PERCEPTIONAL APPROACH IN PHYSICS EDUCATION[1]

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Abstract.

Perception is interpreted as creation of meanings. Subsequent conceptualization leads to terms and language. Science can be understood as a great perception process resulting from an expansive development of the primary sensory perception. Genuine learning has the nature of perception and it involves the processual elements of scientific method. It aims at understanding through unifying concepts of increasing generality. The hierarchical levels in the conceptual structure of physics make learning of physics a unique problem. Quantification, the threshold process from the qualitative level to the quantitative one forms the key problem. Learning of the basic concepts of mechanics is discussed as an example. Possibilities to support the perceptional approach with computers are analyzed shortly.

Meanings and concepts.

Perception refers originally to the creation of sensations from sensory excitations. It builds up *Gestalts* which become organized into mental pictures understood as representatives of entities and phenomena of the real world. It is the basic process of *creation of meanings* followed by *conceptualization*

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[1] In Ahtee M., Lavonen J. & Meisalo V. (Eds.) *Proceedings of the Finnish-Russian symposium on Information Technology in Modern Physics Classroom.* Department of Teacher Education. Research report 123. University of Helsinki 1994. pp. 25–32.

of the Gestalts which leads to *creation of language*. It is primarily unconscious interaction of observation and mind. Some structure and laws of the human mind control the character of possible Gestalts, but all mental pictures are subordinated to observation. Separation of the mutual roles of the mind and the observation is, however, not possible. There are no pure observations, nor any purely mental constructions. Therefore perception is basically not a logical but an *intuitive process*.

Science is interaction of experiment and theory through the scientific method. It is similarly a process of creating meanings where experimental and theoretical elements are inseparably interwoven. There are neither purely experimental experiments nor purely theoretical theories. Science is a result of a development starting from the sensory perception and expanding hierarchically through learning and studying into research and science. The degree of consciousness increases but the basic nature of the process remains. Science is a highly developed and structured perception process and perception is the seed of science.

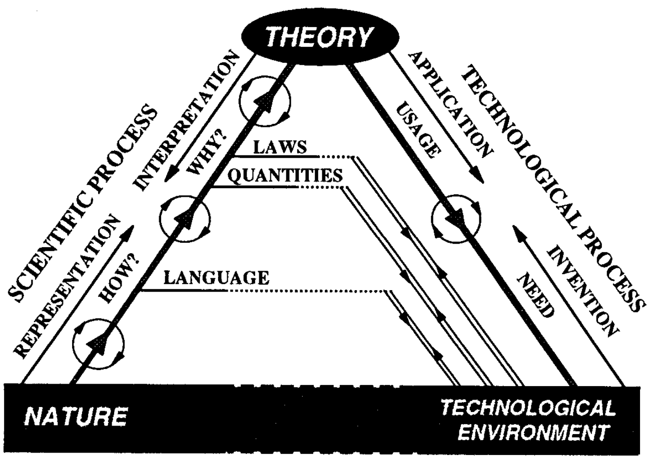

Figure 1 Four-process model of perception.

The process is maintained by two basic motifs, understanding and usage. The questions *why* and *what usage* divide the process into two orthogonal branches, the *scientific* and the *technological* process. Both are one-way processes working between Nature and Theory through two-way dynamics, fig. 1. This four-process structure of perception can be recognized in all stages of the process. The primary excitation of senses, the mental pictures developed, adaptation of behavior accordingly and trial-and-error type searching of ones possibilities are necessary elements of perception. They are the seeds of science and technology, experimental and theoretical, applied and inventive research.

Science operates from Nature to Theory and aims at understanding. It is the primary process of creation of knowledge. *Technology* works from Theory to Nature. It is a secondary process which makes use of the understanding to control the Nature and to elaborate it to meet better the human "needs". The technological process changes the world -- the scientific process changes the world picture.

