THE SECRET OF GENIALITY (I)

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INSTEAD OF ABSTRACT

We begin to publish, in series, the book THE SECRET OF GENIALITY (Yerevan, Armenia, Noyan Tapan Printing House, 2002) by our colleague Robert Djidjian, not only because we all must know the philosophical research and creation (in our domain of epistemology and philosophy of science and technology) from a *wider* area than that provided by the established fashion in virtue of both a yet obsolete manner to communicate and value the research, and extra-scientific reasons; but also because the book as such is *living, challenging and very instructive*. And though we begin with the first chapter, and not with the Introduction – in order to fuel the curiosity and to ease the approach of hasty readers to the book – the problems posed and the sketches of solutions are clear. And the author's sense of humor will influence us to the end.

The title of the book is suggestive enough to make us to focus on an old age question: the dialectic of the insight, of the discovery, its psychology moving between flashes of intuitions and cognizance stored in memory, and its logic of composition of knowledge from hypotheses to their demonstration and verification. The realm of science is most conducive to the understanding of this dialectic and the constitution of the *ideas* which are the proofs of what is the most certain for humans: the "world 3", as Popper called the kingdom of human results of their intellection, and though transient and perishable in both their uniqueness and cosmic fate, the only certain proof of the *reason to be* of *homo sapiens* in the frame of multiversal existence. Therefore, creation is the secret of the human geniality, and how to create science is a main part of this secret.

(Ana Bazac)

Step 1. MAKING REVOLUTIONARY DISCOVERIES

"It is the customary fate of the new truths to begin as heresies and to end as superstitions."
Th. H. Huxley

Great ideas contain tremendous power of change. Scientific discoveries are able to rebuild even the most fundamental principles and concepts of science and change our vision of the world. But just these fundamental conceptions and notions are the channels through which we comprehend reality. By the help of fundamental concepts we conceive the world and understand all the information concerning objects and events around us. Even the bravest thinkers seldom have the courage to question things that build the basis of fundamental theories.

A bit exaggerating the significance of scientific conceptions, philosophers noticed that basic theoretical notions are often unconsciously mistaken for objective realities.

But making a revolutionary discovery, scientists unavoidably come to the task of a profound reconstruction of the most basic scientific concepts. And that is an immensely difficult task since just these concepts determine ways of thinking of men of science. Basic concepts and paradigms determine the mode of thinking of every scientist. And it is long ago established that nothing is stronger than custom.

Explorers of nature resemble a researcher of marine life who observes oceanic creatures through the portholes of his bathyscaph. Fundamental concepts of science are the portholes through which explorers perceive the ocean of information they try to utilize. This is the principle difficulty confronting scientists on their way to a great discovery. Those who have an excessive faith in fundamental theories are not fit to make great discoveries.

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Some concepts of science are so deeply built in our thinking that they are often evaluated as being inborn ideas. Considering the thinking of modern men, one can easily conclude that it apparently is in possession of inborn comprehension of the essence of such fundamental concepts as causality and natural numbers. Immanuel Kant trying to understand the formation and growth of human knowledge presumed that there are some *a priory* forms of human judgment that do not need any personal experience for their acceptance. The scope of these fundamental concepts is the most essential factor that provides the possibility of comprehension of data supplied by experience. Kant believed that the principle of causality and the postulates of geometry as well as the laws of mechanics are distinct instances of *a priori* knowledge.[2]

Even if Kant's conception does not appear completely convincing, one point is unequivocal. We can judge about the world only in terms of the basic concepts of the present day science.

Each epoch has its set of fundamental notions and principles by means of which explorers conceive the information about the objects and events of nature. Guided by these basic paradigms, scientists build their own particular conceptions and scientific theories.[3]

After this general outline of the principal difficulty confronting every scientist on the way to a great discovery, let us revue the most basic paradigms blocking the road to revolutionary discoveries. I would like to start with Aristotle who built the first scientific world picture.

Prominent ancient thinkers were unable to be free of paradigms of the ancient world picture. They could not see the world other way but having an apparent boundary - the celestial sphere of the fixed stars. The motion of the Heavens was eternal and uniform, and the Earth was at the center of the Heavens.

Aristotle never opposed these basic conceptions of the ancient world picture. Just with their help he succeeded to draw the complete picture of the geocentric world.

To reach this task, Aristotle had to explain how the motion of the outermost celestial sphere could be transmitted to the inner heavenly spheres and to the objects of the sub-lunar world. Bringing the analysis of the problem to its logical end, he came to the most extraordinary conclusion of the necessary existence of the First Mover. Anyhow, even this extraordinary idea was grounded on the main paradigms of Aristotle's day. I mean, first, the principle that the motion of a body must be supported by an impact of some other body, and second, the conviction that the uniform rotation was the only kind of motion appropriate for the heavenly world.

For ancient observers, one of the most certain and evident facts was the existence of the celestial sphere of the fixed stars. So the universe itself, in full accord with the scientific conception of the truth, was conceived as a finite sphere (of course, of enormously great size), with the Earth positioned at its center.[4]

As I have just mentioned, great Aristotle himself could not avoid this natural conclusion. Even Copernicus, rejecting the geocentric model, still believed that the universe was a finite sphere, this time the center position being assigned to the Sun.

But already half a century after the publication of Copernicus' fundamental work *On the Revolutions of the Heavenly Orbs,* Thomas Digges suggested the idea of the infinity of the universe.

[2] Kant was haunted by the unshakable impression of the absolute nature of mathematical truth. How can one explain the certainty of mathematical knowledge as well as that of pure natural science? Kant resolved the problem by stating that mathematics and natural science are built on the basis of *a priori* principles. (Immanuel Kant. *Critique of Pure Reason.* Cambridge, Cambridge University Press, 1998, pp.136-146.)

[3] Thomas Kuhn. *The Structure of Scientific Revolutions.* Chicago, The University of Chicago Press, 1966 (third edition), p. 23.

