johnstone, MacDonald, Webb, 1977) more than half of about 100 students in the sixth form were not able to understand that the amount of heat produced during a chemical reaction decreases when the amount of work increases.

I think it is allowed to summarize that comprehending the first law of thermodynamics is not at all an easy task for students in school physics teaching. This statement contradicts the way the aspect of energy conservation is handled in some proposals for teaching energy. Falk/Herrmann (1979) and Schlichting/Backhaus (1979) think that energy conservation is more or less self-evident for students even of grades 5 to 10. They conceptualize energy as a quasi material substance. They deal with energy conservation, but don't mention this aspect. It may be that within such 'materialist' conceptualisation, energy conservation is accepted more easily by students than in other approaches. But there are no empirical studies until now, which give information concerning whether this is indeed so.

2.2. Empirical studies concerning the second law

Only very little information is available concerning the learning of the second law. Studies on heat (e.g. Erickson, 1979) reveal almost nothing about notions of the second law.

In the study of Johnstone, MacDonald and Webb (1977) already mentioned above, we find some results which might be of interest here. Most of the students, for instance, think that entropy is a measure of disorder. But in general the knowledge about entropy is superficial. There is also a tendency to mix up entropy and kinetic energy.

Within the work of Piaget and his co-workers we find studies on the formation of the idea of chance (Piaget, 1973, 1975). The development of this idea as precondition of understanding irreversibility is closely affiliated with the development of the operation of reversibility. When this operation becomes a workable tool for children (beginning at the age level of about 7 to 8 years), first ideas of chance arise too. In much the same way as the operation of reversibility becomes more formal during cognitive development, the idea of chance becomes more formal, too.

Is the idea of energy degradation (in which the central ideas of the second law are included) contained in the everyday meaning of energy ?

Some researchers think that it is so (Schlichting/Backhaus, 1980; Ogborn, 1981; Solomon, 1982). Words like 'energy consumption' or 'useless energy' are given as reference. But there are no empirical studies which give information, whether this is indeed so. My own studies on the meaning of the word energy in German everyday language gave no hints that the idea of energy degradation is contained within the meaning of energy among a significant number of students (Duit, 1983). But it may well be that the methods (e.g. association tests, definitions and examples for energy) employed in my studies for investigating meaning are too limited to get to know something about aspects of energy degradation.

2.3. Concluding remarks concerning empirical findings

We don't know much about learning the first law and we know almost nothing about learning the second law.

What we know about learning energy conservation (the first law) reveals severe difficulties on the part of the students to make use of the principle. This is true even for explaining processes of mechanics which have been used in instruction to convince the students that this principle is valid. To understand the principle of energy conservation in a way which goes beyond a mainly qualitative feeling (nothing comes from nothing and goes into nothing) is not as easy as one could have expected, going by the historical development (see 1.).

3. Summary and some recommendations

I hope that the preceding sections have explained why the question posed in this paper is not a strange one. But it is not easy to give a comprehensive answer. What can be said is the following. The first law is not as easy as one could expect, taking the major role of this principle even in introductory physics courses for grades 5 to 10 into consideration.

There is reason to believe that the minor role the second law plays in school physics teaching is caused mainly by prejudices of people with an uneasy feeling about the entropy concept. The second law seems to be much more in accordance with everyday experiences. Furthermore, whenever we deal with heat in school the second law is implicitly presupposed.

In recent years the number of researchers who are free from the uneasy feeling with regard to the entropy concept and the second law is increasing. There are already proposals to teach aspects of the second law in a mainly qualitative way from the very beginning in school physics instruction (see e.g. Schlichting, Backhaus, 1980; Solomon, 1982; 'lesson dreams' of Ogborn, 1981; Duit, Häussler, 1983).

I want to conclude this paper with the following statement. There is no doubt that we need further proposals for dealing with energy conservation and degradation in school. But it seems to be more urgent at the moment to carry out empirical studies in learning these pivotal aspects of the energy concept. I will try to continue in such research work. I would be glad to share results with other researchers.

Notes

1. This statement refers to the general principle of energy conservation. The experiments on change of work to heat arrived at a quite sufficient standard of accuracy about 1850 already. But evidence for the validity of this principle in other areas still was rather weak.

2. My colleague G. Lind (IPN) mentioned an interesting reason when commenting on this paper. The first law was much more in accordance with the main philisophies among physicists of the 19th century than the second law. It met both ideas of romanticism and mechanistics. The second law was in contradiction to the idea of evolution inherent in some way in both mentioned philisophies. This idea starts from the principle that there is a progression in the world. The second law seemed to point out that on the contrary there is a retrogression.

3. The search for a constant amidst change is an old problem of philosophy. Concepts we use to recognize and structure our environment always point out in some way an invariance, an invariance in time of a material or quasi-material something or a structural invariance (Sachsse, 1967; Weyl, 1966).

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