SEMANTIC DIFFICULTIES IN SCIENCE AND THEIR IMPLICATIONS FOR EDUCATION

Abdelkader Anakkar
University of Lille 1, France

Generally speaking, a scientific activity consists in observing phenomena of nature, quantifying the observations, measurements & modelling data, eventual theory would be birth. Each of these steps is based on a *vocabulary*, more or less specific to the relevant discipline, and depends on a critical way, and making use of oral-and-written scientific expressions; partially within natural language. Nevertheless, if some scientific words correspond, generally speaking, to words used in the daily life-natural language (for example *weights*, *force*, *energy*, *work*, *heat* etc.), it does not mean scientific concepts are discussed: i.e., reputedly difficult such as entropy, the total change in entropy or entropy production, etc. *How can we make a sense of these semantic difficulties*?

Williams (Williams, 1999), by highlighting linguistic confusions in the field of mechanics, shows linguistic difficulties, which inevitably have repercussions in teaching. Further, the reasons for which physics is universally regarded as "hard" go beyond the inevitable difficulty of its concepts and its association with the mathematics. Williams pointed out that all the textbooks present semantic problems: imprecise definitions or even contradictory, differences in the statements of principles, which normally should no longer be a subject of disagreement. Pisano also discussed on that (Pisano, 2011, 2009;) and recently, too (Pisano, 2013; Mellone & Pisano, 2012; Pisano & Bussotti, 2012). Thus, pedagogical difficulties, or even a large part, are also located in scientific language used: it is scientifically formalized, and make us of a non formalized language. Therefore, the role played by language in science should be largely taken into account. For example, in the following few lines on thermodynamics teaching:

*A few ideas mentioned in literature***.** This choice is motivated by the fact that it is a topic deemed very difficult to teach and to understand, in particular the concept of the entropy. In Ralph Baierlein's words (Baierlein, 1994, p. 15):

> For the instructor and the student, no single step is terribly difficult to teach or to learn, but in the course of time, students easily lose sight of the big picture, and an intellectually satisfying understanding of what "entropy" represents remains elusive.

In addition, in order to make clear the difference between the internal energy and heat, he reported some students' difficulties. Marcella (Marcella, 1992) thinks that the meaning of the entropy is often obscured. Christensen [Christensen, Meltze, & Ogilvie, 2009) declare that the physics meaning of the entropy is often associated with both macroscopic and microscopic concepts of disorder, but the precise definitions are often omitted. The differences between authors on the meaning of the concept of heat source are very detailed by Duprez (Duprez & Méheut, 2007). Cannon (Cannon, 2004) shows, that the physical meaning usually attributed to the thermodynamic potential is not clear. In a very detailed article, which treats about reversible and irreversible transformations, Méheut (Méheut, Duprez & Kermen, 2004) showed that the students meet many difficulties and do not have effective criteria allowing them to analyse the situations and to conclude in a sure way to the reversibility or not of a transformation. The difficulties experienced and the mistakes made by students are explained by misunderstandings and ambiguities, which surround the definitions given in textbooks concerning a reversible transformation. Indeed, Thomsen (Thomsen & Bers, 1996) believes that the concept of a reversible process defined as a process such that the system can be restored to its initial state without any change in the environment is not

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sufficient. Samiullah (Samiullah, 2007) specifies that the problem has its origin, mainly, in the given definitions which generally mention a return to the original conditions without any additional precision.

Some false popular ideas. Since it is the language, which allows the construction of the thought, it becomes obvious and essential that a teacher takes into account in its reflections teaching the linguistic dimension which could interfere at any time with scientific trainings [Loverude, Kautz & Heron, 2002). For example, it is known that most students have early false ideas such as the heat and temperature are the same (rather that *weight* and *force-weight,* or force and energy) the heat is a substance, the heat is not energy or even the heat only moves upwards etc.

On the vagueness of the statements. Among the historical statements of the second principle of thermodynamics, let us look at the way in which is presented the traditional statement of Kelvin-Planck in some manuals. The following statements, corresponding to four books published at different time intervals, are rich of information:

- It is impossible to construct a heat engine whose only effect, when it operates in a cycle, is heat transfer from a heat reservoir to the engine and the performance of an equal quantity of work on the surroundings (Devoe, 2014).
- It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work (Çengel & Boles, 2006).
- No cyclic process is possible whose sole result is the flow of heat from a single heat reservoir and the performance of an equivalent amount of work (Burghardt & Harbach, 1993).
- No process is possible whose sole result is the absorption of heat from a reservoir and the conversion of this heat into work (Zemansky, 1968).