[4] Aristotle summed up his position on the issue of the eternal rotation of the Heavens as follows: "The mere evidence of the senses is enough to convince us of this, at least with human certainty. For in the whole range of time past, so far as our inherited records reach, no change appears to have taken place either in the whole scheme of the outermost heaven or in any of its proper parts." (*De Caelo* I 3, 270 b 13).

Continuing the newly revived Democritus tradition, Giordano Bruno preached the infinity of the universe full of innumerable worlds: “The universe is of infinite size and the worlds therein without number... there are innumerable suns, and an infinite number of earths revolve around those suns.” In its main features, Bruno’s fantastic picture of the universe came out to be true. But it cannot change the fact that his preaching was rather a poetic fantasy than an empirically grounded scientific conception.

Thinkers of the past on their thorny way to a revolutionary discovery had to fight paradigms of geocentric world picture that for long centuries appeared absolutely true due to innumerable confirmations by everyday experience and rigid logic of Aristotelian argumentation. The first scientist who had the courage to develop a new revolutionary vision of the world in complete defiance of the restricting power of basic scientific paradigms of his day was Nicolas Copernicus.

To free himself from the paradigms of Aristotelian principles of natural philosophy and cosmology and create his heliocentric system of the world, Copernicus had to overcome serious theoretical difficulties. In fact, the task of creating a new theoretical system of the world was practically insurmountable. I mean Aristotle’s arguments rejecting the idea of the Earth being in motion. If the Earth were moving, one should feel a head wind as it does each one who rides on horseback. And if one would suppose that the atmosphere of the Earth was travelling together with the Earth, there was a second argument ready. Since nothing could hold the air around the Earth during its hypothetical space travel, the atmosphere of the Earth had to be dissipated and lost long ago.

There was also an astronomical argument. If the Earth were rotating round the Sun, stars would be seen from different points of its orbit. That should bring to the observation of the phenomenon of *parallax*: the position of a star on the sky should be different when observed from the different points of the orbit of the Earth. But no astronomer had ever observed star parallax, at least until the second half of the nineteenth century when powerful telescopes had been built in Europe.

Now let us turn to difficulties Newton should face building his mechanical system of the world. Newton was a deeply religious man. Therefore, he should be absolutely sure of the principle difference between the Earth and the Sky, between the sublunary world of transient material objects and the eternal Heavens. How then could the idea come to him that there is a universal law directing the motion of the Earth and earthly objects as well as the motion of the heavenly bodies all over the Universe?

Everyone would agree from one’s own experience that the bigger is an acting force, the higher is the speed of motion of the body under the action of this force. Why then should one consider an almost unknown notion of acceleration instead of the clear notion of speed?
No one ever saw a body to move without being forced to move. To shift a body, one had to apply a definite effort. How then could one jump to the strange idea of inertial motion? Why should a body move if no force were applied to it?

The revolutionaries of modern science confronted even more serious difficulties. The new principles of their theories were strange and bewildering, and that not only regarding common sense people. Take, for instance, Planck’s idea of *quanta* of energy. By the end of the nineteenth century there was no doubt in the wave conception of light. Only the wave conception could explain the fundamental phenomena of diffraction and interference. Then, how could one suggest the idea of light composed of corpuscles? Did Planck as the author of the radically new quantum conception conceive an alternative way of explaining the phenomena of diffraction and interference?

Albert Einstein also had to meet insurmountable problems. Experience proved that when two trains pass each other, passengers of one of them would observe the other train passing by as if it were moving at doubled speed. In general, if a body moves in regard of the Earth with a speed w

and a second body has a speed *u* in regard of the first body, then the speed *w* of the second body in regard of the Earth will be a sum of the speeds *w* and *u*. What can be wrong with this entirely obvious picture? Why should one prefer the mysterious Lorentz transformation?

If a passenger is walking along the train moving forward on its track, why should the speed of the passenger in regard of the Earth be in any connection to the speed of the light waves?

And why should one accept that the speed of light is the maximal speed of physical motion? Imagine a “dark” world composed of only two separate gravitating masses that have no information about the speed of light. How these masses should know that *c* is the maximal speed allowed in nature? If these gravitating masses were enormously big, what could prevent them to be accelerated so much as to obtain a speed exceeding the speed of light?

For the pioneer of atomic physics Niels Bohr, the unsurpassable question was why electrons should not radiate electromagnetic waves while rotating on their stable orbits.

For Erwin Schrödinger, the author of wave mechanics, it would be very difficult to answer the question how do the particle-electrons come out of atoms if inside the atom electrons are “spread” over in the form of standing waves?

The deeper penetrate scientists into mysteries of nature, the more difficult problems arise on their way. It is quite certain now that to learn the inner structure of an elementary particle, one must bombard this target-particle with projectiles of such high energy that exceeds by far the inner energy of the target. Is not it evident that by such a bombardment one will observe only the result of the full destruction of the target-particle, getting few information about its inner structure? Some scientists, quite reasonably, conclude that science will soon reach the boundary of human knowledge of the micro-world.

A similar conclusion follows from the quark conception of the modern theory of elementary particles. Contemporary educated men are used to the picture of the world composed of particles with different kind of charges. Interactions of all kind charges are understood as taking place by the means of a corresponding field. Normally, the greater is the distance between the charges, the weaker is their interaction. As a rule, the strength of the field is inverse proportional to the square of the distance. This point of the charge-field interrelation is so logical that one cannot imagine existence of charges, which could act stronger as the distance between them increases. But the modern theory proves that elementary particles are built of quarks, and quarks interact just in the above-mentioned “illogical” way. The bigger the distance between a given pare of quarks, the stronger is the force of their attraction. Such a spring-type principle of interaction of quarks makes the perspective of their empirical study very questionable.

Apart from the general difficulty of freeing oneself from the rigid frames of paradigms of science, each great discovery confronts its own unrepeatable mind-twisting questions. Let us consider Charles Darwin’s theory of evolution in regard of such puzzling questions.

