The Role of Analogy in Problem Solving and Increasing Creativity

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Abstract: *The present paper discusses aspects more extensively developed in the PhD program research paper.*

This article proposes thinking techniques which could be used in different fields of activity and different business functions to stimulate creativity and problem solving ability in order to find solutions characterized by high originality for various challenges. The suggested thinking techniques use analogy, which is the most important operation of thinking and creativity.

The discussed techniques could be of an important help for European countries in reaching their strategic objectives of the economic policies in line with to Europe 2020 Strategy: the creation of knowledge, the technological innovation and the increasing economic competitiveness.

Keywords: *creativity, problem solving, analogy, innovation, economy*

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I. Innovation - Strategic Objective of EU Policies

The existential challenge which EU countries are facing right now is, as the European Commission's General Directorate for Research and Innovation emphasizes in the 2014 report, to reach a sustainable growth and to use for such purpose the disruptive technologies. To achieve this, the research – innovation centers from the EU and the institutions and organizations from different fields of activities must evaluate their paradigms and initiate and stimulate a new one: the collaborative ecosystems. Implementing this type of ecosystems constitutes a

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strategic objective of the European countries' policies, together with creating added value through knowledge and ideas, and innovation.

The Europe 2020 Strategy (p.7) points out that the most important resource we have is the people's talent and creativity. Innovation constitutes the fundamental source of welfare and it is primarily based on research and development.

In this context, the methods and techniques which stimulate creativity are an essential support for innovation and breakthroughs in different fields of activity.

II. Corelations between Problem Solving, Research and Development, Innovation

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, R. H. Smiley, B.A. Lundvall, developed the innovation theory. They included in their studies a diversity of subjects, like the factors that determine innovation, the categories of innovators, the sources of financing for the innovation activities, the impact innovation has upon economic performance of organizations.

The analysis of the innovation inputs begins with the observation that such activities are specific to the research and development (R&D) function within a company or a different type of organization. While the R&D activities might have different forms, they also have a common feature: they are related 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). The Frascati Manual also mentions that the R&D concept comprises of three types of activities (p.30): fundamental research, applied research and experimental development. The scope of the first type of R&D is to acquire new knowledge about phenomena and facts, regardless of the practical applications. Applied research, on the other hand, which is also an examination aiming to acquire knowledge, essentially tries to achieve practical objectives related to the respective knowledge. Experimental development – the third type of R&D - is directed towards generating new objects (products, materials, devices, etc.) or new processes, systems and services, or substantially improve the already existing objects, processes, systems, etc. This type of activity is based on the knowledge gained from research and practical experience.

As specified earlier, the R&D activities have a common feature in the fact that they relate to problem solving. In order to find solutions, one must use different strategies, techniques and/or methods. They are based on problem solving techniques from the field of psychology. Problem solving is a fundamental activity of thinking, with the role to adapt to the environment. In problem solving, the initial contradiction between the present and the desired state is to be integrated within/with the individual's already existing cognitive-operative structures. With this purpose in mind, the problem solver restructures and reorganizes the problem-situation field. During the problem solving process the following steps are required: 1) to identify and to define the problem, 2) to identify and to choose a solving strategy, 3) to organize the knowledge about the problem and about the transition process towards the desired state, 4) to identify the existing and necessary resources and the proper ways to access them, 5) to monitor the process from the initial phase to the desired one, 6) to evaluate the results.

The steps and actions that one can take in order to reach a goal are defined by Polya (1954) and Ormrod (1999) as operations. This set of actions links the problem details to the desired outcomes. Authors like Tuma and Reif (1980), Wilson and Clark (1988), Bender (1996), Payne and Wenger (1998) speak of the problem space - as the space which includes all the possible states of the system. Thus, the problem space contains all the possible goals and the ways to reach them.

To find possible solutions and achieve the desired outcomes, one can use various techniques and strategies: trial and error, hypothesis testing, brainstorming, "divide and conquer", lateral thinking, analogy, etc.

III. Analogy - A Strategy for Stimulating Creativity and Problem Solving

Analogy is an essential operation for both thinking and creative imagination. The term "analogy" originates in 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 the mathematics of Pythagoras, about 2600 years ago, analogy was a formula with four unequal terms forming two proportions that are equal. Subsequently, Plato and Aristotle (*apud.* Ashworth, 2013), considered analogies to be legitimate as an effect of using inductive generalization. Plato and Aristotle explained the analogy as a shared abstraction regarding two terms proposed to our attention. The shared abstraction could consist of a relationship or an idea, a model, effect, etc. Aristotle, which developed the theory of Plato, distinguished between analogy and identity and between analogy and correspondence. He expanded the use of analogy to other fields of knowledge. The theory of Aristotle about analogy was adopted by philosophers, theologians and jurists and thus, over time, the four unequal terms forming two proportions that are equal began to express the correspondence between objects or phenomena in different domains.

