

## CONCEPTS AS GESTALTS IN PHYSICS TEACHER EDUCATION

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### INTRODUCTION

Please, understand that I am – or have been - a physicist without any education in psychology, nor in science of education or philosophy. Such a competence was not required when I in 1973 was nominated professor of physics with the obligation to "*teach physics to teachers*", as it was formulated officially.

Thus, I was not appointed for science of education but for physics, however, without any specified field. I was naïve enough to think that it was up to me to create an own field for my chair. I named my field *didactical physics* to indicate that it is a branch of physics, in contrast with *didactics of physics*, which has its own chair in the Department of Education.

I was using terms like *perception, observation, gestalt, mind, nature, intuition etc.* just as current words of common language. From the point of view of physics teaching, delving deeper into a more accurate analysis of them was never considered very important.

### MEANINGS FIRST

"*Meanings first*" was the initial basic guideline in the development of what I now call "perceptual approach". The basic ideas were worked out in the context of about 25 years of physics teacher education. Apart from a text book in Finnish (1994) and a few conference reports, these ideas are described in just one somewhat more exhaustive paper<sup>1</sup>, which I was compelled to write on my old days.

I explained that *understanding* physics means awareness of the empirical meanings of concepts, and *meanings* are 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

The *concepts* inherit the *intuitive nature of gestalt* from their meanings. Thus, *concepts* can never be given in form of exact definitions. They are adopted as *representations of meanings*, and they are *subject to continuous development*.

### PERCEPTIONAL LEARNING

In perception *nature and mind interact*. The roles of the counterparts can be identified but not separated. They are intertwined into an inseparable whole. Still, only the mind is active. Nature is "activated" by asking and "*compelling it to answer*". Observing and experimenting is the way, how our mind is formulating questions.

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<sup>1</sup> K. Kurki-Suonio: *Principles Supporting the Perceptual Teaching of Physics: A "Practical Teaching Philosophy."* Science & Education (2011), 20:211–243).

The "*structure of the mind*" defines one's mental *facilities for perception*. At the same time, it *regulates the nature of the possible gestalts*. Formation of a gestalt requires continuous and repeated sensations by different senses. 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 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 perceptual learning *exponential*, as compared 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 the reality.

In my 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 at perception of 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 of physics, as well as learning physics, is essentially development of our conceptions of these basic gestalts!*

## THE FORMULAE

I saw 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. They didn't pay any notice on 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 them like that. I am afraid, this disease is still prevailing rather universally, and is not restricted to students.

The formulae, like  $F = ma$ , 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.

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 of the important quantities and a lot of formulae. To help diagnosis of the "formula disease" I gave them a list of quantities asking: *What kind of property of what carriers?* If one cannot answer this question, one cannot understand anything, neither about experiments nor of theory.

This was a laborious exercise. But it helped us to recognise some general principles of *perceptual empiry* supporting meaningful learning.

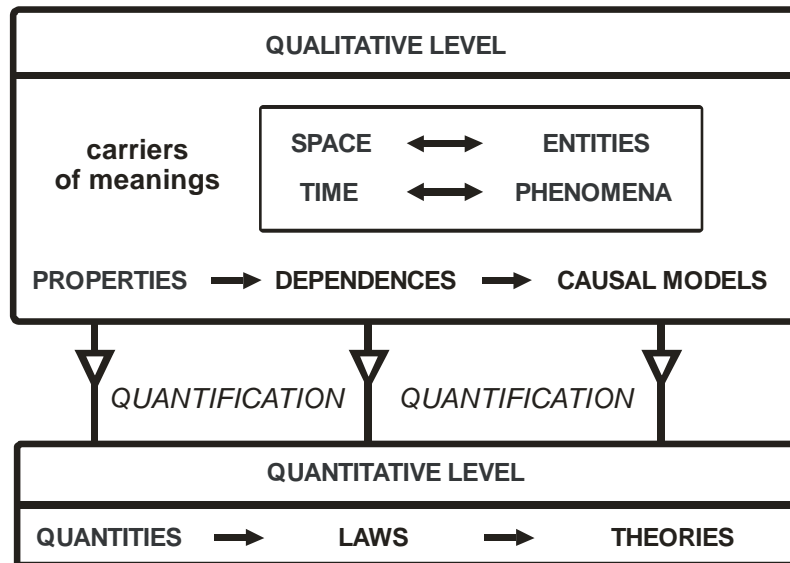
## PERCEPTUAL APPROACH

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 being a priest of the 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 upon their observations and conclusions, pointing out the proper *gestalts* which would guide them towards the insights perceived 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*.

## BASIC GESTALTS OF PHYSICS



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*.

The comparative gestalts awake the quantifying questions?

**1. Comparative:** *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?*

We need a *quantifying idea*, which would justify 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*.

The idea must also enable us to set up a corresponding *experiment* for the comparison? Then also the absolute question can be solved by choosing one well-defined case of the property as the *unit*.

We can note that *quantities are born as invariants*. The quantifying idea and experiment are based on situations, where the property stays unchanged. Therefore the primary validity of the quantity is restricted and calls for a generalising development.

In quantification *no new meanings are born*. The meanings as properties of certain carriers are preserved. Just a *sense of magnitude* is added to the gestalt. This meaning is preserved as the core meaning in all further generalisations.

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 $F = ma$ .

Traditional teaching of mechanics starts from this equation. There are three quantities involved, each of them is problematic in its own special way, which makes the equation a difficult starting point

**a:** Acceleration is the *rate of the change of velocity of motion*. Its problem is a *high degree of abstraction*, 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*. They have learnt 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*. It's fate is to remain intuitive.

\* **F:** Force is the worst problem. It represents the *strength of an interaction*. But the equation

$F = ma$  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.

### INTERACTION.

Newton wrote: "*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."*<sup>2</sup>

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."<sup>3</sup>.

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 perceptual 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 geni.

In the perceptual 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 turning direction.
- \* Experiments can and should be made with different bodies and pairs of bodies and with different kinds and strengths of interactions.

## BASIC LAWS

\* **N1:** The "*law of inertia*" is nothing but the idea of a *free body = a body without any interactions*.

Any possible verification of 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 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 "amounts" of inertia, 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 velocity changes of two interacting bodies* can be interpreted as a comparison of their inertias.

<sup>2</sup> Cajori F., ed., trans.. (1934. 1962). *Newton's "Principia," Motte's translation revised*. Los Angeles: University of California Press.

<sup>3</sup> Kepler J., *Astronomia Nova* (1609)

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, 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 wonderful 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 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 force and counter force*", is implicit in the very idea of interaction. As a common cause, it has *equal effects on both counterparts*. From the quantified meaning of mass we note that *the effects on the motions of the bodies are equal (and opposite), if they are represented in terms of momentum  $p = mv$* .

This is the motivation for adoption of this extremely important quantity, which in the traditional teaching is defined just by the mysterious formula. At the same time, this common value of the momentum changes serves as a *measure of the strength of the interaction* in collision. This in fact is the origin of **N2**.

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This is as close to the meaning of force as we can reach here. There is still some distance to go to the meaning of  $\mathbf{F} = m\mathbf{a}$ , but I stop here, just citing a comment heard on an intermission of my first complementary education course in 1996: "*I have been teaching physics over 20 years and this is the first time I feel like understanding mechanics.*"