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Concepts as Gestalts in Physics Teacher Education

Introduction

In 1973 the author was nominated professor of physics in the University of Helsinki with the obligation to "teach physics to teachers", as it was formulated officially. This was a peculiar definition without any specified field of research within physics. Also, this was for about 20 years the only chair of its kind in the faculties of sciences of the Finnish universities. It offered, however, the opportunity to start developing *didactical physics*, where teaching would be examined from the point of view of physics, in contrast with *didactics of physics,* which is the science of education applied to physics teaching with its own chairs in the Departments of Education. It seemed obvious that the nature of physics as science would have essential consequences for the ways physics should be taught, beyond aspects covered by the science of education. In about 25 years a conceptual framework, now called "perceptional approach", and a full didactical physics program based on it, were developed for physics teacher education (see Kurki-Suonio & Kurki-Suonio 1994, Lavonen, Jauhiainen, J. et al. 2004, Kurki-Suonio 2011).

Starting Points

Two main conceptions were assumed as the starting point:
1. The meanings of concepts and conceptual structures of physics were considered as gestalts to be perceived.
2. Learning and science were considered as manifestations of the same cultural process sharing the nature of a hierarchically expanding perception process.

The adoption of these ideas and their application in teaching of physics was based on the experiences of teaching and research of physics, without conscious connection to gestalt psychology or gestalt theory. Thus, terms like *gestalt*, *perception*, *observation*, *mind, nature, intuition* etc. were used just as current words of common language, in a way understandable to the teachers. From the point of view of physics teaching, delving deeper into a more accurate analysis of them was never considered important. Still, the tradition of Eino Kaila, who established gestalt psychology in Finland, may have had a background influence on the direction of thinking (see Siemsen 2011).

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The first of these ideas appreciates the central role of intuition, i.e. non-conscious elements of the mind, in concept formation. The author's own perception of the process of concept formation had inevitably led to the conviction about the intuitive basis of concepts. The second idea recognizes the important position of the history of science in teaching. Learning can be viewed as the origin of science and science as the natural continuation of learning. In practical terms, history tells how the "correct gestalts" were once perceived, thus indicating how the perception can be reached anew. From the history one can find advice for development of children's preconceptions, about the difficulties in finding the path forward, and about the reasoning, experiments and interpretations which have converged to perception of the "correct" gestalts. The problem of teaching is to find an intelligible "story line" (Arons 1997 p.265) without the necessity of wading through all the historical odysseys.

Similar or parallel ideas are abundant in the literature. Learning as perception of gestalts has been suggested by many scientists – perhaps the most well-known proponent is Ernst Mach (see e.g. Mach 1893/1960). In Finland, ideas about the nature of concepts as gestalts have been emphasised by Eino Kaila and Rolf Nevanlinna (see Siemsen & Siemsen 2009). The basically intuitive nature of invention and concept formation in mathematics has been clearly pronounced by e.g. Jacques Hadamard (see Hadamard 1945). Constructs like "schemas" and "phenomenological primitives" (see e.g. Rowlands, Graham et al. 1999; diSessa, Sherin 1998) can also be interpreted as suggestions of the gestalt nature of concept formation in learning.

There is a quantity of literature dealing with the significance of the history of science in physics teaching. For Ernst Mach the conceptual history of science was key to his historical-genetic approach to physics teaching (see Mach 1893/1960). Also, for instance, Arnold B. Arons has discussed in detail the necessity of the historical perspective in physics teaching (see Arons 1997). The same basic nature of learning and research has been noted many times. For instance, John Dewey has often stated this position (see Dewey 1916 chap.17, 1929a, 1929b chap.8). And Jacques Hadamard wrote: "Between the work of the student who tries to solve a problem … and a work of invention (of a mathematician), … there is only … a difference of level, both works being of a similar nature" (Hadamard 1945, p.103).

The emphasis in the development of the perceptional approach was, however, not in the theory of education but in formulating principles of "practical teaching philosophy" as the aid of physics teachers, in considering consequent teaching procedures for all levels from early childhood to university, and in providing the teachers with the necessary facilities for finding their own procedures of perceptional teaching. In the following a brief account of some of these formulations is presented with an example of their application to the concept of force in the introduction of mechanics.

Meanings First

"Meanings first" was the first motto of the "perceptional approach". It declares that the understanding of physics means awareness of the empirical meanings of concepts. This is equivalent to Arons' principle of "idea first and name afterwards" (Arons 1997, p.27). It agrees also e.g. with Einstein, who wrote: "The concepts...get "meaning," viz. "content," only through their connection with sense-experiences" (Einstein 1970, p.13).

