INNOVATIVE INSTRUMENTS FOR STIMULATING CREATIVITY AND PROBLEM SOLVING

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Abstract
The creation of knowledge, the advanced research in strategic directions, the increasing of economic competitiveness and the transfer of knowledge in the economy are priorities of economic policies. They are based on research, development and innovation activities, which although take various shapes, have something in common: they relate to problem solving. Strategies, methods and techniques used in order to find solutions for problems are based on problem solving techniques taken from psychology.
This paper, which creates a bridge between the field of economy and that of psychology, proposes innovative tools to stimulate creativity and the problem solving ability. The tools suggested are based on analogy, the fundamental operation of thinking and creative imagination, and can be applied in various business functions.

Key words: *analogy; creativity; innovation; invention processes; problem solving.*

JEL Classification: *O310*

I. INNOVATION – STRATEGIC OBJECTIVE OF PUBLIC POLICIES

The European Commission's General Directorate for Research and Innovation report for 2014 stresses that Europe is currently facing a major challenge, an existential one: the achievement of a sustainable growth and the use of disruptive technologies.

Systematic efforts are required and should be considered a priority, both in the sense of widening the scope of activities between research – innovation centers and organizations from various industries and also in the sense of studying these types of interactions, situation which brings forth a new paradigm: collaborative ecosystems.

Innovative ecosystems, the generation of added value through knowledge and ideas and innovation are thus of strategic importance.

The executive summary of Europe 2020 Strategy (p.7) analyzes possible scenarios of exiting the crisis and concludes that Europe can succeed and the first resource it mentions (among the ones that constitute the foundation on which this desideratum can be achieved) is talent and people's creativity. In this type of context, the national policies at the European Union level are aligned with the European strategy, particularly with the Framework Programme for Research and Innovation - Horizon 2020

In Romania, the Strategy for Research-Development-Innovation 2014-2020 stipulates three strategic objectives - 1) increasing the competitiveness of the economy through innovation, 2) increasing the national contribution to knowledge, 3) increasing the role of science in society – and also priorities involving interdisciplinary research and development. Innovation is the main source which generates welfare, and it is fueled primarily by research and development.

II. INNOVATION - RESEARCH AND DEVELOPMENT - PROBLEM SOLVING

Authors like J. A. Schumpeter, C. Freeman, J. Schmookler, B.V. Hippel, G. Saint-Paul, D. C. Mowery, N. Rosenberg, R. R. Nelson, R. Rothwell, P. larger, R. H. Smiley, B.A. Lundvall contributed through their work to the development of innovation theory. Among the topics covered are: determinants of innovation, typology of innovators, sources of financing, the impact on economic performance and innovation strategies.

The analysis of innovation activity's inputs starts from the observation and understanding of activities that are specific to the research and development (R&D) function within an organization and continues with addressing other factors among which we could mention: investment in knowledge (including patents, licenses etc.), purchases of new equipment, training of human resources, marketing, etc.

Although they vary in forms, activities specific to the function of research and development have a common denominator: they relate to problem solving.

According to Frascati Manual, the (R&D) activity consists of "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.(p.30). According to the same manual, the R&D concept refers to three types of activities (p.30): fundamental research, applied research and experimental development. Fundamental research aims, firstly, to acquire new knowledge about phenomena and facts, without taking into account a particular applicability. Applied research, which is also an investigation held in order to gain knowledge, is directed primarily towards the achievement of a practical objective. Experimental development consists of systematic work - carried out based on knowledge gained from research and practical experience - directed towards producing new materials, products, devices, new processes, systems and services, or substantially improving those already produced.

