The Challenges for Science. Education for the Twenty-First Century
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FROM A STATIC TO A DYNAMIC SYSTEM OF EDUCATION IN SCIENCE

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Introduction

Four years ago I was invited by the teachers of an elementary school in Athens to speak about microcosmos to its pupils who had already been exposed to interactions and changes, as well as conservation principles from their activities at school.

While I was speaking about atoms, a little boy, not more than nine years old, asked me: "But why the electron in the atom does not stick to the proton?"

What a profound question!

I had to give an answer, caring to use the appropriate language for a child of that age.

My answer, as I can recall, was:

"The electron does not stick to the proton because it resists to the confinement, it resists to being shut in, it does not like the confinement as yourselves do not, therefore it reacts".

From the expression of his face it was clear to me that the boy was happy with my answer.

Later on I started to tell the story of Big-Bang Theory concerning the creation of matter.[1] After having said a few things about the creation of the existing matter in the Universe, according to the theory, another pupil of the same age, asked me: "It means that my body comes from a recycling process?"

[1] You see I have confidence to the capability of children to assimilate new findings. I always remember the famous physicist Cecil Powell, many years ago saying that when you try to teach new things to a child it is as cultivating a plane. When you do the same with an adult it is as cultivating a desert.

I was surprised to hear that comment from a child nine years old.

Considering the number of questions the pupils of that school asked me that day, it was apparent that they were receptive, curious and imaginative. Furthermore, if they were exposed to some of the major conceptual schemes in science as they were at that school, they could be able to shape patterns of thinking and reasoning, which could help them attain a level of understanding and appreciation of new knowledge in science. This would serve them through their adult lives. This has been for me a very useful lesson.

Having said that, let us now go to the main part of my presentation.

Dealing with new scientific knowledge

The title of this paper could also be: "There is a need for continuous incorporation of the new scientific knowledge to the body of primary and secondary education".

But in what sense is there such a need?

We know that one of the basic principles which the various physical phenomena seem to follow is:

"No change occurs without interaction and interaction implies change".

When man interacts with *Nature* it is implied that *Nature* acts upon him and he, in turn, acts upon *Nature* resulting in mutual change.

All interactions of man with *Nature* have their limits, boundaries, rules and laws dictated by it, and this is something we should remember.

In the last decades man has started to interact with *Nature*, in most cases through the products of the application of sciences, in a novel *unnatural* way. The earth is forced by man to "live experiences" that have nothing to do with those in the past during the entire course of the human evolution and history. In that way man has modified his environment to such an extent that he has lost touch with his biological and ecological base.

Due to these novel interactions with *Nature, mankind now lives in phase of unprecedented and continuous changes of his environment* and nobody can foresee the consequences of these changes.

Among the consequences of the new interactions, there is one connected with the question: how far the new physical environment formed little by little on the Earth's surface will continue to be consistent with life processes, and, in particular, with human life?

There is great danger that at a certain moment this environment will no longer be consistent with life processes as long as, man continuously violates the boundaries, the rules and the laws that he should be followed when interacting with nature, *and this is something that Nature does not tolerate; one either respects the principles of Nature and he survives, or violates them and is rejected as a foreign body*.

This problem, due to the tremendous and continuous accumulation of new scientific knowledge, becomes every day more and more complicated. The new scientific knowledge brings new applications and one has to be continuously aware of their cost. Of course, many times the cost of the application of new knowledge, is usually deeply hidden and, even with the best of all prior assessments, not predictable.

Nevertheless, predictable or not one should fight hard for the survival of mankind, complying with the limits and laws of *Nature* in his everyday interactions with it. Towards this goal we need continuous incorporation of new scientific knowledge to the body of primary and secondary education, since at that level the foundations of society's knowledge are built.

Regarding the problem we are discussing, the incorporation of new scientific knowledge described above is not enough. Science by itself has not helped to bring a balance between man and nature. Apart from knowledge of science we need *wisdom* as well.

Now let me mention some of several other reasons that continuous incorporation of new scientific knowledge to the body of primary and secondary education, is required.