Meanings are considered as gestalts to be perceived before they can be conceptualised. In perception, gestalts are born intuitively in our minds with the support of empiry. They cannot be deduced or derived from any assumptions or axioms. In conceptualisation, linguistic representation is linked to the meanings. Concepts cannot be given in the form of exact definitions. They are adopted as representations of meanings. They inherit the intuitive nature of gestalt from their meanings.

In perception, nature and mind interact. The roles of the counterparts in this interaction can be identified: Nature produces signals which generate the sensual stimuli necessary for the formation of sensations. The "structure of the mind" defines one's mental capacity for perception, while restricting and regulating the nature of the possible gestalts as mental interpretations of the signals or as meanings of the observations. These actions occur simultaneously, intertwined into an inseparable whole. Still, only the mind is active. Nature is "activated" by "posing questions" to Nature. This is declared by the second motto "ask nature", i.e. investigate to find out. Active intervention is necessary to perceive messages in the noise inherent in natural phenomena. Even primary sensory perception requires an inquisitive mind. As Ernst Mach says, "A concept cannot be acquired passively, but only by participation, living through in the domain to which the concept belongs" (Mach 1900 and 1896, p.420). Perception requires directing one's attention, which already involves both a constructive and a testing attitude, running the two-way dynamics of scientific research, *in statu nascendi*.

Observing and experimenting are the ways of formulating the questions. Nature, on her own initiative, provides no answers or speaks nonsense. Nature must be forced to answer. The modification of nature through the careful design of experiments is necessary in order to let Nature do nothing but realise the phenomenon considered by concentrating on the aspect in question.

> "Our early predecessors observed Nature as she displayed herself to them. As knowledge of the world increased, however, it was not sufficient to observe only the most apparent aspects of Nature to discover her more subtle properties; rather, it was necessary to interrogate Nature and often to compel Nature, by various devices, to yield an answer as to her functioning. It is precisely the role of the experimental physicist to arrange devices and procedures that will compel Nature to make a quantitative statement of her properties and behavior." (Kusch 1955).

Perceptional Learning

Formation of a gestalt requires continuous and repeated sensations by different senses. Before the gestalt is perceived as a mental representative of some "aspect of nature", the sensations must be experienced as both mutually consistent and supportive of each other. There is a "groping phase" of longer or shorter duration before the different elements of sensations fit together and with the pre-existent mental structure. An intuitively sufficient degree of consistency results in the formation of a perceived gestalt.

The empirical meanings and, hence, the concepts, are also subject to continuous development. The normal development of the concepts of physics entails, for any particular concept, a chain of successive meanings or a net of interconnected meanings all valid in certain areas of phenomena. As Arnold Arons puts it, "… scientific terms go through an evolutionary sequence of redefinition, sharpening, and refinement as one starts at a crude, initial, intuitive level" (Arons 1997, p.354). "Students should be made explicitly aware of the process of redefinition that goes on continually" (Arons 1997, p.30).

Therefore, in learning physics, perception of the gestalt of any particular aspect of nature proceeds in steps. Each successive step involves a necessary groping phase that precedes the formation of a new, more advanced gestalt. The resulting more developed meanings of the aspect of nature include definitisations, extensions, generalisations, or some other modifications of the established meanings. Each "intermediate" gestalt in this development, however, remains stable with regard to its perceived meaning.

The gestalts are assimilated in the mind as new structural elements. In this way they become elements of further perception, and building blocks for further structural gestalts. This accumulation of the "structure of the mind" entails not only the extension, but – even more essentially – the formation of a structural hierarchy of empirical meanings, which in conceptualisation gives rise to a corresponding conceptual hierarchy.

This cumulative nature of the "structure of mind" means, effectively, that the potentialities for further perception are expanding. The ability to learn improves: the more one learns and understands the better become one's facilities to learn more. This, in fact, is the principle of "organic growth", which, without restricting factors, would make the progress of perceptional learning exponential, in contrast to the linear nature of rote learning.

The Basic Gestalts

We perceive the world in terms of a few types of basic gestalts: Space, time, entities, phenomena, properties, dependences and causal relationships constitute our primary mental imagery about reality.

In this terminology: *Entities* are "subjects of nature", material bodies or particles and immaterial fields. They occupy some position in space, and they have observable properties.