The complete perfection of living organisms and the amazing harmony of their relations with the surrounding world brought many thinkers to a quite natural idea that living organisms are creations of God. But from the day of Cuvier, one has to admit that the evolution in the living world is an undeniable fact. Yet how could Darwin believe himself that the perfectly adapted species could appear merely by chance mutations? Of course, natural selection will give preference to creatures with better construction and more adapted behavior. For instance, it is obvious that animals with eyesight have an enormous advantage compared to primitive creatures.

But how could *blind* chance mutations produce the extremely complex structure of the *eye*? Is not the probability of the chance appearance of a principally new organic property practically negligible? Darwin was really a great genius since he succeeded to resolve this unsurpassable difficulty.

But to come to the incredible principle of chance mechanism of evolution Darwin had to free himself from the chains of a strong paradigm of his day. This paradigm was the common belief that living creatures and their heredity is apparently influenced by the surrounding physical conditions. Darwin himself admitted that the difficulty to realize the real mechanism of evolution arose "in chief part from the deeply seated error of considering the physical conditions of a country as the most important for its inhabitants…"[5]

To sum up. The fundamental notions, ideas and principles are the basis on which science is developed. But these basic means of scientific thinking build the walls of paradigms beyond which one should look for new revolutionary conceptions. "I believe," wrote Richard Feynman, "that to solve any problem that has never been solved before, you have to leave the door to the unknown ajar… Otherwise, if you have made up your mind already, you might not solve it."[6] In this sense, one can agree with Nietzsche's paradoxical remark, that scientific convictions are "prisons".

"Irrationally held truths may be more harmful than reasoned errors," pointed out Th. H. Huxley. But as we have seen above, for the course of great scientific discoveries the most rational and empirically confirmed principles and paradigms too may appear even more dangerous and damaging than apparent errors.

Step 2. IS THERE A METHOD FOR GREAT DISCOVERIES?

"*Here there is no method capable of*
being learned and systematically applied."
Albert Einstein

How wonderful it would be if there were a universal method of inventions and discoveries. One would learn the magic method and then began to produce his share of discoveries and inventions. But is such a method possible in principle? How could it be that one and the same method of investigation were effective in the vast domain of modern science where the fields of research lie so far apart?

To answer this question, ancient thinkers had to reveal first the essence of truth and knowledge. What a difficult task it appeared to make the first steps in this field. Only Aristotle succeeded to formulate a definition of the truth, which then remained classical during many long centuries. Latin writers put Aristotle's definition into a pure formula: *veritas est adaequatio intellectus ad rem* (The truth of a thought is its adequate agreement with the things.)

But can human beings reach the truth or it is only the destiny of god? Only the most daring thinkers could dream of the golden key that opens the palace of the truth.

Aristotle denied the possibility of creating a universal method of research and discovery. His theory of syllogistics gave mankind a strict method of deductive proofs. But to prove an idea, one should first to find it out. No method or rule could guarantee finding the answer to the question under discussion. One should rely here on his *acumen* and quick-wit only. [7]

Molière's hero wandered that grammar "knows how to control even kings". The power of method is perhaps stronger. Method knows how to lead even geniuses. Long after Aristotle, two great thinkers attempted to prove the possibility of creating a universal method of discoveries and inventions. These two great men were Francis Bacon and René Descartes. What is really

[5] Charles Darwin, *The Origin of Species.* Reprint of the first edition. New York, 1951, p. 339.
[6] Richard Feynman, *The Meaning of It All*. London, Penguin Books, 1998, p. 26.
[7] *Analytica Posteriora* I 34, 89 b 10.

remarkable, each of them proved his position not by speculative abstract argumentation, but rather presenting straightforwardly his own universal methods for research and discoveries.

Bacon called his method "true induction". His *Novum Organum*, first published in 1620, was devised mainly for the discovery of the causes and laws of nature.[8] Bacon advised to pile up sufficient number of observational and experimental data and put them into tables according to their similarity and difference. Later on John Stuart Mill presented Bacon's inductive method in the form of four simple rules which he called the method of Agreement, the method of Difference, the method of Concomitant Variations, and the method of Residue.[9]

In actuality, Bacon's teaching was much richer since it included also original chapters about instances of primary importance (*instantia prerogativa*), which dealt with the types of phenomena that must be investigated in first place to guess and reveal causes and laws of natural phenomena.[10]

René Descartes is still popular today with his *Discourse on the Method,* first published in 1637. His famous methodological principles of effective scientific research were formulated just in this essay. [11] He suggested also about twenty methodological rules of problem solving in an unfinished manuscript *Rules for the Direction of the Mind*, which was published only posthumously.[12] The essence of Cartesian methodology can be compressed into a general advice to divide the problem under research into as many parts as possible and to use only concepts that are entirely clear and intuitively evident.

Surprisingly, the path breaking conceptions of Bacon and Descartes did not get any significant support from later generations of scientists and philosophers. The revival of the idea of the universal method of discoveries and inventions took place in the second half of the twentieth century almost independently of the remarkable heritage of these brilliant thinkers. First of all I would like to mention the original conception of Alex Osborn, the author of the popular method of "brainstorming". [13] The characteristic feature of his conception as well as of teachings of other prominent methodologists of the twentieth century was their claim that they possess the "golden key" designed to open the strongly protected depositories of knowledge and solve all the problems in science and engineering design.

At present almost every methodologist tries to develop his own and entirely unique system of discoveries and inventions. This state of affairs is really startling. There is such a simple way to build the fundamental theory of discoveries and inventions that it is really strange that methodologists did not advance just by this clear and universal way.

Already John Stuart Mill had to acknowledge that "nearly everything which is now theory was once hypothesis". If considered from the point of view of certainty of scientific statements, a

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[8] "I did not do great things, but merely made less of things that were believed great," declared the author of *Novum Organum.* Yet he was convinced that his success could be compared to that of Alexander the Great." (Francis Bacon, *Novum Organum*. La Salle, Illinois, Open Court, 1994, pp.106-107.)

