Committee I
The Limits of Science?

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MODEL MAKING

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Discussant Response to **Herbert Pietschmann's**

SCIENCE AT AN END? THREE LIMITS OF SCIENTIFIC KNOWLEDGE

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(discussant paper)

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You are welcome to the limit!

Limits: borders, bounds and limes

Strategem is a simulation game. It was invented by Professor Denis Meadows, a member of the Roman Club in the 70-ies, the author of the famous book "Limits to Growth". In the game 5 persons play the role of five ministers of a developing country, and decide about the national budget of the next period. The decision is feeded into a computer and after a few seconds the computer gives the results of their decisions which results are the initial conditions for the next period. The planning of the next period can come ... The rules, the equations what the computer uses for answering form a simple model of the economy of developing countries. It does not consist random elements.

Young people like to play this game. The game has many degrees of freedom: different decisions - different strategies - lead to very different states of the country after the 10^{th} period. The players feel complete freedom in their decisions. After a few sessions the players learn from the answers of the computer, they develop a strategy to reach the best score (= standard of life). But because of the many choosable parameters there are many different strategies. There is no time and mind capacity to explore all the possibilities (even if their number is finite). When the first faster computer arrived to my school the brightest students came up with the idea: they could write a program code to ask the computer to find out the best strategy. They were not completely successful - the memory and the speed of the computer were not enough. But the students realized: the problem can be solved in this way. And from this moment on their interest in the game was lost.

There is a limit for every game - without any random component - which has a finite number of degrees of freedom. This limit means that the game is no more a game if one knows all the steps what he/she should do to reach a given, well-defined goal. Hopefully Nature has infinite degrees of freedom, so the game: the scientific research can last for ever.

Professor Pietschmann gives two definitions for "limit": the border type limit and the bound type one. (*Border* as borderline between two countries, *bound* as the end of a ruler.) To give meaning to limit is very helpful in the understanding of our problem in a deeper way.

In mathematics there is another possibility to formulate the limit: the *limes*, a word of latin origin.

$$\lim_{x \to 0} \frac{1}{x} = 0$$

means that the series of $1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{1}{5}, \frac{1}{6}, \ldots$ has a limit (0) you can never reach by walking through the members of the series but you can go closer and closer to it.

The *border* and the *bound* have a static feature somehow; you can stand at the border. Of course, this border can be pushed further and further. The *limes* type limit is more dynamical. And in my mind scientific reasearch is more similar to this one, although when walking through the members of the series you don't know by what rule the next member will be created, and you don't know the limit value. And, indeed, a research does not necessary have a linear structure like a series.

But our different approaches of limit may come from the difference between scientific *knowledge* and scientific *research* (or behavior).

The Scientific Method

"Man is a model-making animal. The animal nervous system has a modelling function, processing incoming stimuli, anticipating coming events, and by this guiding the organism. The use of models has reached its highest level in the case of man." (G. Marx, Games Nature Plays, Budapest, 1984.) And I think what we call scientific method is one of the most advanced - or at least the most accurate - using of models.

"The picture of the world which has been designed by scientific method is a description which can be characterized by the following axioms:

i) every notion is properly and uniquely defined

ii) there are no contradictions within this description

iii) there is a sufficient reason for everything to which this description applies.

... the experiment itself is shown to comply with the following three axioms:

i) it must be reproducible

ii) its results are given quantitatively

iii) it is a sufficiently simplified system so that so-called 'systematic errors' can be controlled and corrected for." (Pietschmann, page 8-9)

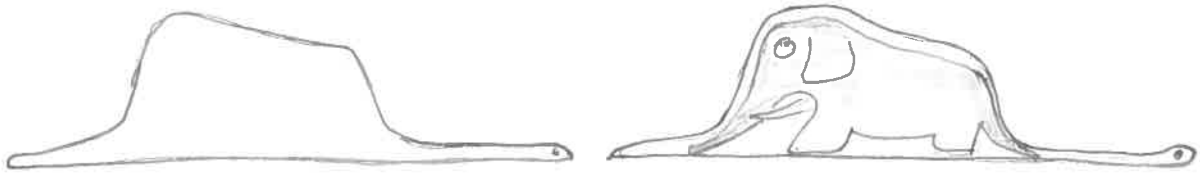
Let me formulate the so-called *scientific method* in another way, maybe in a more practical one from the point of view of science teaching. The formula is a simple description of the activity what we call *scientific model making.*

1. **observation** and of respect for reality
2. decision on **relavant aspects**, and data collecting according to these
3. **creation of a model** which interprets the variation of these data, which has a restricted number of degrees of freedom, and which is simple enough to be easily grasped
4. using of the model to **predict** forthcoming events
5. submission of the model to **experimental check** and **exploration of its limits of validity**
6. **practical applications** of the model within the limits of its validity
7. modification of the model to fit the region that lies beyond its limits and when finally necessary, search for a new model, i.e. re-enter this sequence at step 3.