– Delayed dissemination to general public or, worse, its total missing of new knowledge would perpetuate the society's ignorance and blindness to science and technology.

– Science is the major force shaping the world today. The new knowledge in science and its applications support and determine the economy of a country, creating new products, a new human ecosystem, new concepts of the surrounding world, new modes of thought, and even new societies.

– The new scientific knowledge renders existing professions marginal (reason of unemployment) but at the same time it creates new professions.

The society continues to act, knowingly or not, according to the old concepts of previous centuries, although the new scientific knowledge has established new concepts that should have led to a new system of values governing our everyday life.

Examples of such new concepts are:

– The world is that of universal interconnection
– The world is that of universal interrelationship
– The world is that of universal interdependence
– Globalization

– Complementarity
– Fragmenation of knowledge – Unification of knowledge

The public should know the foundations and the meaning of them and act accordingly, however nothing of the sort has happened.

The education system is at fault

Whatever the reason for all the above problems is, it is evident that our education system is at fault.

For many years the system has remained unchanged. Although last century an unprecedented conceptual revolution took place, which logically should have led to a completely new education system, nothing has really changed. It has remained and still remains in many countries static and closed.

The newly acquired knowledge has not provoked a revision and re-evaluation of older ideas and thoughts that are part of the existing teaching material. The teaching methodology of the physical sciences has missed the experience of research procedures and the acquisition of new knowledge.

As we see schematically in Fig. 1, the higher, secondary and elementary schools have no interaction with sources of new knowledge. Furthermore the knowledge offered is codified and static. The teaching material, with unrelated facts and details, is always the same, sometimes recycled. The classification also is the same for all levels.

Thus with time, while the frontiers of knowledge were being continuously pushed higher thanks to international scientific contributions, the level of schools has remained the same.

The result of that was, and in many cases still is, the continuous increase of the gap between the various levels of education and the frontiers of knowledge. In the last thirty years it has become apparent that if this gap continues to grow it could be disastrous for education.

In some school programmes there has been an attempt to include some of the new findings but to no avail. There are scientists that still believe that the whole can be described and understood as the sum of its parts, but that is a great mistake. *Science is more than a collection of isolated facts*.

So if not by addition how could an educational system incorporate the fundamental results embodied in the new scientific knowledge and develop the educational methodology continuously, so that the system is dynamically developed? *How can we make the most general ideas of modern science part of our culture?*