Analogy has a considerable potential regarding the creativity and imagination because this correspondence could be expressed through a variety of factors and could bind objects from very different domains. We can speak about analogy when, considering two objects in different fields, we notice that they have some similarities, a symmetry regarding their structure and/or a parallelism of the relationships between their constitutive parts. Based on these similarities or this parallelism we can draw assumptions and, thus, understand the less familiar object through the other one, which is more familiar to us. However, because the relationship of equivalence could be only partial, after we draw the inferences, we must determine their validity. In other words, based on the symmetries we are noticing regarding the form, the function and/or structure of the two objects in different domains, one being familiar to us (called source or object/domain source) and the other we are less or not familiar with (called target or object/domain target), we identify a relatively common model of organization and/or operation of the two objects, and based on this fact we can draw assumptions regarding the target object.

The similarities between the two objects could go to deeper aspects not only to superficial level. For example, the correspondences could refer to the component elements of the objects, to relationships between the components and even to relations between relations. We speak about relations between relations when a certain relationship between two components of the source corresponds to a certain relationship between two elements of the target object.

The most influential theory regarding the operation of analogy is Structure-Mapping Theory (Gentner, 1983). According to this theory, two fundamental principles must be considered when drawing (or mapping) the correspondences between the source and target objects (or relations): one-to-one correspondence and parallel connectivity. The first principle affirms that an element from the source domain must have only one correspondent element from the target domain and *viceversa*. The second principle states that the relationship between some objects of the source domain must correspond in the target domain between the same objects corresponding one-to-one to the source objects previously mentioned.

Only if the source and the target domains are arranged according to these two principles, then we can proceed to draw inferences regarding the target domain. We can talk about an analogy only when the correspondences can be found both at the level of simple relationships - meaning the relationships between objects - and at the level of secondary relations – which is the level of relations between relations. In such a case, the correspondences are valid. Often it is very hard or even impossible to discern the relationships between relations regarding the target domain. For this reason, the inferences drawn (or at least part of them) may be, in the end, invalidated. But even so, being guided by the partial equivalencies, the scientists can acquire essential understandings of the target domain.

Another influential theory about the analogical reasoning is the Theory of Pragmatic Schema and Multiple Constraints, developed by Holyoak and Thagard (1989, 1996). This theory gives the structural similarity (Holyoak and Koh, 1987) an essential role in determining the degree of overlap between the source and target and keeps the process of mapping the common abstract relations between the source and the target as being one of central importance.

The authors identify three types of constraints which must be perceived as favoring or inhibiting pressures in the process of aligning the corresponding pairs. The systematicity principle constitutes a structural constraint. The pragmatic constraint relates to the goals and objectives of the individual and, thus, influences the choice of relevant similarities between the source and the target domains. The semantic constraints consist of assessments of the degree to which the source and target objects are perceived to be similar.

Runco and Pritzer (2011) indicate that the analogical thinking process must respect the following stages: identifying a target object/domain, detecting the source object/domain, drawing the correspondences between pairs of source elements and target elements which we suppose are similar, the evaluation of the adequacy or inadequacy of the proposed analogy, the statement of inferences starting from source-object elements and their attributes to the ones of the target object. If the conclusion we infer is that we have made inappropriate correspondences, then we must repeat the process, or we could keep some relevant mappings and restart the process with other domains/objects.

Presently, the analogical reasoning is the main focus point of several important authors who are studying it in an extensive manner, particularly related to the activity of software development.

The scientists use the analogy primarily as a thinking operation, where as the artists, the designers, the engineers, the architects, the people from R&D departments, the marketers and communicators use it especially as an operation of creative imagination. One has a high level of freedom in choosing the source and target domains. This fact gives the analogy an important creative-imaginative valence. When the source and target domains are distanced, the result has a higher potential to be creative, original, unique. It is also recommended for the two domains to be as distant as possible or even uncommonly associated, since the aim of the creative-imaginative process and the one of the thinking process are also very different. When analogy is used as a creative operation, the mapping of correspondences might require a systematic approach, but objects, attributes and relationships can be processed in various ways and mapped by different criteria, for example symbolic and/or aesthetic ones. Also, the individual can apply transformations, distortions, modifications and re-significations in order to generate new items.

