THE DEVELOPMENT OF CREATIVE THINKING THROUGH AN ADEQUATE ENGINEERING EDUCATION

Stefan Bartzer[1]

Abstract *¾ In view of the conditions that "learning must change the behaviour", "a modern education must be preponderant formative" and "the engineering education must form and develop the creative thinking", the present study is emphasizing and analyzing those attributes of the scientific, technical and technological creative thinking, which facilitate the transition/leap from the intuitive/empirical knowledge to the rational knowledge, by deduction, induction, analogy, generalization and abstraction, based on notions, judgements and reasoning. There have been taken into account twelve fundamental procedural attributes, which have a great value for the enhancement of human performance based on creativity. Among these attributes, six are implicit attributes, as an expression of the quality of thinking and six are explicit attributes, as result of a complex process of comprehension. The finality of the study is to support the specialists with specific knowledge and skills for efficient creative activities. With this purpose in view, there have been emphasized some important aspects concerning the way to be followed in the future in the field of engineering education.*

Index Terms ¾ Creative thinking, engineering education, theory of systems, trans-disciplinarity, paradigm of innovation.

BACKGROUND

The approach of this study is based on the findings made by the author with regard to:

- A model of synthetic representation of the essence of the inventics as scientific and educational discipline [1] and as science and art of technical creation [2].
- The types of reasoning implicated in the processes of research, discovery and creation [3].
- The modern tendencies in approaching the research and creation problems [4]-[6].
- Some general systemic models of the object and actions of the technical creation [7].
- The types of trans-disciplinarity applied in research, creative design and engineering education [8]-[10].
- The domains of competence of the technology of technical creation [5] as part of the paradigm of innovation [6].
- Some heuristic methods applied during the activity with the students [11]-[12].

In all these circumstances it was emphasized that the creative-inventive actions can be the more productive so as there are enhanced, to a great extend, the value of certain "procedural" attributes of thinking, which can be considered fundamental for any researcher, designer, creator, inventor.

"There are truth such little obvious, that there discovery is nearly a creation".
Lucian Blaga (1895-1961)

THE FUNDAMENTAL PROCEDURAL ATTRIBUTES OF THE HIGH PRODUCTIVE CREATIVE THINKING

A useful classification

Among the attributes of thinking, which proved themselves very productive in any activity of research, discovery, projection and creation, there have been emphasized twelve. These can be divided into two categories as follows (FIGURE 1):

A. **"Implicit" attributes**, as an expression of the qualities of thinking: "convergent", "divergent", "causal", "deductive", "inductive", "analogical (by analogy)".
B. **"Explicit" attributes,** as result of a complex process of comprehension: "systemic", "trans-disciplinary", "principled", "simplifying (oriented towards simplification), "essential", "successive".

All these attributes look upon the verb "to make" and therefore they constitute in the same time "technological" attributes, respectively are reflecting a "technological thinking".

It also deserves to be underlined that between all of these attributes there is a very close connection and that in the process of creative thinking they support each other.

It is known that at the basis of the human attitude, behaviour and action stands the comprehension of the information and facts. Therefore, the mode to act of a specialist (researcher, projector, inventor) in a certain "problematical situation" is determinated to a great extend by the level of comprehension of all those implicated into the process to solve the respectively situation. Because "learning" can be considered efficiently only when it is "changing the behaviour", the comprehension deserves a special attention in any educational process.

[1] Stefan Bartzer, University Politehnica of Timisoara, Faculty of Electrical Engineering, 1900 Timisoara, Romania, sbartzer@et.utt.ro