CLOSED – STATIC EDUCATION SYSTEM

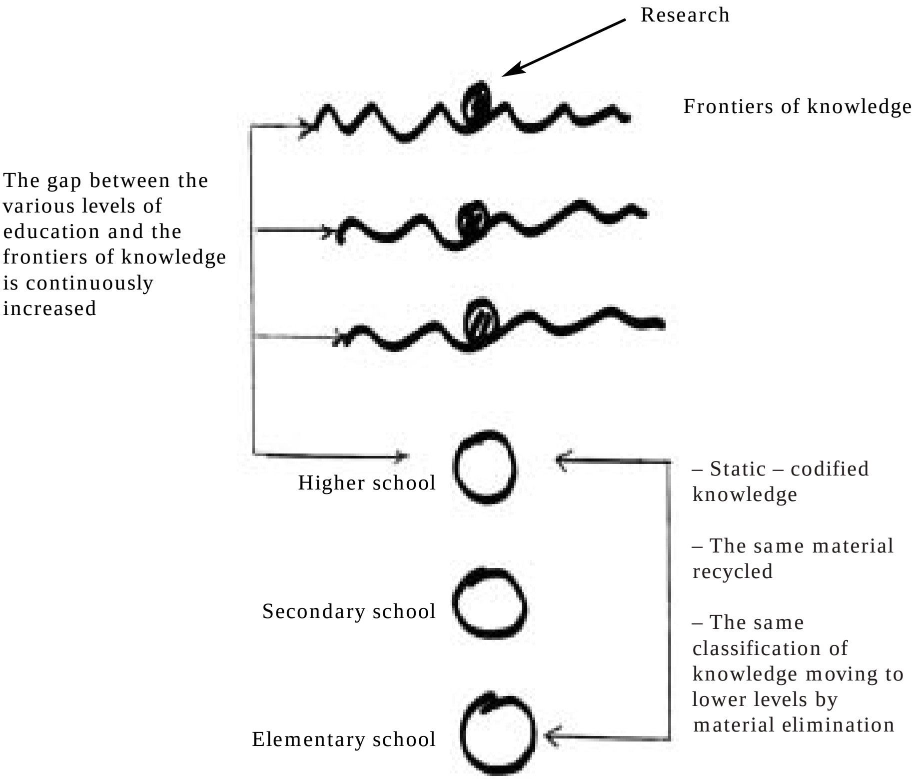

Fig. 1. The Higher, Secondary and Elementary Schools have no interaction with sources of new knowledge.

Presupposition for the dynamical development is that the system allowes, an immediate and continuous flow of new knowledge from the producing sources (research institutions) to the various grades of education.

The path of the flow of new knowledge in a dynamic system

Fig. 2 shows the path of this flow. It forms an expanding triangle. At the top there is the source (research institutions) of new knowledge, which moves on the frontiers of knowledge. At base there is the elementary education and at its sides the higher and secondary education.

By using the appropriate language and mechanisms and if the existing conditions allow it, the knowledge is going from the top to the higher and from the higher to the secondary and from the secondary finally to the elementary level.

As the new knowledge is passing through the various grades it is absorbed and in that way the system is refed.

This way, the foundations of the base (elementary school) are strengthened and they contribute to the elevation of all other levels on the right side of the triangle. The result is the top of the triangle goes higher, raising the frontier of knowledge as well. From its new position the source of knowledge gives new findings etc.

Open Dynamic Education System Continuously refeeded

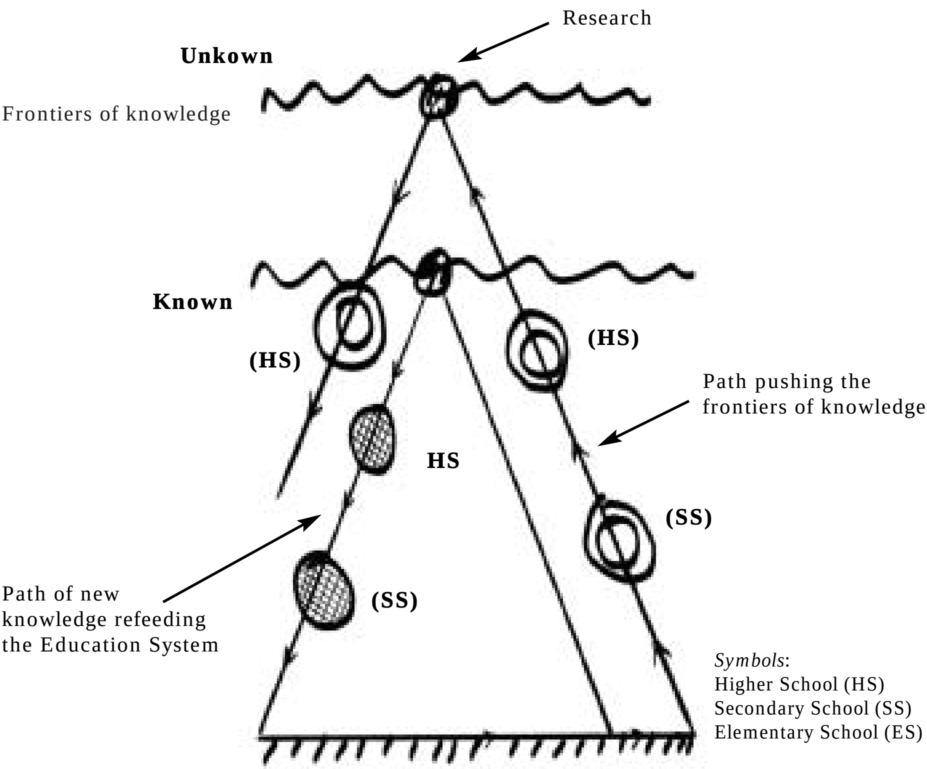

Fig. 2. The path of the flow of new knowledge.

