Complementary education course for physics teachers 2011. *The empirical basis of modern physics.*
Monday 06.06. 10.15-11.00.

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Introduction to the course

The title, *"The empirical basis of modern physics"* refers to the empirical compulsion, which necessitates changing of the basic classical mental images of physics. The course is built around the recently founded *F2k-laboratory.* In this laboratory, modern equipment for certain key expiriments of modern physics have been set up for demonstration or student excercises. These experiments belong to that phase of the process of science and learning, which could be called *arrival at the entrance gate of modern physics*. Thus, the logo F2k or Fysiikka[1] 2000 should, actually, be F1,9k. On this course we shall discuss these experiments and their significance for the development of science, and the problems, which one necessarily will encounter in teaching and learning when entering the gate.

The purpose of this first lecture, *Structural Perception,* is to offer some background for the possible interpretation of the problems, encountered at the gate, in terms of the basic principles of perceptional approach. In a recent article[2] of mine, these principles have been discussed in more detail.

In the next two lectures of today prof. HEIMO SAARIKKO will set the experiments in question into a historical perspective of concept formation and will draw attention to that conceptual and mental imagerial basis, from which the ideas and interpretations of these experiments emerged. His lecture "*The History of the Measurement of the Speed of Light"* on Thursday morning will broaden the discussion of the empirical basis of modern physics towards the theory of relativity.

On the two lectures "*The F2k experiments 1 and 2"* by myself and ARI HÄMÄLÄINEN, to morrow, the experiments and their equipments will be introduced, and their role in that empirical compulsion, which necessitates the change of the classical basic images, will be discussed. On Wednesday and Thursday afternoon the participants will be guided through the laboratory and will get a personal touch to these experiments in practice.

My lectures on Tuesday afternoon, *"Meanings and Their Carriers",* and on Wednesday morning, *"The Ontological Crisis of Modern Physics",* are closely related. I shall discuss, in more detail, *"the elements of reality",* their classical gestalts and the changes required by modern physics. I shall also try to enlighten the consequent problems in teaching of modern physics.

My final lecture, "*Plato and Aristotle of the present*", on Friday morning will be a discussion of perceptional approach as a building principle of the picture of reality, as a contrast to the "opposite" world picture, which is based on "the theory of everything" attempting to explain the whole observable reality starting from one mathematical basic idea and proceeding in progressive steps of "coarsening".

The course is concluded by the lecture *"What are the Basic Constants of Nature?"* by prof. KARI ENQVIST.

[1] Physics = Fysiikka in Finnish.
[2] K. KURKI-SUONIO (2011). *Principles Supporting the Perceptional Teaching of Physics: A "Practical Teaching Philosophy"* Science & Education, **20**: 211–243.

1. STRUCTURAL PERCEPTION

The perceptional approach in modern physics[3]

The possibility of the perceptional approach in modern physics has often been asked and questioned. It has been thought, that, in such an approach, everything should start from observation and experiments, but at school the key experiments of modern physics can be approached only through "*narrative empiry*".

The basic idea of perceptional empiry is crystallised in its motto: "*Meanings first*". It implies that understanding is born first and is followed by conceptualisation.

Understanding is perception of meanings.

Perception is an intuitive process, not logical.

Meanings are *Gestalts,* mental images and imagerial structures emerging intuitively.

Concepts are their definitized representations, which make possible the language of physics, speaking about meanings. This is the *qualitative level* of concepts.

Thus, the question is, *how is it possible to aid the perception of empirical meanings so, that it gives a foundation for the progress of concept formation.*

The components of meanings

I am speaking about empirical meanings, but empiry alone does not create meanings. A "pure empiry" does not even exist. Starting from formation of sensory gestalts and the simplest observations, *all empiry is theory-laden,* in the same way as *all theory* with its concepts is *empiry-laden,* or has an empirical meaning.

The meanings always carry an empirical, a theoretical and a metaphysical component.

The *theoretical* component of meanings is due to their structural nature and structural relations of meanings, and to their conceptual representations.

The *metaphysical* component consists of mental images and imagery structures which give rise to the experience of understanding and can therefore regarded as the core of the meanings..

Empiry, or observations and experiments, has, however, the primary position as the basis of the meanings. *The theoretical and metaphysical elements are submitted to the empiry.* Consent to this subordination as the guideline of learning and research is the *attitudinal facility*, which forms the *foundation of all science*. It is also the starting point of the perceptional approach. That's why I am speaking of empirical meanings.

The perceptional approach means creation of metaphysical mental images with the support of and under the compulsion of empiry, and formation of theoretical, conceptual representations of this imagery.

The approach can be empirical without being perceptional.