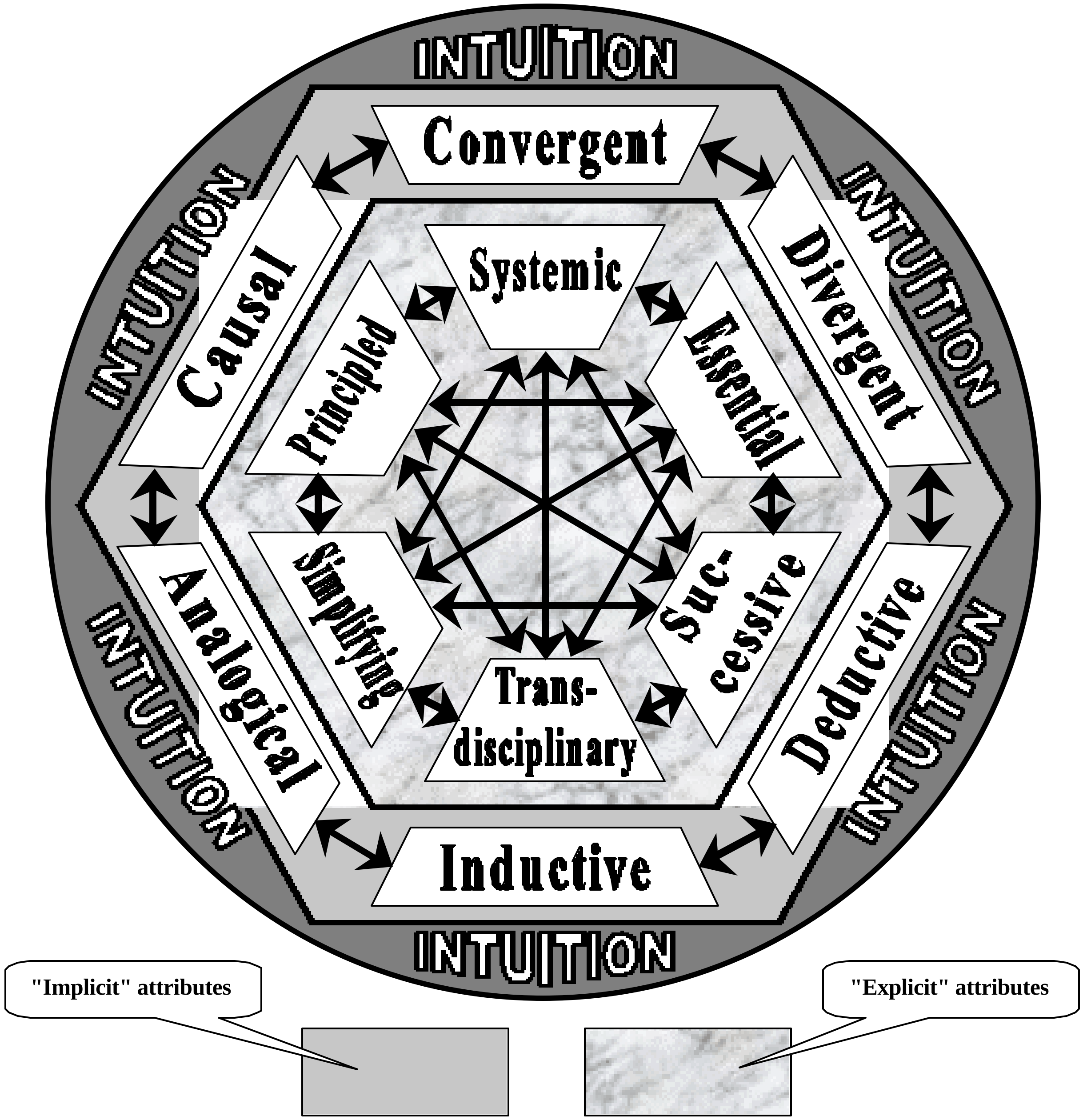

FIGURE 1
FUNDAMENTAL PROCEDURAL ATTRIBUTES OF THE HIGH PRODUCTIVE CREATIVE THINKING

All the analysed attributes of creativ thinking are supported by **"intuition"**. Therefore, the development of the intuition must be also taken into account within adequate learning situation. It is obvious, that any process of creation, in order to find new solutions, appeals to intuition.

Causal links between the "implicit attributes" (the quality of thinking) and the human performance

The activities of research and creation have a particularly complex character. The modalities to realize these complex heuristic processes are determinate [8], [12]-[14], besides other psychological mechanisms, by the level of thinking and the implicated types of reasoning [3]. In any case, the capacity to create of the human beans is in a close relation with the qualities of thinking.

Without **convergent thinking** the understanding between people becomes impossible, while without **divergent thinking** (the strongest expression of the productivity of human thinking) the problems with more solutions cannot be solved, the creation is not possible.

Without **causal thinking**, that is without observing and understanding the relation **"cause-effect"**, the reflection, by thinking, of the reciprocal conditionings and determinations existing between the objects and phenomena of the reality becomes impossible.

Without **logical and deductive thinking** there don't exist not even the capacity to respect rigorously the lows and rules of an exact reasoning, to look for and justify the truth, to accept only those theses which result out necessarily from the link of true judgments (theoretically and experimentally proved), to reflect the causal relation of the phenomena and diverse objective aspects of the reality and to maintain in the frame of the same premise during the whole reasoning.

Without **inductive thinking** there is missing the capacity to generalize and to determine the essential and common characteristics of a group of objects, facts and related concepts, in order to develop notions, to formulate definitions and to characterize objects, phenomena and processes.