It is useful to note that the first three books introduce the idea of a cycle and it is not the case of the last book. This means that the idea of the cycle is very important. Why? Because (Kubo, 1968), it is possible to convert all the heat taken from a heat reservoir by an isothermal expansion of an ideal gas that is kept in thermal contact with the considered reservoir. Indeed, the internal energy of the gas depends only on the temperature which does not change during this transformation and then the variation of the energy is $DU=0$. Finally, from the first principle of thermodynamics $DU=Q-W$, we deduce then $W=Q$ i.e., the work performed by the expanding gas is equal to the heat absorbed from the heat reservoir. (In effect, Carnot's second principle establishes operative conditions: not all heat is converted in thermal work. A part is lost within reservoir at lower temperature).

Is it an error or a contradiction? The answer is that it is neither the one nor the other. The subtlety is in the condition "sole result" since the transformation of heat into work is not the sole result of the process. At the end of the process, the gas occupies a volume larger than it did at its initial state. Pisano wrote on that both historically and educationally (Gillispie & Pisano, 2014) Nevertheless, to avoid any ambiguity and to help students to develop a quantitative understanding, it would be better, as it is the case of the third book, to specify so clear that this statement is implying a cycle.

We find in books 1 and 3, even though it is implicit, the idea of the conservation of the total energy, which is not the case with books 2 and 4. This association between the two principles could be useful for students. In effect, even though physics books specify the thermodynamics behaviour of a system is determined both by the 1st and 2nd principles of thermodynamics, the 2nd principle is generally not taken into account by students (Baierlein, 1994; Marcella, 1992; Christensen, Meltze & Ogilvie, 2009).

If it is normal to use the word "a reservoir" in the statement, then is it important to add the word "single" as is it for the book 2 and 3? Certainly, yes, since the word "single" is used here in the sense of a quantity to insist on the fact to use one and only one reservoir. In other words, without addition of the word "single", there is a risk to understand that if there was a necessity, we could add another reservoir or something else.

On the other hand, these four kinds of writing of the Kelvin-Planck statement can be divided into two groups according to the nature of the words used.

Thus, the first two could be classified in a field qualified of a practice area. Indeed, they refer to keywords having a direct link, on the one hand, with science and technology and, on the other hand, with society and everyday life: device, engine and surroundings. Moreover, the sentence starts with an assertion expressing *impossibility*; which means in plain words that there have been attempts to carry out such machines by the human being, but all attempts have failed repeatedly. In summary, the statement keeps an experimental aspect. This description is consistent with the historic and scientific approach of the thermodynamics construction.

The last two could be classified in the theoretical field since the word process has rather a theoretical connotation and the sentence begins by a negation sentence expressing no need even to think on the achievement of such a machine. We could say the statement is presented as a natural law, exceeding the human framework, valid whatever the time and space which a priori could be interpreted as required conditions for access to the status of a universal principle.

This analysis demonstrates that the freedom of the statements writing reflects the subjectivity of authors. In his respect, Popper wrote:

> Si nous … usons du langage avec légèreté, c'est nous qui sommes cause des difficultés qui en résultent. If we […] use language in vain, then it is we who are to blame for the trouble that ensues. (Popper, 1998, p. 92).

On the multiplicity of meanings of a concept. The multiplicity of meanings of some concepts constitutes an exceptionally rich cultural and scientific for researchers. However, regrettably, that is not always the case for students because it may be a potential source of learning disabilities. Among the various meanings assigned to the entropy, a concept known as a theoretical property, the meaning as a measure of disorder is very interesting and increasingly used by the student. Similarly, a survey was carried out on the subject (Brosseau & Viard, 1992): *what does the entropy of an ideal gas becomes in a reversible adiabatic transformation?* The authors have shown that the improper reasoning performed by most students is this: «The entropy is the degree of disorder; if the volume increases, the disorder also increases, therefore the entropy increases too». Students forget that the entropy variation is equal to the sum of two variations (one as a function of volume, the other of temperature) which can vary independently of one another. These variations may move in opposite directions and can then offset each other. The first quantity related to molecules arrangement is the spatial part of the entropy and this is the one favoured by students, totally abandoning the kinetic part.

To conclude this short report, the meaning of a word in a sentence probably depends on time, culture and scientific field, but it can also be changed completely by authors of scholars manuals. That is why a research in this way will be very useful, interesting and promising.

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Abdelkader Anakkar	HDR, Physics & Physics Education, Associate Professor, SCité, Department of Physics, University of Lille 1, France. E-mail: abdelkader.anakkar@univ-lille1.fr