[9] John Stuart Mill, *A System of Logic Ratiocinative and Inductive Being a Connected view of the Principles of Evidence and the Methods of Scientific Investigation*. – In*: Collected Works of John Stuart Mill*, volume VII, Book III, chapter VIII, On the Four Methods of Experimental Inquiry. University of Toronto Press, Routledge & Kegan Paul, 1973.

[10] Francis Bacon, *Novum Organum*, pp.174-273.

[11] René Descartes, *Discourse on the Method.* – In: *The Philosophical Writings of Descartes*, vol.1. New York, Cambridge University Press, 1985, p.120.

[12]Descartes advised to build the science on the bases of simplest statements. "The method consists," tells us one of his rules, "entirely in the ordering and arranging of the objects on which we must concentrate our mind's eye if we are to discover some truth. We shall be following this method exactly if we first reduce complicated and obscure propositions step by step to simpler ones, and then, starting with the intuition of the simplest ones of all, try to ascend through the same steps to a knowledge of all the rest." (René Descartes, *The Rules for the Direction of the Mind*. – In: *The Philosophical Writings of Descartes*, vol.1, p. 20.)

[13] Alex Osborn, *Applied Imagination. Principles and Procedures of Creative Thinking,* New York, Screibner, 1957.

hypothesis is quite a weak statement. The term hypothesis (*hypo-thesis*) literally means "beneath an assertion".

Yet, it is hardly necessary to prove that all path-breaking ideas had been suggested first as hypotheses. "Every generalization is a hypothesis," believed Henri Poincaré. Anyone who has a slightest knowledge of the practice of scientific investigation will readily agree that no discovery can be made without hypotheses. From this simple and absolutely true statement, a conclusion of principle importance can be derived: *the method of hypotheses is the universal method of scientific discoveries.* In this sense, hypothesis is the author of truth.

So it should be clear that to build the theory of scientific discoveries, one has to develop the conception of the process of thinking that produces scientific hypotheses.

To make the first step in this direction, let us consider the next question: "What general requirements should be met to make effective the process of building hypotheses?"

It is quite evident that to solve a problem one must first understand it appropriately**.** The deeper is one's understanding of the problem under investigation, the closer are his ideas to the true solution. In the language of methodology this first phase of the process of scientific investigation is that of *problem analysis*. "The method which proceeds without analysis is like the groping of a blind man," noticed Plato.

When a problem is analyzed to a certain extent and depth, then all of a sudden comes the idea of its solution.

Since, in general, analysis is followed by synthesis, this second phase of the process of scientific investigation may be called the phase of *hypothesis synthesis*. Being influenced by Alex Osborn's terminology, I often use the term "idea generation" in regard of this phase.

Let us, for a moment, stop our inquiry and sum up our results. First, *the universal method of scientific discoveries is the method of hypotheses*. Second, *the process of building hypotheses has two main phases - problem analysis and hypothesis synthesis (or idea generation)*.

Now we have to concentrate on hypotheses. Wise men had noticed long ago that there could be no hypotheses clean of chance of being false. Every hypothesis or newly suggested idea of solution must be checked empirically and theoretically. Of course, in absence of relevant facts and observational data all ideas sound reasonable. But facts are truly stubborn things. A cardinal fact may decide the fate of an entire theory. Yet scientists have no choice but follow Plato's recommendation, "let us go forward and try". Suggesting hypotheses is like getting into the river supported by the hope that the experiment will show the true way. George Polya gave the most laconic expression of the essence of scientific method, "Guess and test".

No great name can guarantee the correctness of a hypothetical solution. "He who never made a mistake never made a discovery," underlined S. Smiles. So the third phase of the process of scientific discovery is the checking of the correctness of suggested_hypotheses. While seeking the truth, the object of research appears to be the first and the last word. A false hypothesis never lives to be old.

To emphasize the importance of strict testing and verification, it is usually said that any hypothesis that disagrees with empiric data or theoretical principles should be rejected. Yet this simple general principle needs some significant commentaries. First of all, one should bear in mind that in science some failures are not less instructive than partial solutions. Secondly, when the testing of a given hypothesis brings negative results, no one hurries to throw it away.

When we deal with a fundamental scientific problem, its hypothetical solutions have usually the form of complex theoretical constructions. One can seldom check these theoretical statements directly comparing them with empiric data. As a rule, to check the correctness of a newly suggested conception, one must deduce from it a number of more simple conclusions that can be empirically verified. So the method of hypotheses is often called *hypothetical-deductive* method.

To have the full picture of the process of scientific discovery, it must be mentioned also that the departure point of any given scientific investigation is a definite scientific question or problem. In a sense, there is no problem with finding research problems since the life of science is always full of problems. Sometimes they are formulated by the investigator himself or by his colleagues. Scientists inherit also many problems from preceding generations of explorers.

In general, the process of scientific research proceeds by cycles. Before a scientist makes his discovery, he suggests and examines numerous alternative solutions. But it does not mean that the investigator just throws away unlucky hypotheses and thinks up completely different solutions. Hypotheses are born with such difficulty and pain that scientists love them as their own children. A scientist clings to his hypothesis even facing empiric data that apparently deny his conception. Instead, the author of the hypothesis, first of all, tries to modify and improve his original idea. To improve their hypotheses more effectively, scientists return to the problem under investigation and analyze it anew. Investigators do their utmost to reach a deeper understanding of the problem, always taking into account also the negative results of the verification of previous hypotheses. Improvement by improvement the final truth is stated.

So, in fact, the improvement of a hypothesis proceeds in following stages: problem analysis - idea generation - hypothesis verification - return to the original problem. Cycles of hypothesis improvement get continuously repeated until there appears a satisfactory solution. Of course, repeating analysis-synthesis cycles, scientists may produce some completely new solutions, too. So the phase of hypothesis improvement should not be understood merely as a slight modification of the initial solution. Radical changes are needed when the investigator faces considerable gaps between his hypothesis and new experimental data.