Phenomena involve the time aspect. They are events or processes, ways in which entities behave or anything that happens to them: motion, changing of properties and interactions. They take place at some instant in time or over some time interval. By observing phenomena we aim to perceive ideal "pure phenomena" with characteristic relations of properties, time and position. They give rise to the gestalts of dependences and causal relationships. These relations are properties of phenomena.

In this imagery, properties are what we can observe; they are "the handle of empiry". Entities and phenomena are perceived as carriers of properties. Their gestalts are built up by the totality of their observable properties, giving us an intuitive conviction of their real ontological existence.
Progress in physics, as well as learning physics, is essentially a development of our conceptions of these basic gestalts!

The Formulae

There was a great problem which I call "the formula disease": The students regarded physics just as some play with formulae without any connection to the real world. As Arons wrote: "the students are not reasoning either arithmetically or algebraically but are simply arranging the symbols, in patterns that have become familiar" (Arons 1997 p.8). They didn't pay any attention to the empirical meanings. They didn't care, or still worse, they seemed to be unaware of the existence of any meanings. Obviously, physics had been taught to them like that; "We are crushing our students into the flatness of equation-grinding automats" (Arons 1997 p.363). I am afraid this disease is still prevailing rather universally, and is not restricted to students.

The formulae, like $\boldsymbol{F} = m\boldsymbol{a}$, consist of letter symbols combined by mathematical signs and operations. Each letter denotes a quantity, like distance, velocity, acceleration, mass, momentum or force. Quantities are, by definition, measurable properties of natural entities or phenomena. This tells definitely that every quantity as such has an empirical meaning, independent of the formulae. In international standards this has been expressed in slightly different formulations: "Quantity is a property which can be identified as to its quality and measured as to its amount" (ISO 1993). "A quantity is a property of a substance or a phenomenon that can be measured or calculated from other measured quantities" (ISO 2008). "Quantity: property of a phenomenon, body, or substance, where the property has a magnitude that can be expressed as a number and a reference" ISO (2009). The earliest one of these is most explicitly related to perceptional concept formation.

Quantities, indeed, are the basic concepts of physics. Whenever experiments are made, quantities are measured. Theories consist of laws, and laws are relations of quantities.

The students knew names and standard symbols for the important quantities and a lot of formulae. When they were asked the definitions of quantities in test inquiries or exams, the answers were regularly little more than mere collections of formulae. Questions about their empirical meanings evoked only confusion. To help diagnosis of the "formula disease" they were given a list of quantities asking: What kind of property of what carriers? If one cannot answer this question, one really cannot understand anything, neither about experiments nor of theory.
This was a laborious exercise. But it helped us to recognise some general principles of perceptional empiry supporting meaningful learning.

Perceptional Approach

Interpretation of concepts as gestalts liberates the teacher from the duty of giving exact and exhaustive definitions and from frustrating trials to find logically binding deductive routes to the formulae. Instead of pretending to be a priest of scientific truths he can take the role of a temporary guide of the pupils' life-long learning process.

The pupils need encouragement in their own queries. The teacher has the permission to trust their observations and conclusions, pointing out the proper gestalts which would guide them towards the insights perceived before by the great scientists.

Initial understanding of any phenomenal area can be built by qualitative observations and experiments, discussions of the pupils' experiences and interpretations, without any need of formulae.