According to the basic idea of empirical science *"how" is the only way to "why"*. *Interpretation* becomes possible through *representation* of Gestalts. Perception is understanding and understanding is perception. The whole structure of physical knowledge is based on unifying ideas of increasing generality, Fig 2. There is no final understanding but a hierarchical chain of more general interpretations.

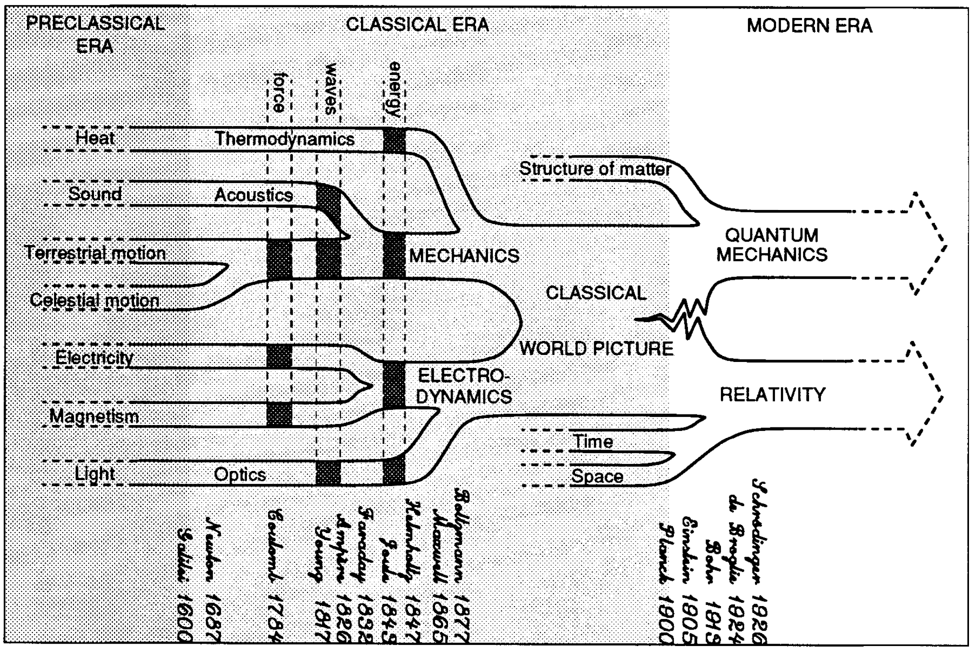

Figure 2 The achievements of science are unifying ideas.

Learning is part of the development of sensory perception into science. It involves all processual elements of science, and it has the processual nature of perception. The core of learning is increasing understanding through unifying concepts. But the key question is not how to introduce concepts but how to help creation of their meanings. Meanings are developing processual elements of mind, Gestalts born first. *Concepts* are introduced as their representations. They are *elements of language* and tools for further perception.

Physics and quantification

On all fields conceptualization of the empirical world leads to increasing generality and abstraction and yields a hierarchical structure. Higher concepts are born as structural Gestalts of lower ones. Transition to quantitative methods and concepts gives this development a new dimension, which is characteristic to physics only. This makes physics different from all other branches of science and learning of physics different from any other learning. In *the conceptual structure of physics* three successive hierarchical levels can be identified, fig. 3. Learning of physics involves, thus, processes of "normal" conceptual development within the levels and threshold processes from lower levels to higher ones. Creation of concepts on a higher level is based on the lower levels. At the same time it gives new possibilities to proceed on the lower levels and builds thus further basis for perception of higher level Gestalts.

Concept formation of physics starts from the level of qualitative knowledge. In *basic perception basic Gestalts* are identified, classified and connected into mental structures through perception of their mutual relationships. The basic Gestalts include particularly, the *entities* or subjects of nature, the *phenomena* or events of nature and their *properties* and the Gestalts of *conservation* or *change*, *dependence*, *cause* and *influence*.