Children: Experts in Model Making

The number of neurons of our nervous system is finite. World has an infinite number of degrees of freedom. Our mind is able to consider only a few of them at a time. The scientist focuses his/her attention on only a few variables, but most relevant ones. The scientific world is a very simple, but at the same time a very abstract description of reality. Very abstract descriptions are far from most of the people. To introduce science to a wider population you have "to nicely dress the scientific laws". This action is not alien to the young people.

Children often play with very simple objects. Their actions seem to be very abstract when playing with a wooden block as if it were a car or an aeroplane. Behind their simple actions there livess a rich picture in their mind, they "nicely dress their abstract actions". Perhaps the most poetic description of this psychological phenomenon was that given by A. Saint-Exupery in his tale book "Le Petit Prince":



"this is not a hat ... this is a boa after having eaten an elephant"

Games and plays are outcasts from many schools all over the world because "they are not serious enough to teach the strict scientific method". Games and plays, however, are models of real life, but without life-danger. The toys of the man-child are material models of the adult objects. Children play to learn the adults' behaviour by them, thus being able to gain experience before meeting real adult problems. Not only human children play, baby birds and mammals do too. To play is of evolutionary advantage! The race survives if its youths have played enough, i.e. they have prepared and trained themselves for the future problems with the help of models.

When the boy uses a wooden block as a car, he knows it is not a real car. When the girl plays with a doll, she knows the doll is no real baby. Children are perfectly aware of the difference between model and reality. But when they become six, they enter school ...

Models in School

At traditional schools the process of model making is usually not taught. The adult generations were so proud of their more or less successful models that they did not offer the schools but the models themselves. And this is done *not only* because old and wise scientists consider there is no time to transfere the whole four-hundred years' story of modern science during the school years.

From Galileo modern science has invented very useful models e.g. Newtonian Dynamics, Maxwell Equations, Kinetic Gas Theory, etc. These models worked so well (beyond their limits, of course) that there was no reason to doubt their validity. It is easy to mistake the successful model for reality. Success is often the mother of dogmatism. Geocentric world-order, action at a distance, light carrying ether, electron orbits – all looked so convincing that academic judgement, public opinion and even our minds remained their slaves far too long. The scientific revolutions fought to overthrow these outdated models. But the main battles were not fougth at scientific conferences, the swords were crossed within the mind of the traditionally educated scientist.

From the seven steps of model making only the 3^{rd} (models invented in the past by famous scientists) and the 4^{th} (using of the model) is taught in traditional schools. This means that the teacher gives lectures about concepts and laws, then the students will be given problems based upon the lectures. Sometimes the 5^{th} step is also introduced as an experimental proof of the textbook's statements. In this way a school exists only for the sake of school, science and Nature are completely separated in the child's mind: "The school physics by chalk and blackboard are only valid at school, the teacher's demonstrations are usually successful in the school laboratory. The home and the street, the forest and the breeze exist 'only' in our every day life."

(The separation of school science and Nature is different from the separation of mind and objects mentioned by Prof. Pietschmann and Prof. Marx. The latter one is the necessary step to invent science at all, while the one in question is a failure of teaching method.)

The school curriculum presents science through a variety of models: the mass point, the rigid body, the incompressible fluid, the ideal gas, indivisible atoms, integer valency, the carbon cycle of the ecosphere, and invariable species, etc. In transporting this "final" knowledge to the children the teachers do not care about the students accepting these models as ultimate thruth or even considering these as "reality". This method can cause a rigid knowledge, and for the majority of students an un-useful one. But this is the easier way for the teachers as well as for the society in case it preferes obedient "well-educated" members.

