Linguistic analysis and exercises in the education of physics teachers[1]

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The linguistic practices of physics were studied on a course for teachers. The analysis and exercises were based on a classification of concepts into entities, phenomena, qualities and quantities. It was noted that a) an intermixing of conceptual categories is common on all levels b) this confusion occurs also in the terminology of physics, where words may have meanings within more than one category, c) such intermixing is confusing and makes proper learning of concepts difficult, d) the development of physics has led to the replacement of entities and phenomena by quantities in the theoretical language, e) the intermixing is connected with the traditional theoretical approach of teaching. The linguistic exercises developed and the students' responses to them are reported. No research was conducted on the students' linguistic development during the course. Improvement in their linguistic ability and criticalness was, however, evident.

1. Physics as a language

Physics is a language for speaking about the phenomena of nature. It is possible to express ideas and to convey one's ways of thinking only with the aid of language. Adoption of new concepts means, above all, their incorporation into the language. There is nothing which could reflect the degree of the comprehension of concepts more clearly and more fully than linguistic presentation. Erroneous use of concepts always indicates some basic misunderstanding of their nature.

The teaching of physics involves always also the teaching of language. It is not sufficient to define the concepts and to explain their physical basis. It is necessary to teach and to learn how to use them in practice. A language cannot be learned just by looking up meanings of words in a dictionary. The comprehension of new concepts increases gradually by practicing their use in different linguistic and factual contexts. Therefore, all teaching must offer enough models for correct linguistic use of concepts.

[1] In J. Laurén (ed.) Science education research in Finland. Yearbook 1987–1988. University of Jyväskylä. Institute for Educational Research. Publication series B. Theory into Practice **36**, 51–61.

For some ten years we have been developing a new type of course for the education of physics teachers. The emphasis has been on the consideration, development and practicing of ways and methods of teaching, which would be well-founded and motivated from the point of view of the concept formation, method and cognitive structure of physics. Analysis of the linguistic practices of physics has grown into one of the most important subjects on this course. The following set of quotations from physical texts used on different levels illustrates one of the main problems met and studied.

2. Examples

Textbooks for school:
The acceleration of different masses ...
The mass has two properties, inertia and weight.
The oscillating mass in the figure ...
The circuit is connected to an alternating electromotive force ...
We couple the coil and the capacitance ...

Problems for the student examination:
... the straight lines ... are 3,2 miles and 2,8 miles, respectively, calculate ...
Calculate the kinetic energy of a mass of 2 kg with a speed of 3 m/s.

Textbooks and exercises at the university:
The mass is attached to a string ...
What is the angular momentum of m?
If mass M is pulled down slowly through a vertical distance y, what is the speed of mass m?
A circuit is composed of an alternating electromotive force
... and connected to a capacitor C.
Let E be an arbitrary electric field ...
Calculate the field.
A dipole moment of small dimensions ...
A rotation about the distance ...
An atom is sending a frequency f or a wavelength $\lambda = c/f$.

Students' answers in an examination:
The electromotive force has an internal resistance.
The sum of the source of voltage and the lost volts is equal to zero.

Licentiate thesis:
The length of atomic chains gets shorter.
The main part of atoms are moving in the peak volume.
The angle between the normal of the surface and N(Θ)...

Thesis:
... incident energy minus the fluorescent lines ...
... evaluated by subtracting the photoabsorption from the total cross section.
... small angle scattering was very small.

A national standard:
A physical property having the same value in all circumstances ...

An international standard:
The steradian is a solid angle which, having its vertex in the
centre of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of a length equal to the radius of the sphere.

3. Conceptual categories

The physicality of the language was discussed in the light of a simple classification of physical concepts into *entities, phenomena, properties* and *quantities.* Each category of concepts has its characteristic linguistic usages. They reveal and express the general nature of a concept. A well-defined physical language would require distinct terms for concepts of different categories.

Awareness of the category of a concept is necessary for its understanding, and it is essential for its pertinent linguistic use. The concept can be learned properly only, if its use in the language of teaching consistently reflects its nature. Any inconsistencies confuse.

Entities are subjects of nature. The category of entities includes particles, bodies, fields, matter, any systems, instruments and their parts etc. The entities exist, move, act and influence. They may change, for instance, grow and contract, they may increase, decrease, spread, collide, unite, break, etc.

Phenomena are events of nature, anything that the entities do and the way they behave. The category of phenomena includes thus all motion, action and change, such as growing, contracting, increasing, decreasing, spreading, colliding, uniting, breaking, etc. or just existing, for instance, being in equilibrium.

In a linguistic sense, also the *models* of entities or phenomena, like the rigid body and the harmonic motion, are entities or phenomena. Thus, geometric entities, such as edges, lines, curves, triangles, spheres etc., belong among entities. There is no sharp distinction between the real ones and the models. All physical concepts used for phenomena or entities include some degree of idealization, which involves modelling. However, the same word can, depending on the context, refer to a real entity, a phenomenon or a model. For instance, a "particle" can refer to a real constituent of nature, such as an electron, a proton or an atom, or to the classical particle model as compared with the wave model. So the particles can be represented by particles, waves or dual quantum mechanical entities.