The empiricalness of this level consists of observations and qualitative experiments supporting the basic perception through variations of the system and surroundings. Its theory consists of conceptualization of the Gestalts, creation of terminology and language using it, and of construction of corresponding mental pictures.

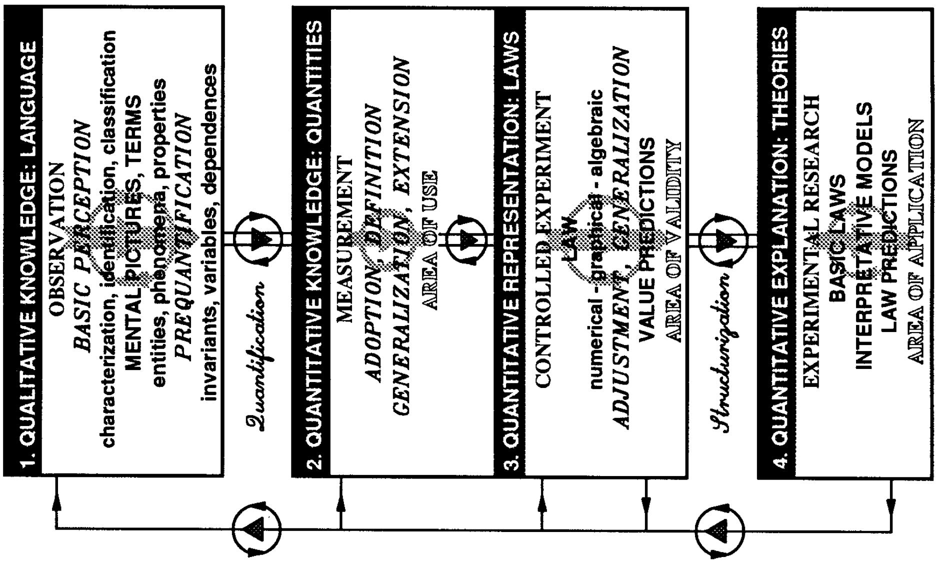

Figure 3 The hierarchical levels of physics.

Quantification is a threshold process which transforms qualities into quantities. It builds a quantitative structure of concepts on the foundation of the qualitative system of Gestalts. The idea of measurement has been introduced also in other fields. But nowhere else does it give rise to representation of properties in terms of quantities which are combinations of units and numerical values, and to quantification of correlations into laws representable as equations between quantities.

Quantification is the first great abstraction. There is an immense gap between qualitative and quantitative thinking. Many difficulties in learning physics trace back to trials to neglect it or to find some short-cut instead of pointing it clearly out. *Prequantification* prepares the way for it. It means perception of *comparative Gestalts* referring to degree or strength of properties. It makes possible to speak about stronger and weaker properties, larger and smaller entities or faster and slower phenomena *etc*. It awakes the questions "how strong, how large, how fast".

Quantities and laws are the quantitative parallels of properties and phenomena - or actually of the Gestalts of conservation, change, dependence, cause and influence characteristic to the phenomena - respectively. Laws are relations between quantities. In this sense they are higher in hierarchy. However, definitions of quantities are based on laws. Thus, the levels of quantities and laws are tied tightly together.

Quantities form the conceptual basis of whole physics. Quantitative representation is based on quantities. They span the bridge from observations to theoretical models. They tie together the empiricalness and exactness of physics. Empirical information is expressed in terms of them. Theories are defined through basic relations between quantities. Therefore understanding of the meanings of quantities is the key problem of learning physics.

The empirical meaning of a quantity is a Gestalt born before the quantity. It is conceptualized on the qualitative level as a property of some entities or phenomena. Without such *characterization and attachment* the quantity is left without meaning.

The quantity itself is born by the property through a *quantifying experiment* which, at the same time, is verification of the *defining law* of the quantity. This is a narrow gate. It requires *reduction and idealization* in order to invent a simple experimental situation, where comparative Gestalts attached to the property can be given a quantitative meaning, so that quantitative comparison of different degrees of the property becomes possible. This involves always the possibility of choosing a unit either by taking some easily reproducible degree of the property as the unit or coupling the unit to the units of quantities measured in the quantifying experiment. The guiding principle is that *quantities are born as invariants*.