As previously mentioned, the R&D activities relate to problem solving, which involves using various strategies, methods, techniques with the aim of finding solutions. The strategies used to solve problems in various areas are based on the ones used in psychology. Problem solving is one of the essential activities of thinking, having an important adaptive purpose. It involves mental processes such as the restructuring and the reorganization of knowledge and of the problem-situation field; these are processes during which the still unresolved contradiction is to be integrated within/with the already existing cognitive - operative structures. The problem solving process requires following steps: identifying the problem, defining it, identifying a solving strategy, organizing what is known about the problem and about the steps to be followed to solve them, identifying existing and necessary resources, establishing ways in which they are accessed, monitoring the problem-to-solution process, result evaluation.

Polya (1954) and Ormrod (1999) define operations as actions that a person can take to achieve a goal. They bind the initial situation (the problem's details) to the desired situation (objectives). Tuma and Reif (1980), Wilson and Clark (1988), Bender (1996), Payne and Wenger (1998) talk about the problem space - as the one containing all possible states. It includes all possible purposes of the problem and all possible ways of achieving them.

In order to identify possible solutions, one can use various techniques and strategies, among which are worth mentioning: trial and error, hypothesis testing, brainstorming, "divide and conquer", lateral thinking, analogy, etc.

III. ANALOGY - PROBLEM SOLVING AND CREATIVITY STIMULATION STRATEGY

Analogy is a fundamental operation of thinking and creative imagination. It has a long history of about 2600 years, dating back to the Greek philosopher and mathematician Pythagoras (580-495 BC). The term "analogy" originates from the Greek words "ana" (meaning "on", "according to", "form") and "logos" (which means, among other things, "word", "thinking", and "fraction "). According to Ashworth (2013), in Pythagorean mathematics, analogy was a formula with four unequal terms forming two proportions that are equal. Subsequently, Plato and Aristotle (Apud. Ashworth, 2013), who considered analogies as being legitimate as a consequence of the use of inductive generalization, explained this operation as a shared abstraction concerning two terms submitted to attention, which consisted not necessarily in a relationship, but which could also refer to an idea, a model, effect, etc. Aristotle developed the theory of Plato, made a distinction between analogy and identity and also between analogy and correspondence and found its applicability in many other fields, his theory being taken over by other philosophers, theologians and jurists. So it is that, over time, the ratio of equality of the two fractions with different terms has been expanded to other areas, expressing correspondence between objects or phenomena in different fields of knowledge. The partial nature of equivalence and the fact that it can be applied on a variety of factors gives the analogy a remarkable creative imaginative potential.

We can talk about analogy when, while focusing on two objects in different areas, we notice a parallelism, a symmetry or a certain similarity between the characteristics of those objects and/or between the relationships of the characteristics; then, based on these symmetries or similarities we can draw inferences that can guide our understanding of the less familiar object, and then determine their validity. In other words, based on the observed consistencies of the form, function and/or structure of the two objects in different areas, one of which - called (object/domain) source - is familiar to us, and the other - called (object/domain) target - we are not familiar with, we identify a relatively common model of organization and/or operation of the two objects, and based on this model we can draw assumptions regarding the target object.

Correspondences between source and target are not necessarily limited to superficial aspects, but can go to deeper levels. They could also refer to their component elements, to relationships between them and even to relations between relations. In the latter case, a certain relationship between two elements of the source object corresponds to a certain relationship between two components of the target object.

The most influential theory on correspondences drawing between source objects and target objects and between source and target relations is Structure-mapping Theory. According to this theory, following these two principles is essential: one-to-one correspondence and parallel connectivity. The first principle implies that an object from the source corresponds to only one object from the target domain and vice-versa. The second principle implies that the relationship between some objects of the source domain needs to be found in the target domain between the same objects that correspond one-to-one to the source objects previously mentioned.

If the source and target structures are aligned so that the principles mentioned are followed, we can proceed to advance hypotheses about the target structures. Expanding relations from source to target is only valid if correspondences can be found both at the objects' level, regarding simple relationships (relationships between objects) and at the secondary relations' level (relations between relations). Only then can we can talk about an analogy. Since most often, relationships between relations in the case of the target are difficult or impossible to discern, inferences drawn (or part of them) may prove ultimately to lack validity. Even so, in science for example, analogical reasoning can be of great help to researchers, as they can reach important comprehensions of the target range, guided by partial equivalencies, as we shall see in what follows.

