Critical Features of Word Meaning as an Educational Tool in Learning and Teaching Natural Sciences

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Abstract
The educational challenge of polysemy of words used both in non-formal (every-day) and scientific formal languages is addressed. An analysing tool, the triadic approach, has been elaborated to make this kind of polysemy of words explicit by discerning three different sets of meaning: non-formal, a scientific quality and a physical quantity, respectively. The discernment process is a particular way of seeing the critical aspects of variation of meaning simultaneously connected to one and the same invariant word (symbol).

Keywords: Conceptual change, physical quantities, polysemy, science education, temperature, word learning

Introduction

It is a well documented fact that words imported from non-formal every day language and used as defined terms in formal scientific language makes up a challenge in both teaching and learning. The extensive research on learners' conceptions of scientific concepts is a salient exponent of that fact (cf. Duit, 2007). For instance, the foundational scientific terms force, temperature, electric current, heat and energy are found to be difficult to attain among learners both on elementary and advanced levels. Even science teachers in secondary schools have shown deficiencies in their ability to define such terms (Galili & Lehavi, 2006).

In science educational research, learning scientific terms is generally treated as a process of conceptual change. In the standard dyadic approach the learner is supposed to make a cognitive transition from a pre-instructional conception of a natural object or phenomenon to the current scientific concept (Duit, 2003) (see Fig.1).

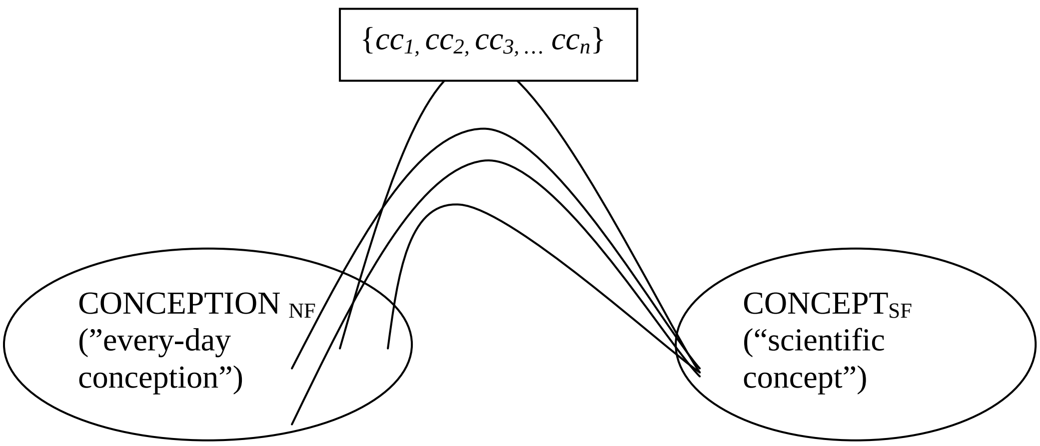

Fig 1. The standard dyadic conceptual change approach. The set {$cc_1, cc_2, cc_3, \ldots cc_n$ } denotes 'conceptual change' – theories aiming at identifying the educational conditions for the transition from a non-formal conception to the formal (scientific) concept.

For instance, learning the scientific formal (SF) concept $TEMPERATURE_{SF}$ is looked upon as a transition from the every-day non-formal (NF) conception $TEMPERATURE_{NF}$ to the scientific formal (SF) concept $TEMPERATURE_{SF}$.

However, starting from semiotic/semantic perspective the word 'TEMPERATURE' expands a "sense-spectrum" (cf. Cruse, 1986, 71- 74), a space of meaning, simultaneously including the common parlance meaning $TEMPERATURE_{NF}$ or, more correctly, a set of non-formal meanings {NF}, $TEMPERATURE_{\{NF\}}$ and the dual scientific meaning enclosing the current scientific scientifically delimited property/quality (SP) of a phenomenon, $TEMPERATURE_{SP}$ and the physical quantity (PQ), $\mathit{TEMPERATURE}_{PQ}$. This *triadic approach* analysis makes the polysemic situation of a term as TEMPERATURE explicit, opens up for consecutive discernments of critical features in the meaning making processes and thereby also revealing the conceptual complexity involved in the attainment of scientific knowledge (Strömdahl (in preparation for an international journal)). The fine-grained analysis of the relationships between world and language using 'the semiotic triangle' including the elements symbol (word), meaning and referent (Ogden & Richards, (1923) 1989) is elaborated in Strömdahl (ibid.) but is only implicitly accounted for in this article.

Aim

The educational implications of the application of the triadic approach will be explicated by using the word TEMPERATURE as an example. By applying the triadic approach to the word (term) TEMPERATURE its "sense-spectrum" will be briefly identified. Focus is put on the critical features of discerning the scientific meanings of TEMPERATURE within the categories of qualities and the coherent system of physical quantities.

