LINGUAL ANALYSIS AND EXERCISE IN THE EDUCATION OF PHYSICS TEACHERS[1]

by

Riitta and Kaarle Kurki-Suonio
Department of Physics, University of Helsinki
Siltavuorenpenger 20 D, SF-00170 Helsinki

Physics as a language

Development of language is an essential part of any teaching of physics. Physics is a language for speaking about the phenomena of Nature. Only language makes it possible to express ideas and convey one's ways of thinking. Adoption of new concepts means above all their incorporation into the language. It is not sufficient just to define the concepts and to explain their physical bases. It is necessary to teach and to learn, how to use them in practice. A language cannot be learned just by looking meanings of words at a dictionary.

The understanding of the meaning of a new concept grows gradually by practicing its use in different contexts. Therefore all teaching must offer sufficient models of correct lingual use of concepts.

For some ten years we have been developing a new type of course for physics teachers with the emphasis on discussing and practicing physically meaningful ways of teaching.

One of the basic subjects on this course has been the analysis of the language used by physicists, teachers and students or pupils. Let me point out some examples of one specific lingual problem.

The 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.

---

[1] Nordisk Forskarsymposium: Naturvetenskapen i Grundskolan. Hindås, Rapport utgiven av den lokala kommittén. Institutionen för pedagogik, Institutionen för ämnesdidaktik I lärarutbildningen. GÖTEBORGS UNIVERSITET, Box 1010, S-431 26 MÖLNDAL, 1988, 350-359.

Textbooks and exercises at the university:
The mass is attached to a string...
What is the angular momentum of m ?
If the 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 $\boldsymbol{E}$ be an arbitrary electric field...
Calculate the field.
A dipole moment of small dimensions...
A rotation about the distance...
An atom is sending the frequency f or the 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 $N(\theta)$.

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...

The international standard:
The steradian is the 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 length equal to the radius of the sphere.

(Many of the examples are translated from Finnish.)

Categories of concepts

It is possible to define some general categories of physical concepts according to their meaning. Particularly, it is useful to distinguish concepts referring to **objects**, **phenomena**, **properties** and **quantities**. Each category has its characteristic ways of lingual use. It is through these characteristic ways the general nature of a concept is expressed and recognized. Consciousness about the category of a concept is necessary for its understanding, and it is an essential condition of its correct lingual use. The concept can therefore be learned properly only, if its use in the textbook and in the verbal teaching consistently reflects its nature. Any inconsistencies do confuse.

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

The **phenomena** are anything that the objects are doing, how they behave and what happens to them. The category of phenomena includes thus all motion, action and change, like growing, contracting, increasing, decreasing, spreading, colliding, uniting, breaking, etc. or just existing, for instance being in equilibrium.

In lingual sense also the **models** of objects and phenomena, like the rigid body and the harmonic motion, belong to the categories of objects and phenomena. Thus, geometric objects, like edges, lines, curves, triangles, spheres etc., belong to the objects. There is no sharp limit between the real and the model objects or phenomena. All physical concepts used for phenomena and objects include some degree of idealization, which involves modelling. However, the same word can, depending on the context, have an emphasis of a real object or phenomenon or of a model. For instance, a "particle" can mean a real constituent of nature, like electron, proton or atom, or it can particularly refer to the classical particle model as compared with the wave model. So the particles can be regarded as particles, waves or dual quantum mechanical objects.

Properties are qualities of objects and phenomena. **Quantities** are well defined physical concepts used as quantitative representations of properties. They consist of a numerical value and a unit. One should not confuse quantities for properties although there are words meaning both a property and the corresponding quantity. All qualities such as goodness, beauty, intelligence or colour do not even possess a corresponding quantity. Neither do they become physical quantities through possible numerical scales based on opinion inquiries, on appraisals of boards of referees or on psychological tests.

Objects 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. On the other hand, the quantities do not move, act or influence, and they do not possess vertices, edges, sides or any other parts. On the contrary, phenomena, objects and properties cannot be added, subtracted, multiplied or divided with each other or with quantities.

Looking now back to the examples we realize a widely unrecognized problem in the language of physics on all levels. The categories are intermixed. Almost all possible confusions between categories occur.

Quantities are treated as objects. 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 about them. A quantity cuts off an area of a surface. Atoms can move in a quantity and send other quantities. It is also common that quantities, like charges, are accelerated and focused by objects, like electric and magnetic fields, or even with the aid of other quantities, like the electric field strength or magnetic flux density.

On the other hand, objects, phenomena and properties are treated as quantities. They have values which are calculated, added and subtracted with each other or with quantities. It is also easy to find examples were phenomena are treated as objects, sometimes properties are called phenomena and vice versa etc.

It is true, that most of these sentences are understandable. They do not cause problems for us. But this is no excuse for such intermixing of conceptual categories. It is incorrect and misleading, and pupils, who are only just trying to learn the meaning of the concepts, get confused. We are convinced, that careless language is a much more general reason of misunderstandings and poor results of physics teaching than has been realized. There are many other lingual problems, the present one is just a well defined example, easy to recognize and analyze.