The theory of pragmatic schema and multiple constraints developed by Holyoak and Thagard (1989, 1996) keeps in the center of analogical reasoning the mapping of common abstract relations and also highlights the importance of structural similarity (Holyoak and Koh, 1987) in determining the degree of overlap between the source and target domains. The systematicity principle is seen as a structural constraint and the two authors identify another 2 types of constraints: pragmatic and semantic.

The first type is related to the goals and objectives of the agent influencing the selection of relevant similarities between source and target. Semantic constraints consist of estimations of the degree to which the source and target items are perceived as being alike. These constraints are not perceived in a rigid sense but rather as pressures that favor or inhibit potential corresponding pairs.

Therefore, applying the analogy involves following some steps (Runco, Pritzer, 2011): identifying the target domain, identifying the source domain, drawing correspondences between pairs of source elements and target elements which we suppose are similar, assessment of the adequacy or inadequacy of the proposed analogy, enunciation of inferences starting from source-object elements and their characteristics to the ones of the target object. If we reach the conclusion that we have drawn inappropriate correspondences, we will either resume the process, or we keep some relevant correspondence and will resume the process with other source/ target domains.

The analogy was the point of focus of many important authors and it is still studied extensively, especially in connection with the development of software.

In science, the analogy is used mainly as a thinking operation while domains such as art, design, engineering, architecture, R&D, marketing and communication use the analogy mainly as a creative imagination operation. The creative-imaginative valence of analogy comes from the freedom that the subject has in choosing the source and target domains. When they are further away from each other, the result has a high probability of being original. It is also best for the two domains to be different, since the purpose of the creative-imaginative process is different than the one of the thinking process. The process of mapping correspondences might require a systematization but objects, attributes and relationships can be processed in different ways and mapped by various criteria, including (or especially) symbolic and/or aesthetic. Distortions, modifications and re-significations can be made, thus generating new objects.

IV. EXAMPLES OF DISCOVERIES, INVENTIONS AND INNOVATIONS BASED ON ANALOGIES

Human creativity and thinking are at the basis of all discoveries, great inventions and great ideas that have guided the path of human evolution. Analogy is the operation that lies in the core and at the interference of these processes, so that it accounted as an inspiration to many approaches to problem solving by the great minds of humanity.

Here are some examples of paradigms, discoveries, inventions and innovations that had great scientific and socio-economic impact and which were based on analogy:

Boden (1991) recounts how German chemist August Kekulé (1829-1896) acknowledged the real benzene configuration. While sitting in his room by the fireplace, Kekule looked a moment at the burning fire and he thought he saw "a snake that kept his tail in his mouth" (p.16). In 1865, the chemist was particularly interested to find chemical structure of benzene and thought that all molecules were linear. The dancing flames shaped like circular snakes biting their tails made August Kekule reason analogously and leave behind the assumption that benzene would be a linear molecule. The circular structure he proposed revolutionized the field of chemistry.

Almost 50 years later (in 1911), physicist and chemist Ernest Rutherford analogously compared the solar system with the structure of atoms (which was not well known by the physicists and chemists of that time). Rutherford saw some similarities between planets and electrons, the Sun and the core of the atom, even if there were obvious differences in scale, and based on these similarities, he issued the inference that, as the solar system has gravity, there should be a correspondent force at the atomic level. Later on, by using theoretical and empirical ways, steps were taken to identify any evidence of this type of structure. Wilson (1983) tells us how Rutherford worked with physicist Niels Bohr in this direction. Bohr (1913) also used analogical thinking of the solar system to identify the quantum model of the hydrogen atom. In recognition of the importance of their discovery and efforts, the model was named Rutherford - Bohr.