Analysis

The polysemic situation of TEMPERATURE is visualised in Fig 2. The non-formal set of meanings $TEMPERATURE_{\{NF\}}$ includes ideas of warmth and cold, bodily experiences of events connected to these ideas and e.g. quantitative statements of temperature by simple readings of thermometers. Previous empirical research has revealed a lot of sense confusion among pupils and students about the differentiation between heat and temperature (see e.g. Tiberghien, 1983; Kesidou, Duit & Glynn, 1995; Wiser & Amin, 2001; Duit, 2007). In non-formal situations these non-formal senses can be sufficient for proper every-day communication and actions. Similar non-formal ideas have also been a starting-point for finding out the material nature of warmth and cold in the history of science. By painstaking efforts classical thermodynamics has ended up in attaching the word TEMPERATURE to the property, here denoted $TEMPERATURE_{SP}$, of every body that follows the zeroth law of thermodynamics: 'If two bodies are each in thermal equilibrium with a third body, then they are in thermal equilibrium with each other'. If the third body is a thermometer its readings will have physical significance. The quantitative aspect is expressed by $\mathit{TEMPERATURE}_{PQ}$ which is a base physical quantity belonging to the coherent system of physical quantities within the International system of Weight and Measures, SI, and the mathematics of quantity calculus. From a statistical thermodynamic point of view $TEMPERATURE_{SP}$ is interpreted as the relative change in possible energy distributions among the particles in bodies when a given amount of energy is transferred between them. The total number of distributions increases when energy is transferred in the direction when the one body gains more distributions than the other loses. Spontaneous transfer of heat (energy) takes place when the relative gain of numbers of distributions of that body that receives the energy is bigger than the relative loss of distributions of that body who releases energy. This direction is the most probable. The body with biggest relative change in distributions has the lower temperature

since it spontaneously receives heat from the other. This interpretation is in alignment with the notion of absolute temperature (*T*). The formal expression for this interpretation and the notion of absolute temperature is $dU/dS = T$, where d*U* denotes change in inner energy and d*S* change in entropy.
From a more general phenomenological point of view TEMPERATURE_{SP} can be looked upon as the intensity of the motion among the molecular and atomic particles.

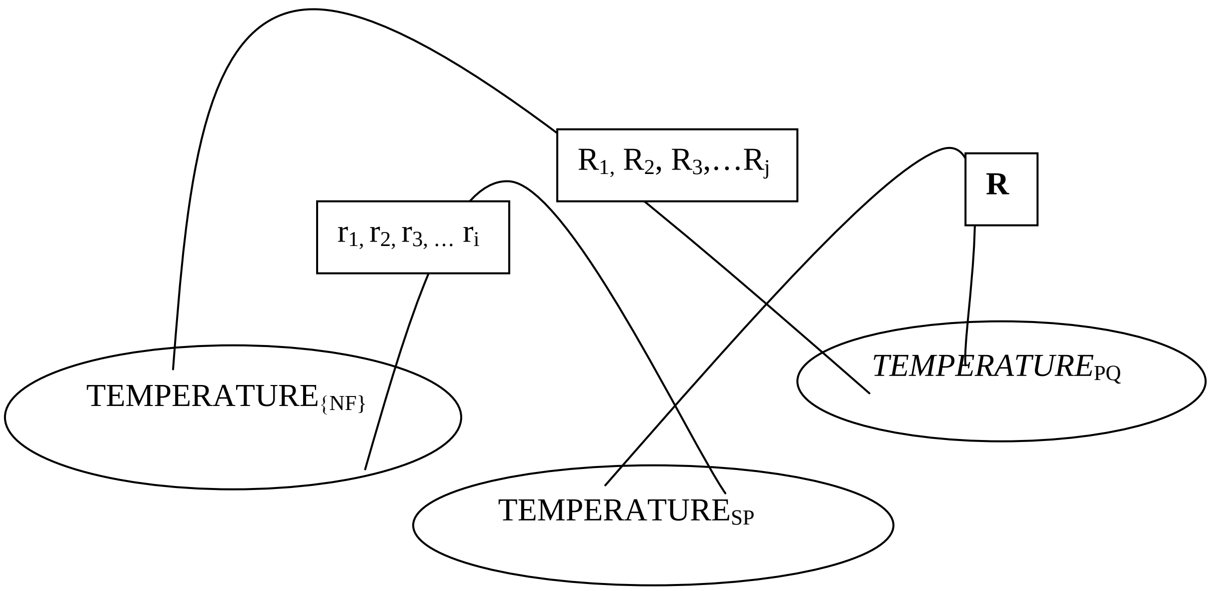

Fig. 2 The triadic approach applied to the term TEMPERATURE. The possible relationships $\{r_1, r_2, r_3, \ldots r_i\}$, **R,** $R_1, R_2, R_3, \ldots R_j\}$between the different senses can only be empirically determined but are not further focussed in this paper.