In forming an efficient and high productive creative thinking, the **induction, deduction and analogy** are playing a role of a fundamental importance. The inductive and deductive thinking are supported to a great extend by the causal thinking, which presumes the explication of the reality through its natural causes. Interesting is the finding that the analogy stops at the formulation of the hypothesis and does not offer certainties. Therefore, the analogy must be completed with the induction and deduction, either on a theoretical way, or on an experimental way, or on both ways, depending on the given situation.

In a process of research, discovery and creation, the deduction and induction apply alternatively and complete each other. The induction gives to the deduction the **content** (what is general, abstract, rational, essential, the cause, the necessity, the theory), while the deduction offers to the induction the **form** (what is individual/particular, concrete, sensorial, the phenomenon/fact, the effect, the occurrence, the practice) [3].

The "explicit attributes". Brief description.

It has been experienced that the specialists can be the more efficiently in their actions of research, projection and creation, as they are applying in a greater extent a **technological creative thinking**, characterized through the **explicit procedural attributes** synthetically emphasized in Figure 1 and Table I.

- **Systemic** - with the attention focalized upon all the subsystems and relations emphasized by the representation models **"FCT"** (F - function, C - construction, T - technology), **"Ch-Ca"** (chains of causality), **"Tf-Co"** (technological feature of the construction) and **"PCoE"** (P - preparation, Co – carry out, E - evaluation) of the systems from type object [7-I], respectively process [7-II]. On this way, it is easier to emphasize the constitutive subsystems, to identify the perfectible elements of a system, and to optimize the studied object/process in its whole.
- **Trans-disciplinary** [8]-[10] **(interdisciplinary and pluridisciplinary thematic, monolevel and multilevel)** - with the attention focalized upon the multidisciplinary character of the representative objects, phenomena and processes of the system studied and upon the possibilities of integration, interpenetration and juxtaposition of the common **"axiomatics"** of more sciences and/or domains of specialty, in order to adopt and co-ordinate the specific **"paradigms"** [6] of these sciences/domains and apply them advantageous for solving the complex problems raised by the object of creation. The common axiomatics refers to knowledge and skills, conceptual schemes and modalities to moot problems, fundamental notions and general methodological elements, phenomena, principles and general lows. Each of the disciplines (domains of specialty) can offer a number of concepts, principles, lows, ideas and solutions applicable in other domains. Further, a particular methodology of a certain domain, transferred into other domains, can lead to very good results, to advance the efficiency of the activities. Therefore, the trans-disciplinarity appears like a proceeding necessary for the study of the complex problems of research and technical creation, respectively for the creative projection.
- **Principled -** with the attention focalized upon the fundamental principles, lows and theses (universal truth), basic ideas and notions/concepts and general rules/norms, applicable to a larger class of physical/technical/technological systems and on which are basing the scientific theories of the domain out of which the represented reality (the object of creation) is part. On this way, it becomes possible to emphasize the cause of things and to diversify the applications of the studied objects, phenomena and processes.
- **Simplifying** (oriented towards simplification) - with the attention focalized upon the **"functions"** and the **"technological feature of the construction"** of the object of technical creation and of its components. An important condition is to provide the necessary and sufficient quality. On this way, the creative-inventive effort is oriented towards finding such technical (constructive) solutions which are the best from both the functional point of view and the technological point of view.
- **Essential** - with the attention focalized upon what is fundamental, principal, profound, objective required, real important, general, universal and relative stable, mostly hide (but accessible by thinking) in the represented reality (the object of creation). "Undressing" the studied objects, phenomena and/or processes from the "form" and "apparent", the loss in "details" without significance can be avoided. It is an important finding that one and the same essence can

appear under more forms and that usually it is difficult to penetrate into the essence owing to the variety of the external manifestation forms of the essence.

- **Successive -** with the attention focalized upon the **"chains of causality"** [7] in the functional-constructive-technological structure of the represented reality (the object of creation), acting **"from near to near "**, without to omit/skip none of the links of the chains. The basic working tool and instrument in this proceeding is the **"low of causality"**. One is seeking for the **immediate** effect of a cause, respectively the **direct** cause of an effect. On this way, all the perfectible elements within the structure of an object of creation can be identified and emphasized surely.