To sum up, we can fix the following phases of the process of scientific discovery: *problem formulation - problem analysis - idea generation - hypothesis verification - hypothesis modification.* The entire process is guided by the necessity to bring scientific ideas in agreement with phenomena under investigation. Martin Heidegger wrote in his picturesque style, "Obedient to the voice of Being, thought seeks the Word through which the truth of Being may be expressed."

Problem analysis together with hypothesis synthesis composes the core of the process of scientific discovery. The remaining phases do not require much examination. Really, why should we pay special attention to problem formulation if the life of scientists is always full of problems? Of course, to find a problem in a situation where the scientific community is satisfied with the existing state of knowledge means a big service to human cognition. But, I repeat, there are so many questions to be answered in science, and their number is so rapidly increasing with the progress of civilization that scientists can do well enough without a special theory of problem formulation.

The same is true concerning the phase of hypothesis verification, too. It was mentioned above that the main procedure of the process of hypothesis verification is the deduction of conclusions from a given hypothesis. Since the theory of deduction is one of the most advanced fields of scientific knowledge from the times of Aristotle, hypothesis verification is in no way a burning topic in the methodology of science.

The phase of hypothesis modification does not require an immediate research too. As a matter of fact, it eventually comes to the cyclic repetition of the preceding phases.

Thus we see that to make further progress in the theory of scientific discoveries one should proceed closely tied to its central phases of problem analysis and hypothesis synthesis. For this reason, the conception of the method of hypotheses I am going to present in this section I call *analytic-synthetic conception.*

Now, which are the main steps of problem analysis?

The basic procedure preparing a discovery is the *revelation of the main points* of the given problematic situation, or, which is the same, the uncovering of main features of the problem under investigation. The phenomenon a scientist explores has uncountable connections with various objects of the surrounding world. If scientists did not concentrate on the main points of the problem shifting aside the enormous amount of data only slightly related to it, then they would have to deal with such a complex and complicated problem that no one could ever resolve it. Revealing main features of a problematic situation and pushing aside all non-relevant factors, scientists bring the object of their research to a reasonable dimension.

This task of revelation of main points often results in building a simplified model of the initial problem.

The method of *simplification* is apparently the most effective "craft" of scientists. Using this tool, scientists begin their research considering extremely simplified models of phenomena they explore. After solving such a simplified problem, investigators try to take into account previously omitted factors and parameters thus gradually moving closer to the original problem.

Here are some examples of effective implication of the method of simplification. Starting the study of mechanical motion, physicists abstracted from the dimensions of moving bodies regarding them as material points. They neglected the influence of the force of friction and concentrated their efforts on the study of linear motion. Describing the motion of the planets of the solar system, astronomers first neglected the influence of the planets on each other's motion. But later on, Neptune and Pluto were discovered just taking into account the gravitational interaction of the planets.

A particular case of the simplifying approach is the method of *idealization*. Construing an idealized object, scientists prescribe it minimal number of characteristics, usually in their extreme manifestations. A number of notions of ancient natural philosophy, for instance, the uniform circular motion of heavenly bodies, the basic four elements, the celestial spheres and the firmament, atoms and empty space were examples of ideal constructions. Modern theoretical knowledge is based on a variety of idealizations like the concept of ideal gases, the "absolutely black body", quanta of energy, physical vacuum, virtual particles, etc.

After revealing the main points of the problem under investigation and building its simplified models, scientists turn to the second basic procedure of the process of problem solving – *the subdivision of the problem into sub-problems*. Great discoveries usually come out of investigation of complex research problems. To make his task easier, a scientist breaks the complex problem into simple parts, or sub-problems. So, instead of being involved in the investigation of complex problems, scientists study series of much more simple sub-problems.

The process of subdivision is easy to carry out if one begins "*from the end*", i. e., from the question of the problem, and moves "backwards" to its conditions. The question of the problem may directly require knowledge of a set of factors. Each of these factors needs to find out its subset of parameters. If we present the results of this process of subdivision graphically, beginning with the question of the original problem and then descending backwards to its successive sub-problems, we eventually draw the so-called "*sub-problem tree*".

The tree of sub-problems helps to form the plan of research. To be able to carry out this plan, one should build a sub-problem tree of a reasonable dimension. The simpler is the sub-problem tree, the easier is the way of its verification. But restricting himself to "modest" sub-problem trees, a scientist may omit branches necessary for true solutions.

Problem analysis, as well as any other phase of problem solving is based on the scope of available knowledge. Scientific research, and especially its bases – the process of analysis of problems – requires total *mobilization* of relevant information.[14]

[14] George Polya, *Mathematical Discovery. On Understanding, Learning, and Teaching Problem Solving*, vol. 2. New York, John Willey & Sons, 1965, p.66.

To mobilize information means to make it ready for the solution of the problem under investigation. It is evident that if the knowledge concerning an object of research is not systematic, it cannot be mobilized effectively. Scientists, in this sense, have a definite advantage since they are used to systematic learning and research. The way of thinking of many scientists is so scrupulously systematic that they are often considered dull pedants.

Regarding the task of mobilization, the scope of knowledge acquired by a scientist can be divided into two groups: the "operational" knowledge and the "reserve" knowledge. The first group consists of information that the scientist can reproduce and put into operation immediately. The "reserve" knowledge cannot be reproduced with a sufficient level of accuracy, though the investigator knows well where from one can obtain it.

In the process of discoveries, the most important one is the "*terra incognita*" type information. Scientists often feel an urgent need of some information relevant to their research. By that time, they are unable to tell either the possible sources of this information, or its definite content. Scientists are not sure even if such information does exist at all. Obviously, this type information cannot be "mobilized" in the literal sense of the term. "*Terra incognita*" information needs persistent search, and sometimes requires undertaking laborious research.

It would be quite natural to ask what amount of knowledge is optimal for the task of great discoveries? The question itself presumes implicitly that one should not expect that the bigger is the scope of the available information, the more probable is the discovery. Factually, excessive knowledge is sometimes a handicap. "Many a man," believed Nietzsche, "fails to become a thinker for the sole reason that his memory is too good." Having at hand lots of facts never means finding the right answer. First, one cannot effectively single out the relevant information if his knowledge of the subject is of an enormous dimension. Second, the excessiveness of the knowledge of an individual indicates that he is more inclined to solve research problems with the help of the knowledge of details and standard methods, rather than using general principles and original approaches.