The analogy did not change only science but also some industries.

In the 1870s, electricity - which was at that time a new technology of high visibility - attracted the attention of many great minds who were seeking opportunities for inventions that would bring them success. In 1872, Alexander Graham Bell gets a Vocal Physiology job at Boston University. At the time, scientists were looking for a solution to transmit several telegraph messages simultaneously through the same cable. Voice transmission by wire idea was considered pure speculation. In 1872, Bell was working on both projects. The telegraph was using alternating current to transmit information. In the summer of 1874, Bell made an analogy with the nature of sounds and realized he needed an undulating current. On February 14, 1876, he filed a patent application to register his invention. A year later it was already a business.For inventing the phone's membrane, he also reasoned by analogy, with the human ear.

In 1913, Ford Motor Company was far from selling millions of cars to Americans. Hounshell (1984) talks about how the inefficient processes were significantly transformed at the Ford plant. William Klann, one of the company's machinists, paid a visit to a slaughterhouse in Chicago. The industrial activity was one of increased efficiency: butchers were placed in line and performed certain tasks on advancing meat carcasses hanging from a mobile chain. Although the domains were different, William Klann saw something similar in the process of constructing an engine, just turned upside down - in one case it was the dis-assembly and assembly in the other. He thought that the adoption of this model in the assembly line at Ford Motor Company would greatly increase productivity and could drastically reduce costs. The assembly line model entered a test phase. Eight months after the first test, lines were implemented in connection with all its parts, including chassis assembly stage. Productivity increased dramatically, up to 1000%, which allowed for a decrease in the price of almost half, in the context of market prices rising. Ford arrived in 1921 to hold a 50% share of the market. Allan Nevins, a journalist at the time, had called the mobile assembly line "leverage that moves the world" (Apud. Hounshell, 1984, p.10).

Another example, this time from the present: Professor Henry Markram of Ecole Polytechnique Federale de Lausanne leads an international team of researchers in an initiative which is to integrate all the knowledge in the field of neuroscience - Human Brain Project - simulating all processes of a human brain using a supercomputer.

The computing power of the Blue Gene supercomputer from IBM will be used in shaping the human brain. IBM has developed a complementary project starting from the analogy with the modality of information transmission between neurons. Once, in 2011, IBM researchers were able to complete two prototypes of cognitive chips - one containing 262,144 programmable synapses and the other 65536 - in August 2014, IBM announced the completion of a chip with 1 million neurons and 256 million synapses. Cognitive chips will be part of cognitive computers of the future. They will be able to learn from experience, to find correlations and think, exactly like the human brain.

V. ANALOGY TECHNIQUES TO STIMULATE CREATIVITY AND PROBLEM SOLVING

The analogy is used in a variety of fields of activity, often intuitively, due to the fact that individuals relate to diverse personal experiences when faced with new challenges. Analogy is characterized by a certain degree of simplicity that favors a sufficient understanding so as to be used in various situations or environments.

However, the analogy can be used even more efficiently when the analogical thinking process is followed systematically. Such techniques emphasize its potential to generate better performance in thinking, in problem solving and in creative imagination.

Probably the most popular technique which is based on the analogy and which has a wide recognition is Synectics. It was invented by W.J.J. Gordon (1961) and developed with George M. Prince. Synectics is a technique for problem solving by stimulating creativity at a group level. By 1950, the authors studied thousands of hours of recordings of the activities carried out within the groups to identify exactly what helps individuals to become more creative and also to successfully implement the ideas generated within the creative process. The quality of the innovation process is dependent on the quality of the social climate, the thinking process and behaviors (Apud. Nolan, Williams, 2010). The procedures applied in Synectics aim to ensure a protective non-judgmental and non-critical working climate for the people in the group, in order to better direct energy constructively towards solving the problem.