Model Making at School

The avant-garde schools in some countries intend to change their teaching style: their students can get practice in model making as a scientific activity rather than to memorize a huge amount of facts, rules, laws and so-called problem-solving routins. These schools try to introduce science as a lively action and not as a cool, well-structured palace of rules.

From the point of view of the teaching method the model-making oriented science requires a large number of observations and experiments by the students. These experiments are to be accomplished before the creation of the definition of concepts and of laws, rather than after the theoretical statements. The emphasis should be on discovery situations as opposed to proving experiments. There is an increasing number of schools all over the world where students are asked to make some kind of project work. In these projects the students will not repeat some old scientific experiment at a "lower" school level but they will explore something new in their environment. (Luckily, Nature has infinite degrees of freedom.) *There are* unknown, non-mapped areas around us. One of these interesting project works is the measuring of the radon density in the air (radon is a radioactive innert gas). Other schools make projects on acidic rains or on dust concentration in the air or on examination of bacterium cultures in different environments. These activities include data collection as well as creating models for understanding the huge manifold of data, and also checking the prediction of the models by experiments.

Creating the models during these project works students prefere to use the computer much more than their teachers, and use of computer encourages them to plan experiments with plenty of variables. Maybe the new generation of scientists will feel at ease with systems of many degrees of freedom than at the Newtonian systems of one, two or three bodies.

The students who get practise in model making in the science class will easily realize that every model has its own limits. They might even search for limits themselves by testing their models in different situations.

Contradictions

When my students use the kinetic gas model they suppose that the small particles of the gas are spheres. (This is the most simple and obvious assumption.) The spheres can travel in 3D, and we say they have 3 degrees of freedom. But when the students measure the specific heat of different gases, it turns out that there are certain gas particles (as oxygen, nitrogen) which have 5 degrees of freedom, and some (methane, water) 6 degrees. Arriving at this stage causes it is an exciting shock for the students. There is something wrong with the "small-tiny-spheres" of the gas model. This shock leads them to the discovery of molecules of two atoms (O_2, N_2) and molecules of more complicated shapes (CH_4, H_2O).

When you take a rubbed hair comb close to a thin water stream the water turns towards the hair comb. The rubbed hair comb has negative electric charge, while the rubbed glass rod is positive. What will happen if you bring the glass rod close to the water stream? Your common sense says: if the hair comb attracts the water, the glass rod should repulse it. However, the checking experiment will say the opposite. This contradiction of the model in the children's mind and their experience with the real objects leads them to find out the bi-polar structure of the water molecules.

In the last decades there has been a new tool for helping the young generation to make them feel more at ease in model making. This tool is the computer, the model making machine. With the help of computers the students (even the very young ones) can build up their own models, test these with many different variables (input), check their predictions by the answers of the computer (output), and easily modify their models. Beside that the process, in which the children are trying to find the bug in their code, helps them to learn about their own way of thinking. When the running code does not give the appropriate result the situation is similar to the experiments of "shocking results".

Facing an "unsuccessful" experiment is of a very high importance, surely not only from the educational point of view. The failure is needed to find the area where our model does not work. Perhaps the quest for limits is raised every time when a new model (a new theory) is born and the scientists try to apply it in surprisingly far away topics. (*"In our days, the game seems to go through a new cycle of similar nature; the development of theory of non-linear systems brought about the notion of 'Chaos and Order' [and Fractals]. Just as in the years after the development of Quantum Mechanics, this new concept is now carried into many domains of human interactions, even into economy and management."* Pietschmann, page 5)

Look into the faces of a group of bright students when you introduce a contradiction to them! Their eyes are shining with enthusiasm, they forget everything but the challange of the contradiction that does not fit to their former model. This is the very moment when the model reveals its limit. To modify it or to seek for a new one is an exciting job for the thinking mind with all those enjoyable emotions escorting creative brain activity.

It is also very important that the students understand that the similarity of a model and the modelled object is valid only from a few but very precisely defined aspects. By grasping that they will accept the existence of different, or even contradictory models of the same object. They will realize that there is no ultimate truth in scientific knowledge. One should just be clever enough to choose the appropriate model in oreder to solve a specific problem. And if there is no such model, a few of our students will be gifted enough to create a new one. In science classes when wnatin to prepare your students for an unknown future your only chance is to teach them scientific method, scientific behaviour, **model making**.