So, it quite certain that scientists should not possess excessive knowledge. By contrast, no depth of understanding may be excessive concerning scientific knowledge. The way to a deeper understanding goes through asking questions and finding out their answers, drawing conclusions from basic principles and disclosing relations between statements of different levels of generality.

Another obstacle in the process of discoveries is presented by "*hidden information*". To mobilize some information, the investigator must be aware of its existence. But the most needed information is often hidden from him, and the ways information can be hidden are unlimited and innumerable.

One more point concerning the phase of problem analysis. It was mentioned above that an effective way of problem analysis is the subdivision of the problem moving "backwards" from the question of the problem. Hidden information can be uncovered also through "direct" steps, by drawing conclusions from the conditions of the problem and relevant information. Normally discoveries require both the ways of problem analysis – the "backward motion" from the question of the problem and the "direct motion" by drawing conclusions from given conditions.

Step 3. HOW DO SCIENTISTS GENERATE PATH-BREAKING IDEAS?

"Say first, of God above or man below,
What can we reason but from what we know?"
Alexander Pope

It is the destiny of analogy to generate great ideas and revolutionary principles.

Problem analysis, though absolutely necessary, only prepares the ground for discovery. When a serious problem is analyzed, the investigator shifts aside all non-relevant information, uncovers the main features of the problem, builds the simplified model of the problem under research, and divides it to a number of more simple sub-problems. But the analysis of a difficult problem eventually comes to such a knot of the sub-problem tree where the investigator is unable to subdivide it father. In other words, the analysis of a difficult problem finally terminates with an "insoluble" sub-problem. George Polya described the situation as follows: "When none of the solutions tried fits the problem, we feel lost, nothing else comes to mind".

So how can one resolve an insoluble problem?

Such a problem is insoluble only in the sense that its further analysis is unproductive. Then it is time to put emphasis on the procedures of synthesis. Now I am going to prove that solutions of scientific problems, including ideas of great discoveries, are synthesized in *one single way – by analogy with the solution of some similar problem.*

Being scientific means to have the habit of tracing something unknown to a thing well known. Now we have to realize that the only way to get a new idea is to trace the problem under research back to something *similar*. I will not be original proving that ordinary ideas are suggested by analogy with the solution of some prototype problem. Here the role of analogy is well known and widely accepted. Books on the history of science tell plenty of amusing stories of great discoveries attributed to some occasional analogy. This proves that scientists realize that analogy has important role in their great insights.

But only a number of authors, Ernst Mach the most prominent among them, went so far as to prove that analogy produces *all* new ideas and discoveries.[15]

The main obstacle on the way to such total generalization is the fact that the history of science tells us of extraordinary ideas that were opposed to all available knowledge. Is there any reason to insist that these extraordinary and unique ideas, which apparently had no prototypes in the old theories, had been generated also by analogy with the solution of some similar problem?

Yes, I am going to prove now that even the unique and extraordinary ideas are produced with the help of analogy.

Any extraordinary idea to be accepted by scientific community is patiently explained and intensely discussed. In fact, explaining a new idea one builds a bridge connecting the new extraordinary conception with the old familiar knowledge. To bridge the knowledge at hand and the new idea means to find out the way that leads from the available information on the subject to the new conception.

Now, how can one derive the new idea from the available information? There are only three types of inferences: deduction, induction (complete induction and enumerative induction) and analogy. Deduction is out of discussion since we deal with ideas of great discoveries far out of reach of existing theories. The uniqueness of a great discovery excludes the possibility of producing it with the help of an inductive generalization, too. So there remains the only possibility of bridging

[15] Ernst Mach, *Erkenntnis und Irrtum*. Berlin, 1905, S.232. See also Christian Sigwart, *Logik*. 2.Bd. *Die Methodenlehre*. Tubingen, 1911, S.309.

ideas of great discoveries with the available scientific knowledge – that of making inferences by analogy.

But does not the uniqueness of the great discovery reject also the possibility of bridging it with knowledge at hand using some simile and analogy? No, it does not. Any extraordinary discovery is unique, but not in the absolute meaning of the term. Great discoveries are unique only compared to existing conceptions. They are unique in their field of scientific knowledge. But not in regard of all the scope of scientific knowledge. A relation unique and extraordinary in the given field of knowledge appears to be an ordinary one in some remote field. Similarity of objects involves an unlimited range of levels. These two factors combined together provide a possibility to explain any extraordinary new idea with the help of "old" knowledge. And the way through which the new extraordinary idea is explained and "brought down" to ordinary old knowledge can be considered as a sequence of thoughts that could bring to life this great idea.

On the other hand, any explanation of an extraordinary assumption necessarily involves an illuminating similar case taken from the frame of the old knowledge. An explanation of a principally new idea considered as the possible way of its discovery, in actuality, uses the mechanism of analogizing.

Of course, the way a discovery is explained never follows the path that actually had brought an explorer to his discovery. Authors of great discoveries, as a rule, are unable to recollect the particular chain of thoughts that had brought them to their fascinating solutions. Most possibly, we'll never know the real way of a particular discovery. But here the cardinal point is that any reasonable explanation of a great discovery shows us the possible way this discovery could be made with the help of some analogy.

Now I am going to show that my thesis is confirmed by historical evidence concerning the most revolutionary ideas of the history of science – the conception of heliocentric system, the law of universal gravitation, the extraordinary conceptions of the theory of relativity and quantum mechanics.

It is well known that Copernicus did not need any analogy to come to the idea of the heliocentric world. He could read about this hypothesis in astronomical treatises of many authors, the initial source being Aristotle's discussion (and rejection) of the idea that the Earth was in motion. But how could ancient thinkers come to the idea of the Earth revolving round the Sun? Perhaps, it was due to the Greek tradition to consider all logically possible solutions of problems under discussion. Astronomers could think up the possibility of the Earth moving round the Sun while being involved in the discussion of some similar problem.