Properties are qualities, observable features of entities and phenomena. *Quantities* are well defined physical concepts each corresponding to a definite property and being its quantitative representation. They consist of a numerical value and a unit. One should not confuse quantities and properties with each other, although there are words referring both to a property and to the corresponding quantity. All qualities, such as goodness, beauty, intelligence or colour, do not even possess a representative quantity. Neither do they become physical quantities even if they are given numerical scales based on opinion inquiries, on appraisals of boards of referees or on psychological tests.

Entities and phenomena are observed and studied. Also their properties can be studied. Quantities or their values are measured or determined. They can be large or small, they may increase or decrease and they are subject to algebraic operations. However, a quantity does not move, act or influence, and it does not possess vertices, edges, sides nor any other parts. Phenomena, entities and properties, on the other hand, cannot be added, subtracted, multiplied or divided with each other or with quantities.

The examples given should suffice to show both the nature of the problem and its extent. Almost all possible confusions between categories appear in them, and the problem is the same on all levels.

Quantities have been treated as entities. They accelerate, hang and oscillate. They are coupled to circuits. Quantities have properties, like size, inertia and weight. Some of their properties can further be represented by other quantities. There are distances and angles between quantities. Quantities have parts, like vertices and one can rotate around them. A quantity cuts off an area of a surface. Atoms move in a quantity and send off other quantities. It is also common that quantities, e.g. charges, are accelerated and focused by entities, such as electric and magnetic fields, or even with the aid of other quantities, such as the electric field strength or magnetic flux density.

Entities, phenomena and properties have been treated as quantities. They possess values which can be calculated, added to and subtracted from each other or quantities. It is also easy to find examples where phenomena are treated as entities, sometimes properties are called phenomena and vice versa etc.

This does not cause problems for physicists and physics teachers, since most of these sentences are understandable. However, they are examples of careless language, often clearly incorrect and misleading. An error is not exonerated by its commonness or its occurrence on all levels, including the standards. Pupils, who are only just trying to learn to understand meanings of concepts, get confused and learning is disturbed. This kind of erroneous language is probably an important reason for many problems present in the teaching of physics, for many misunderstandings and for inadequate learning achievements, which have been pointed out in numerous studies.

4. The first exercise

Some exercises were developed to improve the linguistic sense of the students with respect to the use of physical concepts. We started by taking the word index of a textbook and asked the students to classify the words according to their meanings into entities, phenomena, quantities, and models. (The category of properties was not yet introduced in this context, the models were included to elicit some epistemological thinking!)

The students worked in pairs or groups of three. Each group had, thus, a list of about 400 words to consider, including, of course, lots of words falling, obviously outside the categories. In each session of two hours the reports of two or three groups were discussed. Naturally only some of the material could be treated and it was necessary to concentrate on a few problems.

Somewhat surprisingly, words for phenomena caused most difficulties. The students did not recognise concepts like gravitation, infrasound, interaction, earthing, double refraction etc. as words for phenomena. This observation is, however, consistent with some others indicating that for the students physics has little to do with nature, instead, they are thinking predominantly in terms of theoretical models.

Words for entities and quantities were more easily recognized. Words which could be best classified as geometric entities, such as phase diagram, orbit, center of mass, and fulcrum (point of support), raised some problems.

Words which did not belong to any of the four categories caused some uncertainty. A vivid discussion arose on words referring to properties(!), units, mathematical terms or branches of physics (e.g. dynamics) etc. and on the possibility of classifying them into some further categories.

The fact that one word could belong to different categories in different contexts was in general not recognized, except for some obvious examples mentioned already in the lectures, like the angle (an entity and a quantity) or the electric current (a phenomenon and a quantity). Having found one category for a word students were satisfied and continued further down the list. In this respect the discussion had to be led forward. Pointing out a few more examples of such words was, however, a sufficient incentive and encouraged the students into long and fruitful deliberations on different uses of the same word in different contexts. Possibilities to place words under different categories were discussed with well-founded arguments:

– Is the dipole bond just a model or could it be thought of as an entity, and is there not also a touch of a phenomenon, although the linguistic uses do not indicate this?

– The central force is certainly a quantity because of the main part of the word "force". The attribute "central" refers to a model, and the combination gives us

an impression of a phenomenon, while the linguistic uses are largely those of an entity.
– Words for different types of motion, like uniform motion, rotational motion, standing wave motion etc., refer to phenomena, but the attributes make them models.
– The "field" occurred in the lists of all groups. Some of the groups were quite positive that it is a model and nothing else, others regarded it as an entity. Arguments were presented for both views.

In advance, one might have expected an exercise of this kind to become dull and boring, involving only monotonous reading through of a list of words. However, the two hours of the session went far too quickly in lively discussion. These kind of deliberations offered a good starting point for further discussions in the lectures, where the question of modelling was extended to the entire concept formation of physics, including, for instance, the model aspects of such basic concepts as time, space and motion.