TABLE I
THE EXPLICIT PROCEDURAL ATTRIBUTES OF THE HIGH PRODUCTIVE CREATIVE THINKING. SYNTHESIS (OTC - OBJECT OF TECHNICAL CREATION)

The Attribute	The Instrument or Proceeding	With the attention focalised upon the:	Consequences
1. Systemic	The Theory of systems	**FCT Model** of the OTC [7], starting from the **functions.** (F - Function; C - Construction; T - Technology).	• Emphasising the component subsystems. • Identifying the elements that can be improved. • Optimising the OTC in its whole.
2. Trans-disciplinary	■ Interdisciplinary (divergent). ■ Pluridisciplinary thematic (convergent): • Monolevel • Multilevel.	• **Multidisciplinary character** of the objects, phenomena and processes representative for the OTC. • **Common axiomatics** of more domains of speciality. • **Specific paradigms** of the involved domains of speciality.	• Identifying the involved domains of speciality • Advantageous appli-cation of the axiomatics and paradigms at solving complex problems. • Transferring the knowledge and solutions from one domain to ano-ther (to new applications).
3. Principled	Scientific theories applicable to a larger class of physical/ technical/technological systems.	• **Principles**. • Fundamental lows and theses. • Basic ideas and concepts. • General rules/norms.	• Emphasising the reasons of the things. • Diverse applications of the studied objects, phenomena and processes.
4. Simplifying (oriented towards simplification)	• Value analysis and/or engineering. • Unification. • Normalisation. • Type making. • Standardisation.	• **Functions of the OTC** and the subsystems of them. • **Technological features of the construction** of the OTC [7].	• Constructive solutions, functionally and techno-logically optimised. • A maximum of functionality with a minimum of costs.
5. Essential	"Undressing" the studied objects, phenomena and/or processes from the *"form"*, the *"apparent"* and the *"details"* without significance.	**Essence,** what is: • fundamental; • principal; • profound; • objectively necessary; • really important; • universal; • relative stable.	• Rising the productivity of research and creation. • The loss in details without significance, determinate by the variety of the manifestation forms of the essence, can be avoided.
6. Succesive	The low of causality: • The **immediate** effect of a cause. • The **direct** cause of an effect.	**"Chains of causality"** [7], with reference to the energy, substance, force, movement and information in the functional-constructive-technological structure of the OTC.	• An easy understanding of those studied. • Emphasising all the elements in the structure of OTC, that can be improved.

THE VALUE OF THE ATTRIBUTES OF CREATIVE THINKING FOR THE MODERN PROCEEDINGS OF RESEARCH AND CREATION

General findings

Today and so much the more in the future, in a society with a preponderant dynamic economy, there are required both the intensification of the activities of research and creation and the efficient implementation of there results into production, inclusively as original technical creation.

Two of the important possibilities which are promoted in order to enhance the efficiency of the processes of research and technical creation (PRTC) are represented, in essence, by the **global and unitary systemic and trans-disciplinary approach** of the ensemble of problems concerning the **strategy, tactics and evaluation** of the PRCT, respectively the **object** (OTC)**, actions** (ATC) and **resources** (RTC) of the technical creation [7]. These are important constituent elements of the **paradigm of innovation** (PI) [6], in which they have an operational general character.

A trans-disciplinary approach requires a consistent attention granted to the **sense** and **principal objective** of the creative-inventive actions. From this point of view, there can be distinguished [10]:

- **divergent actions,** in the case of interdisciplinary approaches, when the objective is to find diverse particular applications for given general solutions;
- **convergent actions,** in the case of thematic pluridisciplinary approaches, when the objective is to find optimal solutions for given applications/problems.

On this way, it is easier to apply the research results of diverse domains of specialty. The aim is to **optimize the ensemble** of the object of technical creation. Here the principal way constitutes the "transfer" of knowledge and solutions/applications from a domain of specialty to another, respectively to new situations.

> **"The things have a beginning and an end. When you know what comes before and after, then you are joining the method".**
>
> *Confucius (551 - 479 B.C.)*

The features of systemic structuring

- Large possibilities to approach the OTC and a facile and correct emphasizing and formulation of various research/creation themes, that in other approaching conditions would remain hidden.
- Every emphasized subsystem includes perfectible elements in a more or less measure, constitutes significant sources of research and creation themes.
- Between all of the subsystems, "functional units", of the OTC there exist complex dialectical relations of functional and constructive interaction, interdependence and interconditioning, which, when proper emphasized, constitute other sources of creation themes.
- The systemic analysis can be deepened and extended until a pertinent (necessary and enough) level of complexity, determinate by the proposed aim.
- The systemic analysis supports the delimitation/ separation out of a complex technical/technological system of that part which will constitute the OTC, permitting to the inventor (creative projector) to concentrate his further attention only upon that part.
- The clear emphasizes of the "elements of novelty" (which can be claimed as news).