The first exercise

We included in our course some exercises to develop the linguistic sense of the students with respect to the use of physical concepts. We started by taking a word index of a physics textbook and asked the students to group the words according to their categories into objects, phenomena, quantities, and models. (The category of properties was not yet introduced in this context and the models were included to excite some epistemological considerations!) 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 a part of the material could be treated and it was necessary to concentrate on a few problems. Somewhat surprisingly words for phenomena caused the most difficulties. The students did not recognize concepts like gravitation, infrasound, interaction, earthing, double refraction etc. as words for phenomena. This observation is, however, consistent with many others indicating that physics for the students has little to do with the nature and that they are thinking dominantly in terms of theoretical models.

Words for objects and quantities were more easily recognized. Words which could be classified best as geometric objects, like phase diagram, orbit, center of mass, fulcrum (point of support), raised, however, problems. Words which did not belong to any of the four categories caused some uncertainty. A vivid discussion arose on words meaning properties(!), units, mathematical terms or branches of physics, like dynamics, and on the possibility of classifying them into some further categories.

The extensiveness of the task explained, at least partly, the incompleteness of their analyses. Having found one category for a word they were satisfied and continued further in the list. Meanings within more than one category for the same word were in general not recognized, except for some obvious examples mentioned already on the lectures, like the angle (an object and a quantity) or the electric current (a phenomenon and a quantity). In this respect the discussion had to be guided forward. Pointing out a few more examples of such words was, however, a sufficient impact 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 as an object, and is there not a flavour of a phenomenon also, although the lingual uses do not give this indication?

The central force is certainly a quantity because of the main part of the word. The attribute refers to a model and the combination gives us an impression of a phenomenon, while the lingual uses are largely those of an object.

Words for different kinds of motion, like uniform motion, rotational motion, standing wave motion etc., belong to phenomena, but the attributes make them models.

The field occurred in the lists of each group. Some of the groups were quite positive that it is a model and nothing else, for the others it was an object. Arguments were presented for both opinions.

In advance one could expect such an exercise to become dull and boring involving just monotonous reading through of a list of words. However, the two hours of the session ran out quite too fast in lively discussion. The difficulties met seemed to indicate some fundamental problems in the way the students learn physics at the university.

The second exercise

The next exercise combined the classification of concepts into an analysis of the basic stage of concept formation. The task was to find a short preliminary characterization for each quantity of the word list by answering the questions:

- Which objects and phenomena the quantity is associated with?
- What is the property it describes?

Here the idea was that the physical concept formation is an extension of the natural development of the language. New concepts are adopted only because they are needed to describe properties of natural objects and phenomena after they have been recognized through observation and experiment. Therefore, in the experimental approach of teaching it would be important to be able to point out the property before introducing the quantity, cf. Kaarle and Riitta Kurki-Suonio: The characteristics of the experimental and the theoretical approach in the teaching of physics.

It was noted that lingual distinction between properties and the corresponding quantities is often difficult to make. There are many names of quantities, which have been taken directly from the standard language, such as length, distance, velocity, acceleration, density, force, pressure, work, power and heat, and which according to their standard lingual meaning largely express the property presented by the quantity. This is quite natural as it often gives a good insight of the meaning of the quantity, but it also causes certain problems. It leads to tautological difficulties, when describing the feature or property to be represented by the quantity: "Length describes the length of the object." At the same time the relation between the observable property and the physical quantity to be defined is confused.

Moreover, the whole cloud of meanings of the word in the standard language is smuggled in the pupils impressions about the meaning of the quantity. This is certainly an essential factor in the stubborn preservation of the unphysical everyday ideas.

In their preparation for this exercise the students glanced over many textbooks and considered 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 the physical concepts. It also helps them to build general views about the information structure of physics.

This exercise confirmed the previous observation. The most difficult problem for the students is the coupling of a quantity to phenomena. They simply do not find examples from the surrounding nature or from the everyday life. If anything, they seek their examples from the toy world of the 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 dominates inherently the teaching of physics.

Discussion of the experiences

How did the students respond to such exercises? The participants had widely differing backgrounds. A part of them were second or third year physics students, not yet involved in any other way in the teachers' education. Another part had already spent a year in didactic studies and practicing teaching in the ordinary teachers' education class. Finally a few of them had several years' experience as physics teachers on different levels of the school. The interaction of these different groups was found extremely fruitful. The experienced teachers recognized much more easily the propriety of the exercises and their possible applicability to real teaching situations. Their response was important for the younger students, for whom the motivation of the completely new type of tasks was sometimes problematic.

No study was made on the development of the language or the ways of thinking of the students during the course. Improvement of their readiness to discuss and argue on ideas about physics and teaching was obvious. They became clearly more aware of their own and of the other students' ways of speech 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 criticize the language and the approach of textbooks.

As to the language, it was realized that there exists a basic conceptual confusion in the lingual practice in physics and physics teaching extending to all levels. Partly the terminology itself is confusing making no clear distinction between the conceptual categories. However, in the epistemological development of physics the quantities have gradually replaced the objects and phenomena as constituents of the Nature. This is clearly visible in the language of the physical theories, where the lingual use of the quantities is largely that of objects or phenomena. The confusions pointed out are just extensions of this lingual feature from the theory to areas where it is not justified. They have therefore a close connection with the tradition of theoretical approach in physics teaching, where the natural formation of concepts starting from 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, look out through the window instead of staring at the blackboard. We wished them to realize how the physical concepts, laws and theories arise from the need to describe our observations on the surrounding world through ingenious idealizations instead of manipulation of formulae. It became clear that the students have to extend their views from what they had 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.