Thinking and creative processes involve expanding the frontiers of ideas by using what in Synectics is called Spectrum of thinking (Apud. Nolan, Williams, 2010). This implies a delimitation of spheres of thinking which move away from the problem space and go towards the apparently irrelevant elements. This process of idea development is characterized by openness, risk taking, ambiguity, interruption/generation of new connections, the use of analogies and metaphors, and the use of absurd thinking and/or of the apparent lack of relevance. Synectics practitioners use the trip technique - an analogy between a trip for recreation purposes and the distancing from the initial problem field. The reasoning passes through "layers" of thought like diversity, desire, analogy/metaphor, nonsense/irrelevancy.

When sufficient new ideas have been generated, the group focus will get back on the problem, but with a fresh look and a new understanding, forcing associations between apparent irrelevant ideas and the problem, creating new connections, which thus make them more able to generate promising ideas to solve the problem. The selected promising ideas will be analyzed and systematically improved in feasibility.

The TRIZ technique was developed by G. S. Altshuller and his colleagues between 1940-1970. It is a unique philosophy on technology and creative thinking and includes a vast amount of examples that were analyzed and upon which the methodology was developed. Thus resulted the "Matrix of contradictions" which is a database with cases of contradictions and the methods used to solve them. The technique includes 40 types of operations that can be applied to find creative solutions to engineering and/or technology problems. Here are some of them: division, removal, asymmetry, universality, merging, counter-weight, preliminary action, reversing, dynamic partial or excessive action, adding a dimension, vibration, periodical/continuous action, intermediate.

In TRIZ, the problem is understood as a contradiction between the situation and the need. According to Nakagawa (2004), TRIZ essence consists in perceiving the problem as a system, then define the ideal solution and resolving existing contradictions. In order to define the ideal solution is very useful to analyze the trends of evolution of the system problem, of its subsystems and of the supra-system in which the system problem is included.

The method used for solving the contradiction is actually the pattern of relations to be transferred analogically. Basically, a system of relationships is identified in a domain (source) and categorized and, after that, it is used in other areas (target).

TRIZ uses also a database called "Effects Database" which is a collection of physical, chemical, mathematical effects etc. Thus, the knowledge and the techniques from one domain could be applied analogically to another domain.

The ASIT technique (the Advanced Systematic Inventive Thinking) evolved from the art and science of TRIZ. Horowitz (1999) fundamented her technique on the following major principles: "thinking inside the box" – only what exists in the system could be used to solve a problem , "qualitative change" - the main problem is removed or altered in such a way that its effect becomes beneficial, "the maximum resistance path" - counter-intuitive thinking has a high probability to generate novelty, originality.

The 40 operations from TRIZ were reduced in ASIT to only 5: suppression, multiplication, division, unification of tasks, dependent attributes.

VI. Proposal of Innovative Instruments for Stimulating Creativity and Problem Solving Based on Analogy

The "Amusement park" technique (Dafinoiu, 2013) uses as operating framework an analogy between the problem situation and an amusement park. These parks are miniature universes in which we see a multitude of elements that we can use as resources in problem solving processes, or for generating creative concepts.

With this purpose in mind, the constituent parts of an amusement park will be assigned analogical meanings, taking into account the roles they genuinely meet in the assembly. The technique uses two sets of instruments: first set for better organizing the problem situation, and the second one to generate transformations. The technique is applied in writing.

In the first stage, the person will organize the problem in three types of entities: Objects, Attributes and Relations (OAR). The objects are the component elements of the problem situation. The attributes are the characteristics of the objects. In the Relations category we include: relations between objects, relations between characteristics and also relations between objects and characteristics or relations between relations. It is recommended that these columns are situated on the same page and that they are written in the most concise manner possible, keywords preferred.