The place and role of trans-disciplinarity and the status of the specialists in the dialectical spiral of evolution

A natural consequence of the process of diversification of the domains of specialty and deepening of the specialization in these domains was the transition to a **collective** solving of the problems, at the beginning **intradisciplinary** and in the last time **trans-disciplinary**. This phenomenon is registered by the dialectical spiral of evolution, in which there are distinguishable the following **three stages** (Figure 2):

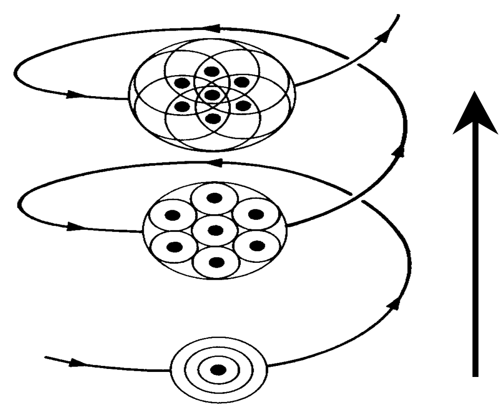

FIGURE 2

I. "**Individual global". The approach is individual (lonely) global**, focalized upon a unique problem, usually with a restricted area; the researcher (creator) is solving alone all the problems.

II. "**Collective on parts". The approach is individual intradisciplinary, coordinated multiple on parts,** focalized upon partial problems of the whole, the researcher (creator) having the status of an "isolated participant" in a multidisciplinary team, accordingly to his specialization.

III. "**Collective global". The approach is collective, global and unitary, systemic and trans-disciplinary,** focalized upon the whole complex problem, the researcher (creator) having the status of an "active collaboration member" in a trans-disciplinary integrated team.

Essential characteristics:

1) The metamorphose of the individual singular researcher (creator) in a collective one, through a stage of an individual multiple researcher (creator).
2) The return to a global and unitary approach of the problems, after a period of approach on parts.

THE NECESSITY TO FORM AND DEVELOP THE PROCEDURAL ATTRIBUTES OF THE HIGH PRODUCTIVE CREATIVE THINKING

The creative-inventive process is a complex process. During such a process, there are put into value and become active, with a certain weight, some theoretical and practical concepts, knowledge, skills and habits specifically of the most divers disciplines (domains of science). Thus, there is easy to understand the significance have by the modern tendency in approaching research and creation problems: systemic analysis and trans-disciplinarity. In such conditions, the creative-inventive activity is **polyvalent** [1]-[7]. The profile of personality of the specialists have to reflect a complete general education/culture, in order to correspond to the requirements of efficient activities of research, design and creation [8]-[14].

It is recommended to promote **formative didactical activities**, oriented towards such qualities of thinking that are favorable in the processes of research, discovery and creation. Besides this becoms necessary a supplementary (self)education of the specialists about the problems of efficient technical creation. In present, there is in full evolution a new scientific and educational discipline called "**Technical Performantics"** [14], which can be also considered as a **"science of efficient human actions".**

CONCLUSIONS

Without fear to be wrong, there it can be affirmed that the **human performance/efficiency** is represented on the greatest extend by **creation**, inclusively by **technical creation**. Through the concept of **"paradigm"**, in general, and through the paradigms of innovation, trans-disciplinarity and system theory, in particular, the specialists in the field of research and creation benefit by a **"mental operator"** with the value of a **"discursive subprogram"** while developing the operations of thinking, respectively the reasoning [6]. Therefore, the necessity to develop, stimulate and support informational and methodologically the creativity of the specialists is imposed by itself.

It has been ascertained that within the framework of a systemic and trans-disciplinary approach of the research and creation problems, all the attributes of creative thinking, emphasized and described in the paper, represent, in essence and together, the intellectual support which permits the specialist to develop a creative-inventive process of great performance. Furthermore, all these attributes permit the transition/leap from the **intuitive/empirical knowledge** (based on sensations, perceptions and representations) to the **rational/general knowledge of principle**, by deduction/ analysis, induction/synthesis, analogy/comparison, concretization, generalization and abstraction, based on notions, judgements and reasoning. The last constitutes the **highest quality of knowledge,** as result of a high productive process of cognition. Also, referring to the verb **"to make"**, all the emphasized attributes constitute in the same time **"technological" attributes,** respectively are reflecting a **"technological thinking"**.

Therefore, it deserves to support the orientation of the thinking of the specialists towards such modalities to put/approach/solve the problems of research and creation. The principal role in this respect has the education, through the creation of proper **"learning situations"** for the students. The trans-disciplinarity and system analysis must be integrated into engineering education with proper methodological/ educational proceedings, which have to be developed.

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