IV. Paradigm Changes based on Analogies, with Significant Scientific and Social-Economic Impact

All famous discoveries, important inventions and significant ideas in the history of humanity, are based on imagination, creativity and human thinking. Analogy is an essential operation for both thinking and creative imagination and it has inspired many exceptional people in their attempts to solve important problems of humanity. We present here some examples and see how analogies influenced our history through paradigm shifts that lead to discoveries, inventions and innovations with significant impact on society:

According to Boden (1991), the German chemist August Kekulé (1829-1896) was sitting in his room when he saw in the burning fire in his fireplace "a snake that kept his tail in his mouth" (p.16). In the year 1865 he was looking for the chemical structure of benzene and he initially assumed that it was linear, like all the other molecules discovered before. However, he abandoned this assumption when he saw the dancing flames that looked like circular snakes biting their tails. He reasoned by analogy, asking his self if benzene could have a circular molecule. Thus, he radically changed the field of chemistry.

A half of a century later (in the year 1911), the physicist and chemist Ernest Rutherford made another remarkable analogy by comparing the solar system to the atom. At that time, the structure of the atom was not well known. Rutherford saw a similarity between planets and electrons, and between the Sun and the core of the atom. Despite the differences in scale, and based on the similarities he perceived, he drew the inference that, at the atomic level, there must be a correspondent force to the force of gravity in the solar system. Later on, he and physicist Niels Bohr tried to detect any evidence of this model of structure using both theoretical and empirical means. Wilson (1983) talks about how Rutherford and Bohr collaborated for this purpose. Bohr (1913) also used the model of the solar system to think analogically about the quantum model of the hydrogen atom. In appreciation of the importance of their discovery and their efforts the model was named Rutherford - Bohr.

The analogical thinking also radically impacted some industries, not only science.

In the 1870s, many inventors who were looking to achieve success were attracted by the potential of a new technology - electricity. In the year 1870, Alexander Graham Bell moved from London to North America and in 1872 got a job at the Boston University as a professor of Vocal Physiology. At that time, inventors were looking for a solution to send several messages simultaneously through the same telegraph cable. The idea to transmit voice by wire was not considered feasible at the time and it was thought to be merely theoretical. In the year 1872, Bell was preoccupied by both ideas. In 1874 he thought by analogy between the nature of sounds and the current telegraph utilized to send information. At the time, the telegraph was using alternating current to transmit information. Bell had an insight about the undulating current and he realized that it would be more adequate. On February 14, 1876, Bell filed an application with the Patent Office to register his invention and in 1877 he already had a successful business. As it is known, when he invented the phone's membrane, he also reasoned by analogy; this time the source object was the human ear. In his work he was using a device named phonoautograph – which Leon Scott invented to record speech vibrations. The human ear model and the phonoautograph model served as analogical source objects in making a calf intestine diaphragm. The diaphragm was touched by a magnetized metal arm that vibrated due to its proximity to an electromagnet connected to the telegraph cable.

Another industry, another revolution: a few years later, in 1913, Ford Motor Company had inefficient processes and a very ambitious goal - to produce cars for millions of Americans.

Hounshell (1984) describes the transformation at the Ford plant. One of the company's machinists, William Klann, examined a new model of industrial activity at a slaughterhouse in Chicago. That activity had an increased efficiency: butchers were aligned and executed specialized tasks on advancing meat carcasses hanging from a mobile chain. The domains were different but Klann saw some similarities between the processes of constructing an engine and cutting pieces from carcasses. He noticed that it was a process of dis-assembly in one case and assembly in the other one. Seeing how efficient was the process at the slaughterhouse he thought that this model could be adopted also in the car industry. Klann urged his boss and the assembly line model entered a test phase. Eight months later the assembly lines were implemented for all parts of an automobile, including the chassis, which lead to an increase in productivity up to 1000%. This allowed to dramatically decrease the price of Ford`s T Model to almost a half. Although on the market the prices were rising, Ford reached in eight years a 50% share of the market.

This invention was named the "leverage that moves the world" (*apud*. Hounshell, 1984, p.10) by Joseph Allan Nevins, an important journalist at the time. Mass media has intensely promoted the assembly line invention and the success it showed at the Ford Motor Company and this led to its adoption by numerous other industries.

Here's another example, this time from the present: Professor Henry Markram of Ecole Polytechnique Federale de Lausanne leads the Human Brain Project - an international initiative which will simulate the processes of a human brain using the Blue Gene supercomputer from IBM. This is probably the most important project in the field of neuroscience.