In the next stage, the person will organize and analyze the problem situation in writing, following the logic of the park`s design. Thus, the elements forming the infrastructure of the park will be assigned meanings that direct the thinking process towards the problem situation and its context and, also, towards the understanding of their implications:

- "The Benches" symbolize a moment of pause, remembrance of achievements. Sitting on the bench, it is time to distance ourselves from the present to project future / ideal scenario, in which case the problem is solved.
- "The Light poles" focus our attention on what needs clarification and verification, and on the positive aspects and opportunities. The metaphor that guides us is "shed some light on the issue".
- "The Dustbins" orient our attention to elements that we consider unimportant and delay the resolution process, which need to be isolated. After we make the final decision we may turn back to those elements and see if we can find any potential utility.
- "The Guard`s cabin" - symbolizes caution. Here we analyze the weaknesses and threats of the problem situation and of the possible options that are available to us in order to solve the problem, and all other aspects that needs special attention as well. We will also figure out how to avoid the threats or how to act in case they cannot be avoided and, also, who/what may offer protection and in which conditions.
- "The fences and other dividing elements" often symbolize the limits, limitations and borders of the situation or of the options we have to solve the problem. We also need to consider rules, laws, principles, etc.
- "The bridges" signify connections with similar situations or problems from the present, the past, (regardless of the place or the domain) but it can also signify a liaison to the resources that we can employ to help us solve the situations and problems.
- "The alleys" signify the directions, the possibilities/opportunities and ways to finding the right solution.
- "The green spaces, the spaces with flowers, the trees": Flowers guide our attention toward the aesthetic side of life, towards aspects related to art, towards the harmony and the natural state of the human being: creativity. In this position, we propose new ideas, we appreciate values. The trees signify implications, creative development, possibly even artistic. They can also lead us to think about personality.

In the third stage, the person should systematically track which new relevant aspect the previous stage has brought. They will be highlighted in the table with OAR categories, depending on the category they belong, with keywords.

In the fourth stage transformations will be applied to the elements from the table, using the second set of tools. The person will imagine a certain path in the amusement park and each play area will have a certain operation associated with it (Dafinoiu, 2013, pp.43-44). For example, the slide corresponds to the amplification operation, and the sandbox corresponds to the suppression/omission operation. If the person has chosen these play areas then he/she will systematically apply these operations on each entity in the OAR table and imagine the system`s design in the new conditions. Examples: what would happen if the entity x in category A would be amplified? What would happen if the entity y in category O would be omitted/ suppressed?

This technique uses the following operations: analogy, association/combination, schematization, amalgamation, adaptation, substitutive imagination, typification/ modification, substitution, transposition, inversion/rearrangement/restructuring, amplification, additions/reduction, suppression/omission, division/ multiplication.

In the fifth stage, based on the new understandings gained regarding the problem and its entities (OAR), the best ideas for the resolution are selected and the possibilities to maximize the feasibility of these ideas are analyzed.

VII. CONCLUSION

Problem solving is essential for the economy and it is also necessary in any other domains of activity. Regardless of the domain in which it is used, problem solving involves changes, restructurings, reorganizations at the level of the problem and it is based on cognitive and imaginative-creative processes. Problem solving techniques initially aim to define the problem and the desired results and then aim to deepen and/or expand the problem field in order to identify the necessary resources for solving the contradictions and the steps to be followed.

Analogical reasoning has had a great impact in science and economy. Problem solving techniques based on analogy utilize cognitive-operational schemes from other situations and/or domains and also the freedom to choose which entities are analogically mapped, operating with different levels of depth of the equivalence. Synectics, TRIZ and ASIT are some of the most representative problem-solving techniques based on analogy and they are thus widely utilized.

The "Amusement park" technique operates with an analogical framework which systematically deepens and extends the problem situation field and which becomes stimulating from the imaginative creative point of view through the re-significations that it produces. In this framework, transformation operations on the entities of the problem are then systematically applied, in order to generate mental restructuring and reorganizations. The mental flexibility thus gained helps identify solutions through original combinations of entities and actions of the problem field.

Besides the possible improvements in the methodological chapter, in the immediate future the technique is to be investigated statistically for validation.

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