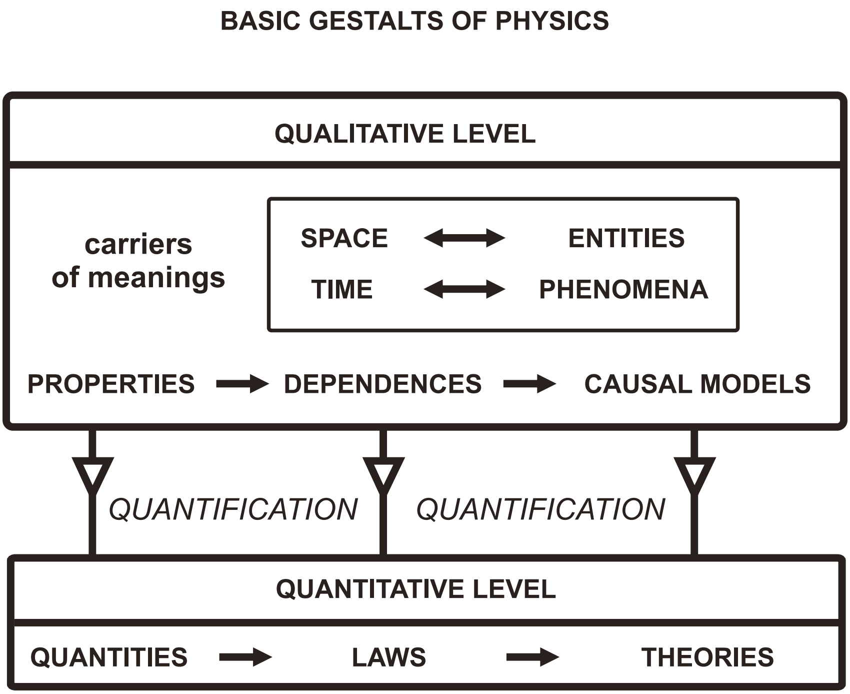

Fig. 1

1. First, identification of entities, phenomena and their properties is necessary, in order to build up a meaningful language for the area.
2. Then, perception of comparative gestalts is important, that is, observations of differences or changes of magnitudes or strengths of properties involved – in order to learn how to tell what is happening in the phenomena.
3. This leads to ideas about causal relationships. The pupils' suggestions can be amplified by inviting possible predictions, discussions of further observations, "what if" questions, simple gedankenexperiments and real experiments.

Quantification

For general understanding of the phenomenal area this would be sufficient. If we wish to go further, we are confronted with the problem of quantification, which is the critical threshold to quantitative physics. The properties must be changed into quantities. Then dependences get converted into laws, and causal models into theories. Thus, the conceptual structure of physics consists of two hierarchically different levels of concepts: the qualitative and the quantitative level, corresponding to each other. The quantitative level is a definitised representation of the qualitative one.

The need of quantification arises from perception of comparative gestalts which awake the quantifying questions.

1. Relative: How to compare the magnitude or strength of some property of one carrier to the same property of another one, in order to know how much larger or stronger it is.

2. Absolute: How to express the magnitude or strength in terms of a numerical value.

Nature should provide the answer. Appropriate formulation of the first question requires a quantifying idea, an intuitively justified principle of quantitative comparison of the "strengths" or "magnitudes" in terms of statements like equal, double, triple etc. This is again a gestalt to be perceived. It cannot be deduced by any logical inference. It must be found intuitively on the basis of the nature of the property itself. Therefore it is a different problem for every different property. Often, similarity and symmetry offer an intuitive indication of equality, and an intuitive additivity can justify multiple values.

After finding a principle of comparison and realizing it in a quantifying experiment, the absolute question can also be answered by choosing the magnitude of the property in one well-defined case of entity or phenomenon as the unit. Then, comparison of the same property of another entity or phenomenon to that of the unit case yields its numerical value in the units chosen. This is the primary principle of measurement of the quantity, which completes the transformation of the quality into a quantity.

Each quantifying experiment requires the measurement of some other quantities which must be known in advance. In this way, the meanings of all quantities are coupled to each other, thus forming a locally ordered net. The development of any specific quantity can be traced in this net as a branching path which in many ways combines it with other quantities. The path begins from a node corresponding to the primary quantification, based on its empirical meaning as a property. At this node, the quantity is born as an invariant of an ideal entity or phenomenon presumed by the quantifying idea. It has a narrow validity, restricted to the reduced circumstances of the quantifying experiment. Each further node on the path is a generalisation, which extends the meaning of the quantity to new kinds of entities and phenomena. For instance, the meaning of "length" is generalised from the permanent length of an object to variable distances of entities, the length of a curved path, the radius of curvature, the lattice constant, the wavelength etc. In descriptions of motion it starts from a one-dimensional or scalar displacement and gets structurised into a displacement vector. And, further, with the advent of relativity the distance gets combined with the time interval into an umbrella quantity of a four-distance of two events. In principle, each node is a new quantification based on the perception of an expanded empirical meaning. At the same time, the expanded meaning offers a new method for measuring the quantity and expands its range of possible values. It is essential that all these further nodes are bound by the preceding path to the primary quantification and, thus, to the perceived property on which the quantifying idea was based. The continuity of the path justifies calling it the same quantity throughout its entire growing area of validity; the empirical core meaning of the quantity is thus preserved.