IBM developed a complementary project starting from the analogy with the way of transmitting information through synapses. After the researchers from IBM have developed two prototypes of cognitive chips - one containing 262,144 programmable synapses and the other 65536, in August 2014, IBM created a chip with 1 million neurons and 256 million synapses. These types of chips are the fundamental parts of cognitive computers which will be able to model the human brain: learn from experience, find correlations and think.

V. Techniques based on Analogy for Stimulating Creativity and Problem Solving

The analogy is used in many domains, often intuitively, since individuals use diverse personal experiences when faced with new situations. The simplicity of analogy favors a sufficient understanding so as to be used in different situations or environments.

However, a more efficient way to use analogy is when the analogical thinking process is followed on a systematic base. Such techniques bring out its potential to increase performance in thinking, in problem solving and in creative imagination.

Synectics is probably the most famous technique based on analogy. It was invented by W.J.J. Gordon (1961) and developed with George M. Prince. Synectics works as a problem solving technique by stimulating creativity at a group level. By 1950, the two researchers had studied thousands of hours of recordings of the activities carried out within the groups. They wanted to identify exactly what were the aspects which helped people to become more creative and also to successfully implement the ideas generated within the creative process. They concluded that the quality of the innovation process depends on the quality of the social climate, the thinking process and behaviors (*apud*. Nolan, Williams, 2010). This is why the procedures applied in Synectics ensure a protective, non-judgmental and non-critical working climate for the indviduals in the group, in order to better direct their energy in a constructive way 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. 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 look back at 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), the TRIZ essence consists in perceiving the problem as a system, then define the ideal solution and the way of resolving existing contradictions. In order to define the ideal solution it is very useful to analyze the trends in the 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, then, 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) based 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 5: suppression, multiplication, division, unification of tasks, dependent attributes.

VI. Innovative Analogy - based Technique Proposed to Stimulate Creativity and Problem Solving

The "Recreation park" technique (Dafinoiu, 2013) is based on an analogy between the problem situation and a playing field. These parks are miniature universes in which a multitude of elements can be used as resources in problem solving, or for generating creative concepts.

Having this in mind, analogical meanings will be assigned to the constituent parts of the recreation park, taking into account the roles they genuinely meet in the assembly. The technique uses two sets of instruments: one for better organizing the initial situation, and the other to apply transformations. The technique is used in writing.

In the first stage, the person will organize the problem into 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 preferred that these columns are written on the same page and in the most concise manner possible, keywords recommended.

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

- "The Benches" represent a moment of pause. Sitting on the bench, we distance ourselves from the present to remember the achievements and to project the ideal scenario and/or future.
- "The Light Poles" orient our attention towards what needs to be clarified and verified, and on the positive aspects and opportunities. The metaphor that guides us is "shed some light on the issue”.
- "The Dustbins" direct our attention to elements that we consider unimportant and delay us from solving the problem, elements which need to be isolated. After we make the final decision we may analyze again those elements and see if they are useful.
- "The Guard`s Cabin" - symbolizes caution. Here we focus on the weaknesses and threats of the problem situation and of the possible options available to us for solving the problem, and all other aspects that need our 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 signify 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" symbolize 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 find 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 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 in the table, using the second set of tools. The person will imagine a certain path in the recreation 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 chooses these play areas then he/she will systematically apply these operations to 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. Conclusions

Problem solving is an essential activity for the economy and it is also very necessary in any other field. Regardless of the domain in which it is used, problem solving requires changes, restructurings, reorganizations of the problem space and it is fundamented on cognitive and imaginative-creative processes. Problem solving techniques initially aim to define the problem and the desired outcomes and then aim to deepen and/or expand the problem field in order to identify the resources needed to solve the contradictions.

Analogical reasoning has had a significant impact on scientific and social-economic level. Problem solving methods based on analogy use cognitive-operational schemes from other domains. The problem solver has the freedom to choose which objects to map analogically and to operate with different levels of depth of the equivalence. Synectics, TRIZ and ASIT are extensively utilized being some of the most representative problem-solving techniques based on analogy.

The "Recreation park" technique operates with an analogical framework. This framework helps to systematically deepen and expand the problem space. It stimulates the imaginative and creative processes using re-significations. In this expanded and more flexible environment, mental restructuring and reorganizations are generated by systematically applying transformation operations on the entities of the problem field. The mental flexibility thus acquired helps finding solutions through original combinations of entities and actions of the problem space.

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

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