> A clear example is my own first textbook representation of the concepts of mass and force[4]. Mass was defined *experimentally* referring to its standard method of measurement, i.e. weighing, which is comparison of weights. However, the connection of the weight of a body to its inertia, which is the meaning of mass in Newtonian mechanics, does not become evident in any way. In this approach, it even cannot without lengthy theoretical considerations. Force, again, is defined, following the example of many textbook representations, as an empirically verifiable "structural invariant" $m\boldsymbol{a}$ of uniformly accelerated motion. In this way the concept of force is left floating in the air without linkage to any entity or phenomenon as its observable property.
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> In Finland BÖRJE EKELUND[5] has defended in detail the principle of such an approach basing it to the learning theory of JEAN PIAGET. He condemns such expressions as "force acts (upon a body)", used in conventional physics teaching to aid formation of an understandable mental picture of force, as metaphysics without empirical basis. Although this very expression does not link the meaning of force to any carrier, rejection of mental images as the basis of understanding means clear withdrawal from the principle of perceptional approach. A treatment of the concepts of mass and force, according to the perceptional approach, is presented in the Galilei-series of textbooks[6].

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[3] See K. KURKI-SUONIO, H. HAKULINEN & J. LAVONEN (2002). *Galilei 8. Opettajan opas (Teacher's guide).*WSOY. Johdanto (Introduction). In Finnish. Chapter 10 of the book *Teaching Introductory Physics* by A. B. ARONS (1997). John Wiley & Sons, New York is an excellent presentation of teaching of modern physics, fully consistent with the Finnish reference.

[4] KURKI-SUONIO K., KERVINEN M. & KORPELA R. (1982). *Kvantti 1. Fysiikan laaja oppimäärä, kurssit 1,2,3.* Weilin+Göös. Secondary-school textbook in Finnish.

[5] B. EKELUND (1977) *Jean Piaget ja fysiikan opetus.* Matemaattisten Aineiden Aikakauskirja 6/**41**, 281 sekä viitteet siinä.

[6] J. LAVONEN, K. KURKI-SUONIO & H. HAKULINEN (1995**).** *Galilei 3. Mekaniikka 1.* Weilin+Göös.

In more detail see K. & R. KURKI-SUONIO (1994): *The Concept of Force in the Perceptional Approach.* H. Silfverberg and K. Seinelä (eds.): Ainedidaktiikan teorian ja käytännön kohtaaminen. Matematiikan ja luonnontieteiden opetuksen tutki-

On the other hand, *the approach can be perceptional without explicit experiments or demonstrations*. This situation is encountered quite generally just in the modern physics.

Primary empiry, sensory perception and experience about the surrounding reality and about ourselves as a part of it, is the starting point of the process of learning.

In the primary empiry we perceive *the "elements of reality": space, time, entities, phenomena, properties of the entities and phenomena, and the relations of properties, understood as dependences or causal relationships of phenomena.* These *basic gestalts* belong to the metaphysical core of meanings. They constitute the mental imagery, which is experienced as understanding of observations.

The theme of my lectures consists of two questions:

What are these mental images like in classical physics?

How and why we are forced to revise them when passing the entrance gate of modern physics?

Dynamics of perception

Perception takes place in *the interaction of mind and nature*. In considering its "dynamics", the *human mind* and the *nature* can be taken, according to the traditional dualism, as two counterparts, even though they are inseparably intertwined. As always, interaction is, in the Newtonian way, reciprocal.

Nature affects the mind through empiry. Observations, qualitative and quantitative experiments and experimental research modifies the mind by creating empirical gestalts and mental images and imagerial structures. We perceive them as representations of genuine elements and structures of nature in a way which give us the experience of understanding nature.

The human mind, for its part, *affects the nature through the action of people.* We modify the properties of natural entities and phenomena and create new entities and phenomena.

I am calling these opposite actions the scientific and the technological process. *The scientific process* aims at understanding nature. *The technological process* is trying to develop nature according to aims and wishes set by the human mind. These two processes can be understood – analogously to Newton's third law – as counterforces of each other, while they, at the same time, are inseparable components of one and the same whole, the interaction, – just like the Newtonian force and counterforce.

However, in this interaction the human mind is the only active counterpart. Empiry, right from the formation of the first sensations, is "*asking the nature",* search for structures conformable to the perceptional capability of the human mind, and adaptation of them to each other and to the pre-existent structure of mind. This involves an endeavour towards perception of *"pure phenomena"*, which could be submitted, one by one, to experimental studies for finding their laws. This is essential in the *reductionism* of science. We wish to resolve the chaotic phenomenal world of nature, where everything is coupled to everything, into a set of pure phenomena with well defined laws, which would give the basis for understanding the intertwined chaotic totality.