We can imply also my general thesis that any explanation of a new idea can serve as a possible way for its discovery. Explaining how can be that we see the apparent motion of the Sun on the sky, and yet insist that the Earth is moving, ancient authors used the following example. When a ship is slowly sailing away from the shore, passengers of the ship get an impression that the seashore is moving away from them. Likewise, if the Earth were moving around the Sun, people on the Earth would conceive the Sun moving on the sky. This way of reasoning shows us how could ancient natural philosophers come to the idea of the moving Earth.

Some authors still insist that Newton's idea of the law of universal gravitation emerged the way the popular story tells. In reality, Newton had no need of the remote analogy between the apple falling down in his garden and the Moon revolving round the Earth. Newton could get a good deal of useful ideas reading papers of his senior colleague Robert Hooke. In the days young Newton made his debut in physics, Robert Hooke was one of the most prominent figures in British scientific community. In his reports to the Royal Society of London, Hooke discussed various problems of physics, among them also the attraction of the planets by the Sun. Hooke was sure he had serious reasons to reproach Newton for not mentioning his name in the *Principia*.

The special theory of relativity emerged from the critical analysis of the classical theory of electromagnetic radiation. Einstein once noticed that Maxwell's discovery of electromagnetic nature of light was based on analogy. There is direct analogy also between Lorentz transformation of relativistic mechanics and the classical Galilean transformation. Minkowski developed his four-dimensional space-time interval also by direct analogy with the classical notion of space interval.

Albert Einstein built the equations of his general theory of relativity by analogy with equations of the electromagnetic field theory. The main principle of the special theory of relativity proves that all physical laws are invariant in regard of the Lorentzian transformation of space-time coordinates. This fundamental principle can be obtained with the help of analogy if we reason as follows. Classical physics proved that all physical laws are invariant in regard of Galilean transformation of coordinates. Lorentz discovered later that electromagnetic phenomena are invariant in regard of the special type of transformation he had suggested. So it would be quite reasonable to suppose that all laws of physics must be Lorentz invariant.

Analogy had functioned productively also when atomic physics was developed. The dominant role of analogy in Rutherford's model of atom was so apparent that it was called "planetary model". The analogy with the motion of the planets was used also when the idea of the spin of atomic electrons was suggested. Schrödinger developed his conception of quantum mechanics keeping in mind the classical model of standing ways.

Max Planck could reach his conception of quanta of energy in a very simple way too. I mean Newton's corpuscular conception of light, well forgotten by the end of the nineteenth century. Though actually, as Luis de Broglie noticed, Planck had come to his quantum conception using an analogy with the molecular theory of gases.

I would like to discuss in more detail the role of analogy in Planck's discovery of quanta of energy. By the end of the nineteenth century, the idea of the discontinuous structure of radiation should be the most unacceptable assumption for any physicist. How could Max Planck suggest a conception that contradicted even his own personal beliefs? It appears that in this case too, the logically impossible step was helped by analogy. Louis de Broglie emphasized this interesting point of the history of formation of modern physics using the results of research of a French historian of science, René Dugas.[16]

For several years, preceding his investigation of the black-body radiation, Planck succeeded to develop a thermodynamical conception of electromagnetic radiation in the frame of classical conception. Being an admirer of Boltzmann's fundamental works in statistical thermodynamics, Planck sent him his new results to know the opinion of the prominent theoretician. Boltzmann answered him that to build a complete thermodynamical theory of radiation one has to introduce an element of discontinuity. Apparently, Boltzmann judged by analogy with the statistical theory of molecular physics. Concluding his presentation of the history of this great discovery, De Broglie pointed out that the roundabout way from the black-body radiation to the idea of the quanta of action was essentially helped by Boltzmann's above-mentioned important remark.

I finish the survey of my conception of the universal method of discoveries by this proof of the decisive role of analogy. Only two additional points should be pointed out. First, the analytic-synthetic conception is a universal method in the sense that it is applicable for the solution of any kind of problems, in any field of human activity, of any level of difficulty.

Secondly, I would like to discuss a particular question. Consider an explorer that learned all the details of the theory of discoveries and came into full possession of the method. Would this scientist be able to solve any research problem and make great discoveries?

[16] René Dugas, *La théorie physique au sens de Boltzmann et ses prolongements modernes*. Paris, Edition du Griffon, 1959.

Francis Bacon was sure that his method of true induction provided an effective means to make unlimited number of new discoveries. These discoveries should exceed everything reached by the great thinkers of the past since they did their discoveries intuitively, not being guided by a true method. The true method, as a bright torch, should light the right way of research and invention.[17]

René Descartes was convinced too that his method possessed an unlimited power. Revealing the rules of methodic investigation, he saw clearly how easily one could solve any scientific problem. Methodical investigation appears quite necessary if one goes to investigate the truth of things. "It is far better never to contemplate investigating the truth about any matter than to do so without method," declared Descartes.[18]

There are over two dozen modern authors who have developed their own quite original methods of creative problem solving. Each one of them is completely convinced that just his method is the magic key enabling students to resolve the most difficult problems of science and engineering design.[19]

All the above mentioned famous scientists and modern authors had a good reason for their optimism. The role of their ideas for the elaboration of the methodology of discoveries and inventions is indisputable. Their methodological advice is very useful and important for any student and young scientist.

Nevertheless, if we sum up all the invaluable ideas and rules of these prominent methodologists and then teach in detail all this knowledge to the most gifted students, even this will not guarantee that they will be able to solve the difficult research problems of science.

And this, not because of the level of the present day methodological science. Even an entirely complete method cannot guarantee either the great discovery or the solution of a given difficult research problem.