If the intended object of learning is the scientific formal (SF) TEMPERATURE_{SF} three discernments seem to be necessary to catch the "sense-spectrum", identifying the often taken for granted set of $\text{TEMPERATURE}_{\{NF\}}$, the identification of TEMPERATURE_{SP} as a quality (property) of a material phenomenological process and the identification of $\textit{TEMPERATURE}_{PQ}$ as a base physical quantity (PQ) within the coherent system of physical quantities (SI) and quantity calculus.

TEMPERATURE_{SP}			$\textit{TEMPERATURE}_{PQ}$	
Quality (property)		Process	Quantity (base physical quantity)	Quantity (derived physical quantity)
Macro-level	Micro-level	Changes of the Quality (property)	Measurable by thermometers graded in the SI unit K (Kelvin)	
Zeroth law at thermal equilibrium	Relative energy distributions among the particles in a body			

Figure 3 Critical features briefly identifying the scientific meaning of the term TEMPERATURE. The category $\text{TEMPERATURE}_{\{NF\}}$ is omitted in this figure, since the focus here is the discernment between TEMPERATURE_{SP} and $\textit{TEMPERATURE}_{PQ}$

The discernment act is even two-dimensional, both a discernment of the three categories (NF, SP, and PQ) and discernment within these categories (see Figure 3) to identify critical features and to focus on them simultaneously (cf. Marton et al., 2003). Discernment within the SP – category is connected to the critical features of a quality (property) on the macroscopic and microscopic levels respectively and as a process. Within the PQ-category the discernment is connected to identifying the coherent system of base and derived physical quantities. As a base physical quantity $TEMPERATURE_{PQ}$ has the same categorical status as the other six base quantities, like e.g. $LENGTH_{PQ}$ and $TIME_{PQ}$. In other words TEMPERATURE can be discerned on the one hand by being a member of the base physical quantities and on the other hand contrasted against the derived physical quantities (cf. Figure 3). As indicated above, TEMPERATURE as a scientific term gets its statistical thermodynamic meaning in the context of other scientific terms like e.g. ENERGY and ENTROPY, making up a coherent whole. These individual terms are also polysemic and can be analysed by the triadic approach.

From an educational point of view the triadic approach makes it possible to classify the sense-space of every scientific TERM by *categorical induction* (Murphy, 2002, p 243ff) according to the categories NF, SP and PQ : $TERM_{\{NF\}}$, $TERM_{SP}$ and $TERM_{PQ}$, revealing the critical features and thereby reducing the cognitive load to attain the scientific term.

Conclusion

The educational value of the triadic approach analysis is to elicit the polysemy, the space of meaning, the 'sense-spectrum' of terms in a way that makes it possible to discern the critical features identifying the intended learning object, here exemplified by the scientific meaning of $TEMPERATURE_{SF}$ as $TEMPERATURE_{SP}$ and *TEMPERATURE*$_{PQ}$. Besides the meaning of $TEMPERATURE_{\{NF\}}$ and its relationships to the scientific meaning is made possible. Subsequently, in learning the scientific meaning of $TEMPERATURE_{SF}$ the demand put on the learner and the teacher is to discern these categories of semantic distinct meaning and references of the one and the same polysemeous word TEMPERATURE and to disambiguate the term according to context.

Discussion

Most research on students' conceptions (especially alternative conceptions or misconceptions) and teaching and learning science concepts is framed by different conceptual change theories. The present investigation starts from semiotic/semantic perspective by introducing *the triadic approach*, expanding a space of meaning, a 'sense-spectrum' of terms comprising three categories. The triadic approach is applicable to any term to sort out its scientific significance and its category membership. As an example let us look at the word 'light'. $LIGHT_{\{NF\}}$ is not only polysemeous but also a homonym, viz. it has senses that are totally different, e.g. a phenomenon connected to human vision, a property of a weight and a nutrition property in the context of "light beverages". In optics, the meaning is a defined scientific phenomenon $LIGHT_{SP}$ (electromagnetic radiation visible to the human eye) but lacks a meaning of a physical quantity ($LIGHT_{PQ}$ is non-existent). Thus, the approach can be applied to rule out category membership, in this case the category membership of a physical quantity.

Compared to the common conceptual change research in science education on attainment of scientific terms, the triadic approach adds among other things the aspect of category membership, facilitating category induction by discernment of the critical features in the categories of scientific qualities and quantities; the latter differentiated in base and derived physical quantities.

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