The above flow procedure presents two serious difficulties:

1. How to insure the prerequisites for passing the new findings through the system and have them absorbed by it, or in other words how to keep the system in dynamical conditions.

2. How to find the mechanism to fulfil the above prerequisites and transmit effectively and quickly to the students of all grades the new findings.

Prerequisites for dynamical development

As it is known, every education system creates patterns of thinking and reasoning. These patterns constitute a kind of filter for the minds of the students. From that filter the general ideas of new knowledge may pass through and be absorbed by their minds.

In Fig. 3 this filter is presented schematically. Its characteristics are shaped by the patterns from which have been created.

FILTER FROM THE PAST

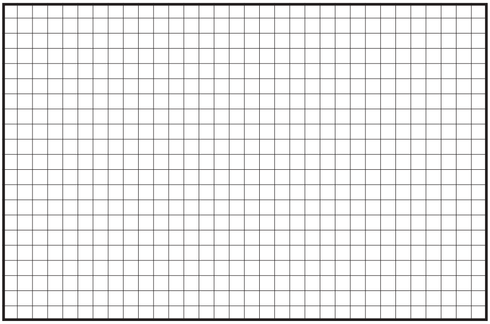

Fig. 3. A Schematic filter through which the new knowledge has to pass.

As is also well known physics taught in schools still today is based on nineteenth century science. At that time the only sources of information were the human senses.

In Fig. 4 you see an example. The observed phenomena were classified according to the way they were sensed. Thus sciences have been developed with the names: Acoustics, Mechanics, Optics, Thermodynamics, Electromagnetism, with little or no connection between them. This fragmentation of Physics, is so deeply ingrained in the minds of teachers of

Physical sciences that is difficult for them to adapt to different ideas of how to teach Physics.

In general man is not always prepared to have the foundations of his knowledge changed by new experience.

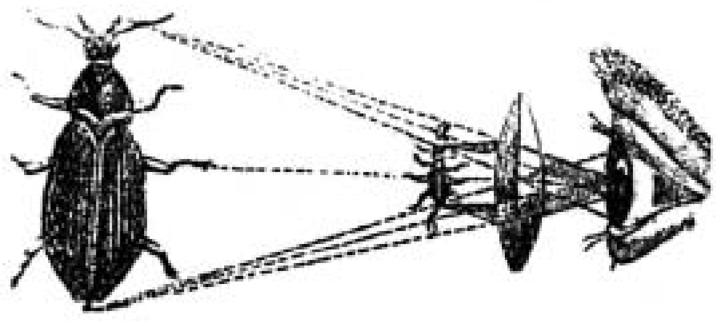

Fig. 4. Simple microscope.

The teachers of physical sciences usually transfer to their students the above "classical" model of physics and based on that they create to them patterns of thinking and reasoning for the physical world. With that "classical" pattern the students shape in their minds the filter through which they absorb or reject new scientific knowledge.

Today, in order to push the frontiers of knowledge further, our senses cannot play any more the role that used to play in the past. Nowadays in research we use instruments that go well beyond the capabilities of the human senses. In Fig. 5 you see a detector which is used in research of microcosmos. The comparison of the past and the present is given by Figs 4 and 5.

This detector reveals a new world in physics. Can we teach these revelations to the students? Will the filter that students have in their minds allow these revelations to pass through and be absorbed? The answer is negative. For pupils with the "classical" filter the new knowledge will be a "foreign body" and it will be rejected. Their basic concepts, their language, and their whole way of thinking are inadequate to understand atomic phenomena.

What should we do?