> A very early example in the teaching of physics is the perception of the kinds of motion: identification of pure translation, pure rotation and pure vibration as changing of position, orientation and shape of bodies, respectively, and interpretation of different real motions as their combinations. For instance, in a 400 m running competition the athletes encounter a severe problem, if only translation is allowed, since on the back straight they ought to run backwards. Looking at the motion of a body hanging on a spring and calling it vibration is a very common confusion, since the body does not vibrate but is in a back-and-forth translation. The motion of the spring, on the other hand, is a combination of vibration and back-and-forth translation, which does not become perceivable until the concept of centre of mass is known. Surprisingly often one also meets such curious sentences like "the Earth rotates around the Sun", which mixes rotation and orbiting or translation along a circular path.

In experimental research, nature is asked questions concerning "pure phenomena". This idea is also a well suited motivation for school demonstrations and laboratory experiments, when, according to the students' opinions, physics at school is considering phenomena which don't occur in nature. Nature must be forced to answer. It does not answer voluntarily. If one just tries to listen to it, it's talking nonsense. Nature must be forced to realise, as pure as possible, the very phenomenon which we want to study, and in a way, which presents that very question we are asking about the phenomenon. Experimental research always requires manipulation of nature, the technological process, to modify the circumstances in a way where the disturbing factors get minimised.

> I remember from my own lectures of mechanics an illustrating episode. We were discussing rolling of bodies on an inclined plane. ARI HÄMÄLÄINEN was assisting, as usual in those times. The rolling body just didn't want to stay

muspäivät 24.–25.09.93. Reports from the Department of Teacher Education in Tampere. University of Tampere. A18/1994, 321–334.

> on its mount, but slipped aside now and again. A girl on the front row then bursted into words: "So, this is the way how physics works, the experiment is repeated until the wanted result is obtained." She was both right and wrong. The experiment must be repeated as long as required to persuade the nature realise the phenomenon studied. But, once nature does obey, the answer to the question set by the experiment will be accepted.

Perception in learning and science is, however, not a process of an individual. The interaction of minds combines the minds of individuals into a common *"social mind"* of the "learning society" or "science society". Perception in science and learning is interaction of this social mind with nature, rather than of the individual minds. The scientific process and the technological process are embedded in the *"social process", which can be characterised as negotiation about meanings.* In both of them the meanings to be perceived and their conceptualisation, as well as the procedures for their achievement are submitted to the social process. Thus, the gestalts and the understanding, which I am speaking about, are common, intersubjective, not subjective. This brings them as close to the ideal of *objectivity* as is possible in general.

Structural hierarchy

The structured primary nature of gestalts.
Perception is never a simple single event. Repetitive sensations and co-operative participation of all senses are necessary, before a gestalt can be born from the perceived mutual consistency of all this. Observing small children shows very clearly how holistic action is going on in the process of perceiving the surrounding nature. All senses are employed, inclusive of the taste and scent. The senses of touch, motion and posture have a central role. Co-operation of all senses, is needed, own active production of phenomena, and own participation in the phenomena are necessary. It is easy to gather a conviction about the presence and the tight intertwining of the sprouts of the scientific and the technological process in the "dynamics of perception" right from the beginning.

Gestalts are always born in relation to other gestalts. The gestalts of entities, phenomena and properties are coupled together already in their *status nascendi.*

The gestalt of an *entity* involves its properties and behaviour, as well as its relations to other entities. It is perceived as a totality of its properties, including its effects on its surroundings and its possible uses. Stone is a stone, because it is hard, it has some colour, shape and size, because one can lift, drop and throw it, because one can stumble on it, because one can break a window with it and because there are a lot of other stones, which together can be used in building various structures etc.

The gestalt of a *phenomenon* is perceived as the totality of the entities participating in it and of their mutual dependences.

Properties are perceived as properties of some entities or phenomena.

Finished gestalts and empirical compulsion.
Formation of a gestalt is based on the mutual consistency of observations. Once this is experienced as being *sufficient,* the gestalt is *ready*. *It is experienced as understanding* of the observations and it becomes a *permanent part of the structure of mind and "basic material" for further perception.* At the same time the set of mutually consistent observations is perceived as *"empirical compulsion"*, which justifies consideration of the gestalt as the representative of a genuine element of reality. Thus, also the *empirical compulsion is an intuitive* experience, which, necessarily, belongs to the perception.

> The mutual consistency of my observations gives me a fully sufficient empirical compulsion for acceptance of this pen as a genuinely existing writing tool, of this lecture hall as the present true position of my existence, and of the presence of everyone of you in this hall as truly existent individual entities, each with your own individual characteristic properties which make you identifiable.

Cumulative and layered structure of gestalts.
The perceived meanings and the concepts representing them accumulate in the mind into a structure, which is very stable. In this way, the human mind, the active counter part of the interaction, has a cumulative structure, which, as a whole, acts as the foundation of further perception. Thus, the conceptual understanding is accumulating in a way, which is parallel to the principle of organic growth. At simplest it means, that the pace of growth is proportional to the size of the organism, which leads to the law of exponential growth.