5. The second exercise

The next exercise combined the classification of concepts with an analysis of the basic stage of concept formation. The task was to find a short preliminary characterization for each quantity in the index by answering the questions:
– Which entities and phenomena is the quantity associated with?
– What is the property it describes?

Here the idea was to emphasize that physical concept formation is an extension of the natural development of the language, based in principle on the same kind of perception and pattern recognition process as the learning of words. New concepts are adopted only because they are needed for describing observed properties of natural entities and phenomena. The pattern is first perceived, then it can be given a name. In the experimental approach of teaching it would therefore be important to be able to point out and describe the property before introducing the corresponding quantity (cf. Kurki-Suonio & Kurki-Suonio 1989).

It became obvious that linguistic distinction between properties and the corresponding quantities is often difficult and that the physical terminology does not favour it. Many names of quantities have been taken directly from the standard language, such as length, distance, velocity, acceleration, density, force, pressure, work, power and heat. Their standard linguistic meanings also largely express the corresponding properties. This is natural and often helpful, providing a good insight into the meaning of a quantity, but it also causes certain problems.

It leads to tautological difficulties in the description of the feature or property to be represented by the quantity: "Length describes the length of an entity." At the same time the epistemological relation between the observable property and the corresponding representative quantity as well as the nature of the whole process of concept formation are obscured. Moreover, the numerous meanings that a word has in the standard language get mixed up with the pupils impressions about the meaning of a quantity. This may be an essential factor supporting the stubborn preservation of the unphysical everyday ideas even during physics studies.

Experiences from this exercise supported earlier observations. The most difficult problem for the students is the association of a quantity with a phenomenon. They simply do not find examples from the surrounding nature or from everyday life. They prefer to seek their examples in the toy world of childhood. For instance, when the angular momentum or some other quantity associated with rotation was discussed, the only occurrence of the phenomenon found spontaneously was the spinning of a top, and after some thinking, the merry-go-round. The difficulty of finding relevant examples outside the children's room is another symptom indicating that a narrow theoretical mind still inherently dominates the teaching of physics.

When preparing for such an exercise, the students have to glance over many textbooks and consider the usage of a quantity in different areas of physics. This in itself is useful as it improves their physical knowledge and their understanding of the development of physical concepts. It also helps them to adopt holistic views about the information structure of physics.

6. Discussion of experiences

The participants had widely differing backgrounds. Some of them were second or third-year physics students without any contact with teacher education. Others had already spent a year in pedagogical studies and in practice teaching in ordinary teacher education classes. A few had several years' experience as physics teachers on different educational levels. The interaction of these different groups was found extremely fruitful. The experienced teachers recognised much more easily the relevance of the exercises and their possible applicability to real teaching situations. Their contribution to the discussions was important for the younger students, for whom the meaning of the completely new type of tasks was not always clear.

No research was conducted on the development of the language or the ways of thinking among the students during the course. Improvement of their readiness to discuss and argue on ideas about physics and teaching was, however, obvious. They became clearly more aware of their own and other students' ways of speaking and thinking. They started to make relevant comments and to respond to careless or incorrect use of concepts and to poor reasoning. They also started to criticise the language and the approach of textbooks.

The difficulties met seemed to indicate some fundamental problems in the way the students learn physics at the university. As to the language, it was realised that there is a basic conceptual confusion in the linguistic practices of physics and physics teaching, extending to all levels.

Partly the correct terminology of physics is confusing in itself, making no clear distinction between the conceptual categories. Particularly, the epistemological development of physics has led to gradual replacement of entities and phenomena by quantities as constituents of nature. This is clearly visible in the language of the theory of physics, where the linguistic usage regarding quantities has characteristics belonging to entities and phenomena. The confusions pointed out can thus be interpreted as an extension of the basic linguistic features of theory into areas where they are not justified. They have therefore a close connection with the tradition of the theoretical approach in physics teaching, where the natural formation of concepts, starting from the recognition of essential features of phenomena through observation and experiment, has been omitted.

The exercises reported formed the first part of a whole set, which was planned to help the students open their eyes and look out through the window instead of staring at the blackboard. We hoped that they would realize how physical concepts, quantities, laws and theories arise from the need to describe our observations of the surrounding world, not through the manipulation of formulae, not even through logical necessity but through ingenious idealisations based on a perception-like generation of ideas. It became clear that the students have to extend the views they have adopted on the basis of their physics studies, in order to be able to transmit to their pupils the idea of physics as a natural science.

References

Kurki-Suonio, K. & Kurki-Suonio, R. 1989. The characteristics of the experimental and the theoretical approach in the teaching of physics. In J. Laurén (ed.) Science education research in Finland. Yearbook 1987–1988. University of Jyväskylä. Institute for Educational Research. Publication series B. Theory into Practice 36, 13–26.