Quantification creates no new meanings but it serves as definitisation of the understanding reached on the qualitative level. The meanings as properties of certain carriers are preserved. While transferring the perceived meanings to the quantities, quantification definitises the gestalts by joining in them the quantitative aspect of magnitudes. This adds to the perception of the properties the sense of the "natural" orders of magnitude in different situations and circumstances, such as an idea of proper distances, sizes, ages or velocities.

The meanings are primary: properties, carriers, relative magnitudes, dependences, quantifying ideas, causal relations are all gestalts to be perceived. They do not result from any algebra or logical inference. They constitute the basic "intuitive understanding".

The formulae are representations of their meanings as dependences and causal relations of properties.

The Problem of $\boldsymbol{F} = m\boldsymbol{a}$

Traditional teaching of mechanics starts from this equation. There are three quantities involved. Each one is problematic in its own special way, which makes the equation a difficult starting point. (Symbols of quantities are printed in italics, vector quantities in bold face (ISO 2009)).

***a*:** Acceleration is the rate of the change of velocity of motion. Its problem is its high degree of abstractness, comparable to that of the second derivative in mathematics.

***m*:** Mass represents the inertia of a body. Its difficulty is due to the fact that in the students' minds it is linked to two wrong meanings:

* *Weight.* The students have learned that the mass is measured by weighing, which is comparison of weights! They don't appreciate the fact that weight is not a property of a body, but of gravitational interaction.

* *Amount of matter.* This is a strong intuitive idea, an old sin of Newton himself. We are used to measure our purchases in kilograms, units of mass. The students may also have learned some chemistry or thermal physics, where mass has been used as a measure of the amount of material. But eventually it escapes all trials of quantification. Its fate is to remain intuitive. (This erroneous meaning is also

dominating the use of the concept of mass in most popular representations of physics.)

* ***F***: Force is the greatest problem. It represents the strength of an interaction. But the equation $\boldsymbol{F} = m\boldsymbol{a}$ is linked to the mental image of one moving body. The carrier of force is not included. Therefore, ***F*** has no perceivable meaning in this context. As the Nobel-prize-winner Frank Wilczek writes:

> "Newton's second law of motion, $\mathbf{F} = m\mathbf{a}$, is the soul of classical mechanics. … The right-hand side is the product of two terms with profound meanings. … The left-hand side, on the other hand, has no independent meaning. Yet clearly Newton's second law is full of meaning, by the highest standard: …" (Wilczek 2004).

Interaction

Newton wrote in his Principia:

> "And though the mutual actions of two planets may be distinguished and considered as two, by which each attracts the other, yet as those actions are between both, **they do not make two but one operation between two terms** … It is not one action by which the sun attracts Jupiter, and another by which Jupiter attracts the sun; but **it is one action** by which the sun and Jupiter mutually endeavor to approach each other." (see Cajori 1934, 1962).

Actually, Kepler had presented this idea already about 80 years earlier: "**Gravity is a mutual affection between parent bodies** which tends to unite them and join them together." (See Kepler 1609).

The idea of interaction as a phenomenon which is the common cause of any changes of motion of its counterparts is the decisive insight. It is the key concept of mechanics. It is, therefore, obvious, that the "pure phenomenon" to be considered in teaching mechanics is not one moving body but "one interaction of two bodies".

This is the fundamental gestalt of Newtonian mechanics. It contains all the necessary carriers of meanings. All quantities of mechanics can be perceived as properties of its elements: bodies, motion and interaction. None are left floating in the air. And the meanings of the basic laws can be perceived with the support of perceptional empiry concentrating on set-ups which approximate this "pure phenomenon".

It is by no means a simple task to guide the pupils towards this insight of great genii.

In the perceptional empiry:

* Different kinds of interaction can and must be identified.

* Observations should cover similarly all kinds of changes of motion: starting, stopping, speeding up, slowing down and changing direction.

* Experiments can and should be made with different bodies and pairs of bodies and with different kinds and strengths of interactions.

Newton´s Laws

Newton's three laws are often introduced as the axioms of Newtonian mechanics. From the point of view of perceptional approach this is an unfortunate characterisation. Meanings cannot be axiomatised. Also their conventional numbering is misleading giving a wrong idea about the way and order in which their meanings can be perceived. Moreover, they are not sufficient to build up the conceptual framework of Newtonian mechanics. Their ideas can, however, be seen to grow in a most natural way from the gestalt of interaction.

* **N1:** The "law of inertia" is nothing but the idea of a *free body = a body without any interactions.* The perceived gestalt of interaction implies that the state of motion of a free body cannot change.