The attained structure of meanings acts as the basic material for further perception. As a consequence, the conceptual structure consists of hierarchical layers, where the concepts of an upper layer are structural gestalts of those of the next lower layer.

This is what I mean with the "structural perception" of the title.

Concepts as processes

Step-by-step development of meanings.
"Finished gestalts" can, however, never be considered final. The development of meanings is an *endless process", as is also emphasized by* ARONS: *"Students should be made explicitly aware of the process of re-definition that goes on continually ...".* "The finished gestalts" are *intermediate stages* in this process. They are empirically valid and internally consistent on certain areas of validity, but they are "final" only as regards perception of that area. The development of every meaning will continue and lead, step by step, to new intermediate stages. As examples, one can think, for instance the development of the concepts of energy and mass.

Generators of conceptual hierarchy.
In this development of meanings and concepts *two generators of hierarchy* can be distinguished: the aims at *generality* and *definitude*.

Generalisation is a central tool of understanding. Single events are understood as occurrences of the same phenomenon. The phenomena are understood as special cases of a certain kind of phenomena, and the kinds of phenomena are understood as different realisations of some more general class of phenomena. This has lead to the generalisation development of physics, to gradually more and more general perceived meanings, which are experienced as *a chain of more and more profound explanations*.

The aim at definitude manifests itself as *quantification*, transformation of properties into quantities. The *quantities are measurable properties* as defined also in the ISO/IEC Standards.[7] This is a key question of physics teaching. Every measurement is measurement of quantities. All laws are mutual dependences of quantities. Quantities are the basic elements of all physical theories. If the meanings of quantities as properties of entities and phenomena has not been perceived, there are no possibilities to understand physics, neither experimental nor theoretical. Therefore, one of the key exercises in my own physics teacher education has been the consideration of this question "what property of what entities or phenomena?" applied on different quantities. And, each time, surprising problems have been encountered.

Quantification does not create new meanings. Meanings are conserved, just transmitted form the qualitative concepts, properties and dependences, to the corresponding quantities and laws. This emphasises the fundamental insight, that *understanding is qualitative by nature*. Quantification, however, adds to it the new and important quantitative element. The *sense of orders of magnitude* gets attached to the perception.

> Lack of the sense of orders of magnitude has remained in my memories from the treatments of innumerable exercises and examination problems which I have got to read during my carrier. One classical example is a problem related to shot put. The answers offered for the initial velocity of the shot ranged from a couple of mm/s to multiple sound velocity. Even though the meaning of the concept of velocity as such had been perceived, the sense of orders of magnitude had remained unattached to it.

Coupling of generators.
Quantification plays, however, a decisive role in the progress of the generalising perception. The proceeding structural perception, which has given rise to the generalisation development of physics, has used, as its basic material, the already assimilated quantitative conceptual structure which, thus, turns out to be a necessary prerequisite for the development of the qualitative understanding.

> The early basic phases of the development of modern physics offer plenty of excellent examples. The quantitative laws concerning chemical reactions had a decisive role in the perception of the concepts of atom and molecule by DALTON and AVOGADRO. Similarly, FARADAY'S quantitative laws of electrolysis offered the basis for the idea of ionisation and a starting point for construction of mental images for the structure of atoms. Also, every one of the experiments of the F2k -laboratory to be introduced on this course yields, in addition to its qualitative perceptual significance, quantitative results, which are decisively important as basic material of the proceeding structural perception of the concepts of modern physics.

Reciprocally, the generalisation development concerns similarly all levels of the quantitative concepts. It leads unavoidably to generalising quantifications of quantities and to new more general forms of laws and theories, extending their areas of validity to wider classes of phenomena.

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[7] See eg. K. KURKI-SUONIO (2011). *Kansainvälisen suurestandardin uudistus* Dimensio **2/75**, 41–45.
(*Reform of the International Standards of Quantities.* In Finnish).

At the entrance gate of modern physics

Interpretation of learning and science as a hierarchically structural perception process widens and structures the concept of perception enormously in a way described in my article mentioned at the beginning of this lecture. All levels of the concept formation of physics can be interpreted as stages of the perception process. Modern science and technology grow from the scientific and the technological process as their ultimate stages of development, and the dynamics of perception structures into the methodical cycle of science.

At the gate to modern physics we are already very far in this process. The *mental images of classical physics* are "finished gestalts", born from the "empirical compulsion" on their phenomenal area of validity. As results of a long process, they are very tightly tied in the structure of our mental imagery. But they are intermediate stages on the endless path of development of the meanings they are representing. When passing the gate, new empiry is encountered, which requires amendment of them. It calls for structural perception on a new layer of conceptual hierarchy. Large-scale structural empiry is now required to develop the "empirical compulsion" for the experience of new "finished gestalts".