The theoretical meaning of a quantity is born through *structurization*, the threshold process leading to the level of theories. It is expressed by the position of the quantity in the structure of the physical theories. This is a rather late stage in the process of creating the meaning. Basic definition gives the quantity a restricted meaning, valid in the ideal situation of the quantifying experiment. It is followed by a process of *generalization*, where the meaning is extended to wider classes of entities and phenomena. Definition of a quantity is, thus, not one step from concrete to abstract but a continual process or a bunch of processes. A quantity has a chain of meanings of hierarchically different levels based on each other. Thus, quantities are rather processes than products.

Starting mechanics

Application of these principles leads to *the perceptional approach*. For instance, in *mechanics* the basic perception should lead to identification of three basic Gestalts, the *bodies* as the entities, the *motions* of bodies and the *interactions* between bodies as the phenomena which have a causal relation. *Inertia* of a body, *magnitude of the change of motional state* and the *strength of interaction* are their respective properties. These are easily pre-quantifyable. Stronger interaction is needed to cause larger change of motional state and larger inertia of a body makes its state of motion more difficult to change. It is concluded that kinematics should not be taught separately from dynamics.

On a qualitative level it is possible to build a mental picture where interactions are understood to be the only causes of changes in the state of motion. As the first step of quantification one is then lead to the idealized concept of a *free body* with no interactions at all and to the *law of inertia*. The existence of an ideal class of even motions is thus motivated and an idealized experiment can be planned to define the *velocity* through the law $\Delta\boldsymbol{r} \sim \Delta t$.

Inertial mass, momentum and impulse or force result from quantification of the three key properties. It is obvious from the basic perception, that the ideal situation for the quantifying experiment must involve two bodies and one interaction. This leads to studies of collisions of free bodies or of bodies on an air table. Collision experiments offer the possibility to compare the inertias of two bodies A and B. After statement of the astonishing independence of the ratio $|\Delta\boldsymbol{v}_A| / |\Delta\boldsymbol{v}_B|$ of the nature of collision they can be interpreted as a measurement of the *inertial mass* of B with the mass of A. The *change of momentum* $\Delta\boldsymbol{p}$ which has equal magnitude for both bodies, follows then as an obvious measure for the change in the motional state. At the same time it yields a measure for the strength of the interaction, which will be called *impulse*.

In the conventional way of starting from one-body motion leaves the concept of force (impulse) is left without meaning. Because its "host phenomenon", the interaction, is excluded from the experimental situation it cannot be seen to represent any property of anything. It is important that the situations where non-uniform one-body motions are studied are understood as idealized limiting cases of two body systems where one of the bodies is very heavy. Then it becomes possible to invent an ideal situation where interaction with a large body acts "smoothly" and to motivate thus introduction of *acceleration* and *force*.

Role of computers

The role of computers in the perceptional approach can be analyzed within the scheme of the hierarchical level structure and the two directions of logics involved in the process. In computer aided measurements, in treatment and analysis of the data, in forming graphical representations of the results to perceive the nature of dependences, in algebraic modeling of them *etc*. the computer supports the primary scientific process proceeding from experiment to theory at different levels. While in simulations and predictions *i. e.* studies of the behavior of theories and models, it works in the secondary direction from theory to experiment. Uses of both types can be and have been developed for supporting any of the critical processual stages, basic perception, quantification and structurization.

It is important to realize that perception is the process of the pupil, not of the teacher nor of the computer. Each processual element has to be learned by the pupil. He learns to observe, measure, plan and realize controlled experiments and do experimental research and to conceptualize observations, represent results, interpret, model, predict *etc*. Therefore computerization should not proceed too fast. Only processes already learnt by the pupil can be automatized without violating the natural learning.