Any possible verification of it as an empirical law is based on the intuitive belief that absence of interactions can be perceived, and that the idea of a free body can be approached by proper experimental arrangements.

Velocity can then be quantified as a constant of motion of a free body.

Inertia is perceived as a property of all material bodies, as their "ability to resist changes of the state of (translational) motion". Perception of comparative gestalts, i.e. different magnitudes of inertia, and of the causal relationships between the strength of interaction, the velocity changes of the interacting bodies and the inertias, doesn't pose any difficulties. Distinction of inertia from weight requires special attention, to gather that weight is not a property of the body.

Interaction offers the quantifying idea, as pointed out by Mach. Comparison of the velocity changes of two interacting bodies can be interpreted as a comparison of their inertias. If the velocity of the body A changes twice as much as the velocity of B, it is intuitively obvious that its inertia is half of the inertia of B.

Noting the primary quantified meaning of velocity, the validity of this idea can be checked by collision experiments. In an idealised collision, the bodies are free both before and after.

It is one of the great observations of physics that this idea works: The ratio of the velocity changes of any two bodies is independent of the kind and strength of their interaction. Also, choosing one body as carrier of a unit inertia leads to a numerical value of inertia characteristic to the body. That is the mass of the body.
* **N3:** "the law of force and counter force" is implicit in the very idea of interaction.

As a common cause, the interaction is understood to affect its counterparts equally. Thus, N3 is not actually an empirical law but a requirement imposed by the nature of the gestalt of interaction, concerning the representation of the motions of the interacting bodies. From the quantified meaning of mass it is noted that the effects on the motions of the bodies are equal (and opposite), if they are represented in terms of momentum $\boldsymbol{p} = m\boldsymbol{v}$. This is the motivation for adoption of this extremely important quantity, which in traditional teaching is defined with just the mysterious formula "mass times velocity". At the same time, the common value of the two momentum changes serves as a measure of the strength of the collision called *impulse*.

The quantitative representation thus obtained for the gestalt of an interaction of two bodies A and B consists of a pair of impulses ($\boldsymbol{I}_A$, $\boldsymbol{I}_B$) exerted by the interaction on the bodies. They are equal and opposite $\boldsymbol{I}_B = -\boldsymbol{I}_A$, as required by the idea of interaction, and can be called impulse and counter-impulse, in line with the common formulation of **N3**. Their common value represents the (vectorial) strength of the interaction. The quantification implies that it is proportional to the value of the momentum changes of the bodies, but, as a choice of unit, it can be agreed to be equal: $\boldsymbol{I}_A = \Delta\boldsymbol{p}_A$, $\boldsymbol{I}_B = \Delta\boldsymbol{p}_B$. This, in fact, is the origin of **N2.** However, from this quantified representation of a collision, there is still quite a distance to go to perception of the meaning of the equation $\boldsymbol{F} = m\boldsymbol{a}$, which is the traditional school formulation of **N2**. Going into detail is beyond the scope of this article. However, in order to close the subject, some principal landmarks of a possible "story line" in the perceptional approach are noted.

Towards the Meaning of $\boldsymbol{F} = m\boldsymbol{a}$

There are two main points to be made. Firstly, in the primary quantification interaction was treated as one single event. The momentum changes and the impulse are "macro-quantities" representing the phenomenon as a whole, independent of its duration. The equation $\boldsymbol{F} = m\boldsymbol{a}$, however, refers to an instant of an extended continuous phenomenon.

For a physicist this is no problem. The corresponding step of conceptual abstractness occurs everywhere in physics. It results in the formulation of the basic laws in terms of differential equations. It is the step from the description of entities and phenomena as macroscopic wholes in terms of *macro-properties* and *macro-quantities*, to their description as continuous extended entities and phenomena in terms of local and instantaneous *micro-properties* and *micro-quantities* varying with time. The momentum changes of the bodies in an infinitesimal time interval d*t* of the interaction can be written in terms of the acceleration $\boldsymbol{a}$ in the form $d\boldsymbol{p}_A = m_A\boldsymbol{a}_A dt$ and $d\boldsymbol{p}_B = m_B\boldsymbol{a}_B dt$. Due to the basic quantification of mass, they are equal and opposite, $m_B\boldsymbol{a}_B = -m_A\boldsymbol{a}_A$. Their common magnitude expresses the instantaneous strength of the interaction, which is called force. To be more exact, the instantaneous (vectorial) strength of interaction gets a representation as a pair of the two forces ($\boldsymbol{F}_A$, $\boldsymbol{F}_B$), $\boldsymbol{F}_A = m_A\boldsymbol{a}_A$, $\boldsymbol{F}_B = m_B\boldsymbol{a}_B = -\boldsymbol{F}_A$.