Obviously we have to take into account the revelations of the new detectors. The analysis of these revelations has led us to a conclusion: The new

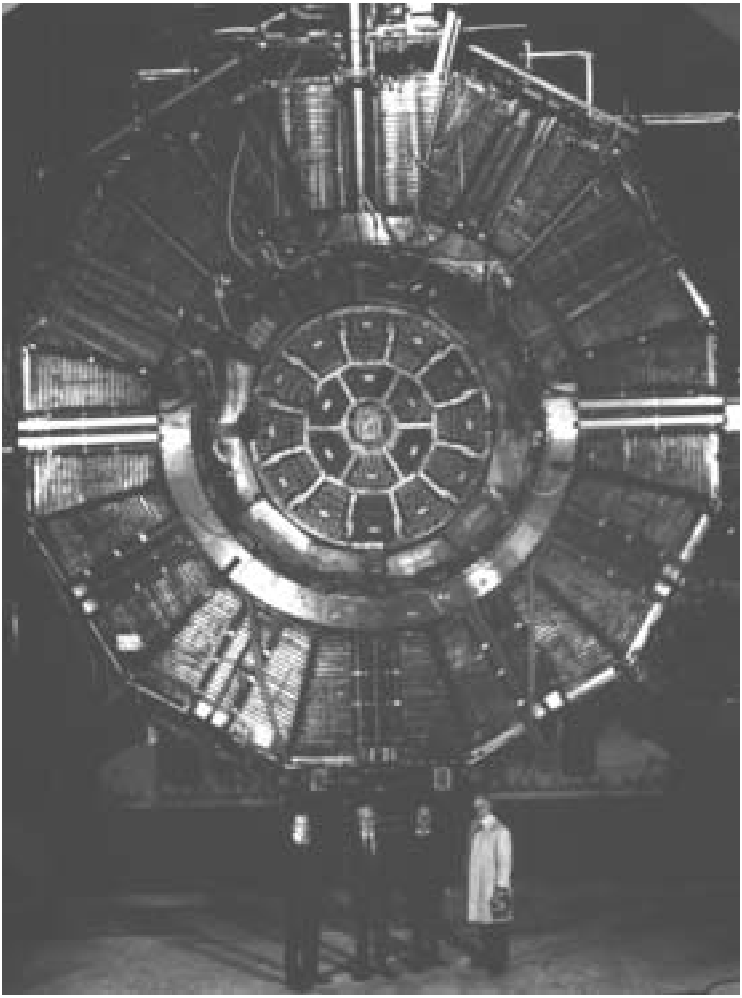

Fig. 5. A detector revealing the secrets of microcosmos.

phenomena that have been discovered follow some fundamental concepts which are valid in both macro and micro levels of the description of nature. If these concepts can be made meaningful to elementary and secondary school children, then with that equipment the children long after leaving school may retain some understanding of new findings.

From the same analysis we have learned that nature is not made up of a multimedia of objects, is not fragmented, but has to be pictured as one dynamic *whole*.

From Fragmentation to Unification

Nature forms a unity, which means that from fragmentation we have to pass to unification.

It is interesting to notice that this result turns us back to some centuries ago when our ancestors tried to understand the world as a whole, reveal the secrets of the Universe, and establish a relationship with their fellow men and their gods.

But after finding themselves unable to answer some questions convincingly, they discarded the attempt of discovering all the mysteries of the Universe and concentrated on certain isolated phenomena.

The success of this isolation rendered marginal the original problem of the relation of man with "nature" and his gods, and favored a false separation of man from nature. At the same time it influenced all aspects of human cultures, led to a fragmentation of their content, and gave a new direction to human thought and to the growth of knowledge.

This situation may have contributed to a certain progress, but at the same time it created boundaries and impasses. The separation of particular knowledge and concepts from others proved more and more dangerous.

Now in the light of accumulated experience we see that we are forced to review our course and change some aspects and the direction of our culture going back to its roots. A very nice result!!

Today the new knowledge is not in most cases a product of analysis but of synthesis of different phenomena. In order to have the necessary background to understand them we have to pass again from the fragmentation to the unification of the teaching of physical sciences.