The reason is simple. As we have seen above, the central point of the process of problem solving is the phase of idea generation. New ideas are born with the help of analogy. The more difficult is the problem under research, the more remote analogies we need for its solution. Great discoveries come with solutions of the most difficult ("super-difficult'') problems. To solve them, one should use the most remote analogies, or so called crazy ideas. "Extreme remedies are very appropriate for extreme diseases," proved Hippocrates. Likewise, extremely remote similarities appear most appropriate remedies for extremely difficult problems.

But the field of remote analogies has no boundaries. The number of possible prototypes for the given problem under research is unlimited. No methodology is able to show even the general direction in which the prototype problem should be searched for. To be honest, one must admit that a great discovery is a matter of great luck. But the Goddess of Luck likes to smile only to men of unlimited devotion. The way to astral heights is wearisome and thorny. The wondrous aspirations of geniuses grow up on the ground heavily shed by their perspiration.

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[17] The famous XCV aphorism of the *Novum Organum* puts the things as follows: "Those who have handled the sciences have been either Empirics or Rationalists. Empirics, like ants, merely collect things and use them. The Rationalists, like spiders, spin webs out of themselves. The middle way is that of bee, which gathers its material from the flowers of the garden and field, but then transforms and digests it by a power of its own." (Francis Bacon, *Novum Organum*. La Salle, Illinois, Open Court, 1994, p.105.)

[18] Emphasizing the importance of the method of research, Descartes mentioned that even those who proceed very slowly, nevertheless, "can make much greater progress, if they always follow the right path, then those who hurry in stray from it". (René Descartes, *Discourse on the Method*. – In: *The Philosophical Writings of Descartes*, vol.1. New York, Cambridge University Press, 1985, p.111.)

[19] I would like to mention here at least a few of them: Alex Osborn, *Applied Imagination. Principles and Procedures of Creative Thinking.* New York, Screibner, 1957; William Gordon, *Synectics. The Development of Creative Capacity*. New York, Harper, 1961; George Polya, *Mathematical Discovery*, vol. 2. New York, John Willey & Sons, 1965; Michael Stein, *Stimulating Creativity*, vol.1 and vol.2. New York, Academic Press, 1975.

Then what is the use of the methodology, why one should develop a universal method of scientific research?

The real and very important task of the methodology of discoveries is to develop a method for *effective search* of solutions of scientific problems.

We have to admit the bitter truth that no one can suggest a method that guarantees great discoveries and solutions of research problems. But scientists have no choice. They have to solve the arising problems in their field of research. So explorers are given only one thing – to *search* unceasingly for solutions. Accordingly, the task of the universal method of scientific discoveries is to suggest the *optimal* way for the search of solutions of fundamental scientific problems.

The universal method of discoveries, as any other method, cannot guarantee the solution of a given research problem. But it does guarantee the most effective way in the search of the solution. In short, the universal method gives the following advice to men of science: analyze your problem, as deep as possible, and then try as many analogies as you can, using also the most remote prototypes and crazy ideas if necessary. Any other advice promising direct and easy solutions can just mislead an inexperienced student. Any other way of action may appear unproductive and ineffective.

The true method has modest claims, but it guides in right direction.

Anyhow, great discoveries have their specific features, too. The specific points of making a great discovery are conditioned by the fact that this task often brings investigators to the domain of super-difficult problems.

There are two main factors making a research problem super-difficult. As it was mentioned above, great discoveries unavoidably land into contradictions with fundamental principles of existing theories. But these principles are the basic paradigms through which scientists themselves conceive the surrounding world and all the information about it. So to make a great discovery, a scientist has to fight his own scientific beliefs. This circumstance eventually forces the investigator to rebuild radically his vision of the world. But the rebuilding of one's own thinking is the most difficult task a scientist ever confronts.

The second factor is the necessity to use most remote analogies to reach a satisfactory solution. As a rule, great discoveries open for science entirely new worlds. Great discoveries raise the bridges by which explorers enter new fields completely different from the domain of normal science. Confronting new fields of research, scientists have no choice but to try the most remote analogies and crazy ideas. What confusion arose in the physics community with the appearance of Einstein's theory of relativity? And how strong was Einstein's own opposition in regard of the probabilistic interpretation of the physics of the micro-world.

The outlined picture of the general logic of great discoveries appeared to me quite clear and convincing. But further reflection revealed a problem, which I called the *paradox of handicapped talents*. Namely, it comes out that a talented scientist has lesser chance to make a great discovery than his less gifted colleagues have. First, as it was mentioned above, the power of intellect cannot be of significant importance in finding out remote analogies and prototypes. Second, basic concepts and paradigms mold the frame that determines the limits of thinking and reasoning for all scientists. And since talented scientists have the most complete knowledge of their field of science, their thinking more readily accepts the strict ruling of basic conceptions and paradigms.

If we consider only these two parameters, bright and talented scientists have no advantage in making a great discovery.

Moreover, according to the above paradox, the great intellectual power and complete knowledge of talented scientists appears to be a real disadvantage here.

The paradox of handicapped talents should be regarded a significant problem of the theory of scientific discoveries if there were at work only the two above mentioned factors of fundamental research. I mean the framing power of basic concepts and paradigms, and the necessity to use remote analogies and prototypes.

But there are a number of additional important factors on the way to great discoveries that weaken the statue of super-difficult problems and thus help avoid the paradox of handicapped talents. The close examination of the history of science reveals that to make a great discovery none of the great scientist had to solve a super-difficult problem. It may sound really strange, but in reality, making a great discovery no scientist had used a crazy idea, or strongly confronted paradigms of his day, or intended to produce a revolutionary theory, or even was aware of the fundamental significance of his new conception.

All these surprising things I discuss in detail in the following chapters. But before starting the discussion of these paradoxical conclusions, I would like to mention a specific point of scientists' attitude to their hypotheses.

In the above discussion we have mentioned that scientists seldom abandon their hypotheses and scientific beliefs. New conceptions gain ground only by new generations of students. William Whewell, the prominent English historians of science, made this observation already in the mid-nineteenth century. "The old opinion," proved Whewell, "passes away with the old generation: the new theory grows to its full vigor when its congenital disciples grow to masters."[20]

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