Teaching this is, however, far from easy, particularly when this step of abstractness is encountered for the first time. At first, the idea of instantaneous velocity of a body subject to a continuous interaction must be perceived. Then, the pupils must be guided to perception and quantification of the acceleration. At first, the acceleration can be introduced as a macro-quantity, a constant of motion of a body subject to a steady interaction. This can then be generalised into a micro-quantity, the *instantaneous acceleration.*

Secondly, and more substantially, the equation refers to motion of one body, and the mental image to be considered must be changed into "one body subject to many interactions". This is a structural gestalt to be built from the fundamental gestalt of "two bodies with one interaction". Corresponding to this image, the meaning of force in the equation $\boldsymbol{F} = m\boldsymbol{a}$ is not just "strength of interaction" but it is "the combined strength of all interactions 'felt' by the body". It is important that the simple school examples of motion, like falling, projectile motion, pushing or drawing a body, gliding or rolling on a plane (inclined or not) etc. are perceived as cases of this basic image, and attention is paid to the role of the Earth as the other counterpart of the interactions.

In building up this mental image by perceptional empiry, special attention must be paid to the gestalt of the "kind of interaction", to identification of different interactions of a body, and to superposition of their effects. Further, each "kind of interaction" must be quantified into a "law of force", expressing how the forces exerted by the interaction upon the bodies depend on the properties, relative positions and motions of the bodies. Finally the *superposition of forces* must be quantified. The special case of equilibrium, where the effects of the different interactions balance out each other, is an important gestalt with which to start. These are matters of quantitative experiments, where the forces are determined either on the basis of motion or by balancing them with a known force.

Thus, two more basic ideas – or axioms number 4 and 5 if you wish – in addition to Newton's three laws, are required to complete the theory. We need:

4. the assumption that each kind of interaction has its own specific "law of force", and
5. the superposition law telling that the "total force" exerted upon a body by all its interactions together is the sum of forces expressed by their laws.

Somewhere along this path the pupils must be guided to share Newton's ingenious perception of "the moon as a big apple" and, *vice versa*, "an apple as a small moon". In the history of science this insight was at the heart of the Newtonian revolution of our world picture. Perception of the free fall on Earth as a special case of planetary motion, i.e. motion under the law of gravitation, implies that phenomena on the earth and in space are subordinated to the same physical laws. In the perceptional approach, this insight plays an important role in several stages. It is vital already for the perception of the very primary idea of a "free body". Realisation of the fact that a "body in free fall" is not a "free body" but one in gravitational interaction with the Earth, rectifies an old historical belief shared by children as quite a natural preconception, and solves the old riddle of the different natures of the vertical and horizontal motions. Later, it gives an intuitive basis for the perception of the free fall and related forms of motions as motions under steady interaction. It offers, thus, the basis for quantification of the acceleration by the Galilean experiments. Further, measurement of the acceleration of free fall gives us the first force known by strength, the weight, and thus opens the important balancing method for research of the laws of force. Finally, Newton's "derivation" of the law of gravitation from Kepler's laws of planetary motion is the fundamental example of the perception of laws of force on the basis of the observable motions.

Final Comments

The concept formation, as a perception process, has a direction. It starts from perception of phenomena and proceeds towards conceptual understanding. The purpose of the perceptional approach is to follow this direction in teaching. In different contexts this direction can be characterised in different ways. It runs from observation to concepts, from experiment to theory, from concrete to abstract, from qualitative to quantitative, from simple and single to structural and general, from macroscopic or total to local and instantaneous, from pictorial or graphical to symbolic or algebraic representations etc. Such different characterisations of the direction can be called by the common name "lines of increasing abstractness" or "abstraction lines". From the point of view of children's learning, the contrast between concrete and abstract is synonymous with the contrast between easy and abstruse. Therefore, it is important that the students in teacher education learn to identify such lines.

In physics teacher education it was not difficult to agree upon the basic processual nature of concept formation and the importance of following its direction in teaching. The basic ideas of the perceptional approach and of its different dimensions of abstractness development were also favourably received – in principle.