If we want to prepare our pupils for this unification we should have the new science curricula focus on fundamental concepts that as we showed before, are valid in both macro and micro levels of the description of Nature.

If an educational system, since the primary school years, helps pupils assimulate the meaning of those fundamental scientific concepts, then it can provide them with patterns of thinking and reasoning which allow the incorporation of every piece of new knowledge into it. It helps to transform the education system from static to dynamic.

This solution is an answer also to the following five problems:

– The research is never ending, what we know today is inevitably just a small piece of what we are going to know in the next century. In our times it seems that the store of human knowledge doubles every five years, so there is a question how we would be able to teach all this material since the teaching hours at schools are always limited. One presupposes that the new knowledge should not remain “foreign body” for the next generations.

– The school has to provide the bases and the foundations for a “life-long education”. What do we have to do to achieve that?

– How to provide teachers and students clearly defined goals, as well as a cohesive picture of science?

– How to ensure that schools produce competent students?

– Since science is more than a collection of isolated facts, how to unify broad ranges of experience?

From all the above we may conclude that prerequisite for an educational system to function dynamically is that the schools, instead of filling the minds of pupils with unrelated facts and details, must focus their attention on certain fundamental concepts of science that form the bases for all explanations of physical phenomena.

In the next two tables a set of such fundamental concepts is presented for elementary and secondary schools respectively:

Fundamental concepts for Elementary School

1. *The Universe is composed of Distinct Units*

2. *Interaction and Change*

3. *The Conservation of Energy*

4. *The Degradation of Energy*

5. *The statistical view of Nature*
   (Nature is predictable only by the play of large numbers)

Fundamental concepts for Secondary School

1. *The Universe is composed of Distinct Units*
   Particles, Properties

2. *Interaction and Change*
   There are only a few distinct fundamental interactions
   In all interactions certain quantities are conserved

3. *The Conservation of Energy*
   The conservation principles are related to certain symmetries observed in the Universe

4. *The Degradation of Energy*
   The laws of thermodynamics
   Direction of energy changes
   Entropy, The spontaneous evolution of a system

5. *The statistical view of Nature*
   (Nature is predictable only by the play of large numbers)
   Uncertainty, Probabilities, Distribution Laws

6. *The Quantum behavior of matter*
   Uncertainty principle, complementarity

These schemes[2] were selected years ago by the COPES (Conceptually Oriented Program in Elementary Science) of the New York University, "because they include most of what is fundamental in science and because they provide the basis for a logical, sequential development of skills and concepts through the elementary grades".

As you see, in booth elementary and secondary school, the same fundamental concepts are used. With the appropriate language they can be meaningful for both. As one goes to higher grades the topics under each concept, progressively expand.

[2] See also M. Alonso, E.J.Finn, Physics Today 50, 140 (1997).

Mechanism to fulfill prerequisite

Let us go now to the problem of how to find the mechanism to fulfill the prerequisites for keeping the system in dynamical conditions and to transmit new findings effectively and quickly to students of all grades.

There are some facts relative to this problem.

– Equipped and suited to teach fundamentals are the scientists.

– The sources of new knowledge are the research institutions. These institutions are the central transmitters of the new “message”. In particular the specific producers of new knowledge are the best for transferring the substance of their findings in a simplified way. They have that substance in their “blood”.

If so desired the new scientific findings to be disseminated quickly and precisely to students of different grades of education and to the public, the research units have to play a new role in education, complementary to that of Universities.

With these facts in mind, one has to adjust the hole education activity.

The scientists that produce new knowledge have to transfer, their findings to the teachers and then the teachers to their students in the appropriate way and language.

In order to have a good communication during these steps the “transmitter” and the “receiver” must function well and be “in tune”. The first “transmitters” (the researchers) have to show “receivers” (teachers) how and what to transfer to their students. It means that the teachers should be scientifically trained in the spirit of fundamental concepts.

The whole problem is the education of teachers, in particular of teachers of elementary schools.