Physics teaching has, however, been heavily burdened by a tradition of "backwards science" (Arons 1997 p.178), i.e. starting from the abstract end of the "abstraction lines". In discussions and exercises of physics teacher education, it became evident that this tradition is deeply rooted in the mind. Many consequent problems were identified. The willingness to start from formulae, from “final exhaustive” definitions, axioms, theoretical explanations, from atoms and electrons or esoteric vocabulary of modern physics etc., arises easily from the good intention to offer children the best products of science, forgetting the process necessary to achieve the products (see Kurki-Suonio 2005).

Starting mechanics from the equation $\boldsymbol{F} = m\boldsymbol{a}$ is a good example. First of all, it starts from a formula instead of perception of phenomena and from a micro-representation in terms of instantaneous quantities. Moreover, the equation cannot be linked to any clear mental image, which could be experienced as the carrier of the meanings of the quantities involved. As described in this article, such a mental image can be built in the perceptional approach, but it is at the abstract end of the abstraction line from simple to structural. In the perceptional approach to mechanics, the most difficult detail to accept seemed to be the idea of the macro-concepts being more concrete, and therefore easier to perceive, than the micro-concepts. In their own studies, the students had encountered the impulse and the momentum late, long after $\boldsymbol{F} = m\boldsymbol{a}$ and its calculatory applications, as integrals of $\boldsymbol{F}$ and $m\boldsymbol{a}$. As a consequence, there was an almost unanimous agreement about their great degree of abstractness. It was, however, a pleasure to distinguish by the buzz of an intermission discussion of my first complementary education course in 1996, a *sotto voce* comment: “I have been teaching physics over 20 years and this is the first time I feel like understanding mechanics.”

Summary

This article is a brief account of the “perceptional approach” developed in the context of physics teacher education in the Physics Department of Helsinki University in the last three decades of the previous millennium. Its leading idea, “meanings first”, was declared as an antidote to the “formula disease” of physics teaching. It implied that understanding means awareness of empirical meanings, which are gestalts to be perceived first, before conceptualisation. The concepts inherit the intuitive nature of gestalt from their meanings. Space, time, entities, phenomena, properties, dependences and causal relationships are the basic types of gestalts beyond the conceptual structure of physics. The initial understanding of any phenomenal area can be built by “perceptional empiry” in terms of these gestalts without need of formulae. The access to quantitative physics goes through quantification, where properties are transformed into quantities and the sense of strength or magnitudes is attached to the gestalts of the properties. The principles of the “perceptional approach” are illustrated by considering the gestalts of the basic concepts of Newtonian mechanics.

Keywords: Perceptional approach, basic gestalts, quantification, interaction, force.

Zusammenfassung

Dieser Artikel ist eine kurze Darstellung der „gestalt-orientierten Herangehensweise", die im Rahmen der Ausbildung von Physiklehrern in den letzten drei Jahrzehnten des vergangenen Jahrhunderts am Institut für Physik der Universität Helsinki entwickelt wurde. Die Leitidee „Bedeutungen zuerst" wurde zum Gegengift gegen die „Formelkrankheit" des traditionellen Unterrichts erklärt. Sie besagt, dass Verstehen Erkenntnis von empirischen Bedeutungen bedeutet; diese sind Gestalten, die wahrgenommen werden müssen, bevor sie konzeptualisiert werden können. Die Konzepte übernehmen von diesen Bedeutungen deren unmittelbaren Gestalt-Charakter. Raum, Zeit, Entitäten, Phänomene, Eigenschaften, Abhängigkeiten und kausale Verhältnisse sind die Gestalt-Grundtypen hinter der Begriffsstruktur der Physik. Mit Hilfe von „gestalt-orientierter Empirie" kann vermittels dieser Gestalten das Grundverständnis für jeglichen Erscheinungsbereich aufgebaut werden, ohne dass Formeln notwendig sind. Der Weg zur quantitativen Physik führt durch die Quantifizierung, indem Eigenschaften in Größen umgewandelt und die Sinneseindrücke von Stärken oder Größen den Gestalten der Eigenschaften zugeordnet werden. Die Prinzipien der „gestalt-orientierten Herangehensweise" werden unter Beachtung der Gestalten der Grundbegriffe der Newton´schen Mechanik veranschaulicht.

Schlüsselwörter: Gestalt-orientierte Herangehensweise, Grundgestalten, Quantifizierung, Wechselwirkung, Kraft.

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