

HOW STRONGLY DOES FUNCTIONAL ANALYSIS INFLUENCE CREATIVITY?

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Abstract

In contrast to many creativity stimulation methods, such as brainstorming, SCAMPER, etc., which are mainly used to generate design solutions, functional analysis method is based on the analysis of the design problem at an abstract level, thus encouraging the posterior solutions finding process. However, the effect of functional analysis on the degree of creativity of the obtained solutions has not been studied.

This paper analyses the effect of the functional analysis method in the solutions obtained for two design problems under experimental laboratory conditions. In particular, the effect of functional analysis on the degree of creativity of the design solutions is assessed, both by means of objective evaluation metrics and by means of the opinion of experts obtained from questionnaires.

The results obtained show that functional analysis does not provide much difference in the degree of creativity in comparison to situations in which no method is asked to be applied, but it seems to provide more useful solutions than when this method it is not used.

Keywords: *creativity, functional analysis, solution evaluation, design experiment*

Resumen

Al contrario que muchos métodos de estimulación de la creatividad, tales como la tormenta de ideas, el SCAMPER, etc, que se utilizan principalmente para generar soluciones de diseño, el método de análisis funcional se centra en el análisis del problema de diseño a un nivel muy abstracto, de forma que este análisis facilite el posterior proceso de búsqueda de soluciones. Sin embargo, el efecto del análisis funcional en el grado de creatividad de las soluciones obtenidas no se ha estudiado.

Este artículo analiza el efecto del análisis funcional en las soluciones obtenidas para dos problemas de diseño bajo condiciones experimentales de laboratorio. En concreto, se determina el efecto del análisis funcional en el grado de creatividad de las soluciones de diseño, por medio de métricas de evaluación objetivas y por medio de cuestionarios a expertos. Los resultados obtenidos muestran que las soluciones obtenidas por medio del análisis funcional no muestran mucha mayor creatividad que cuando no se prescribe ningún método, aunque sí proporciona soluciones con un mayor grado de utilidad.

Palabras clave: *creatividad, análisis funcional, evaluación de soluciones, experimento de diseño*

1. Introduction

There are many well-known design methods for stimulating creativity in the earlier phases of the design process (brainstorming, SCAMPER, six hats, lateral thinking, analogies, functional analysis, etc.), as can be seen in the collections of methods by Jones (Jones, 1970), VanGundy (VanGundy, 1988), Higgins (Higgins, 1994), (Bono, 1970) and others. In addition to these methods, there are other methods, such as functional analysis, that support an abstract problem analysis instead of encouraging free generation of ideas.

However, the precise influence that design methods have on the degree of creativity of the designed product is not clear, due, among others, to the complexity involved in assessing or measuring creativity. This complexity is even higher in the earlier phases of the design process, when usually several ambiguous design ideas are proposed and the designers have to decide which one to select.

A deeper understanding of the relative influence that functional analysis method has on creativity would provide new insights about the advantages of applying this method.

The aim of this work is to evaluate the degree of creativity of functional analysis method in comparison to when no method is applied. For achieving this, creativity is evaluated in two ways: by means of experts' opinions and by applying a research metric.

This paper is organized as follows. Section 2 describes the method used for measuring the degree of creativity of the design outcomes. Section 3 describes the research experiment and the analysis carried out with the experimental data. Section 4 presents the results and Section 5 provides some concluding remarks.

2. Creativity assessment

2.1. Definition

Literature provides over a hundred definitions of creativity, many with overlapping elements, see (Sarkar, 2007, Sarkar and Chakrabarti, 2008, Shah and Vargas-Hernández, 2003, Sternberg and Lubart, 1999). Sarkar and Chakrabarti (2007) proposed a common definition of engineering design creativity by analyzing a comprehensive list of definitions, where the elements constituting creativity from various definitions are found to occupy a hierarchy of influences on creativity, with novelty and usefulness of the outcomes occupying the most direct links with creativity. The proposed common definition of creativity is, 'Creativity occurs through a process by which an agent uses its ability to generate ideas, solutions and products that are novel and useful.' Because of its comprehensiveness, this definition is used in this work. The core elements of creativity are 'novelty' and 'usefulness,' and a direct measure of creativity should be formed in terms of these two. Note that this is an outcome-based definition of creativity, where creativity is adjudged in terms of the characteristics of the outcomes generated as a result of the creative process or person, as opposed to a person or process-based definition of creativity in which the focus is, respectively, on the characteristics of the person or the process involved. The argument for this choice is that outcome-based definitions are the most direct forms, since whether a person or a process is creative is ultimately evaluated by the quality of their outcomes.

An outcome is 'new' if it has been recently created (Cambridge, 2007). 'Novel' outcomes are those that are new to the entire human race: 'novelty' encompasses both new and original (Cambridge, 2007). Novelty is 'not resembling something formerly known' (Sternberg and Lubart, 1999).

Dictionaries define 'Usefulness' as the quality of having utility value or practical benefits to the society (Merriam, 2007, Oxford, 2007). Usefulness of a product therefore should be

assessed by its actual use, and when this information is not available, using estimation of its potential use.

2.2. Measure of Novelty

The assessment of novelty of an outcome, therefore, requires comparison with previously known ideas. Novelty may be defined with reference either to the previous ideas of the individual who developed that idea, or to the whole of human history. The former definition is concerned with P-creativity (P for Psychological) and the latter with H-creativity (H for Historical). H-creativity presupposes P-creativity, for if someone has a historically novel idea, then it must be new to the person as well as to others (Boden, 1999). Thus, generation of novel ideas, solutions or products requires H-creativity.

In order to detect novelty of a new product, we need to compare the characteristics of that product with those of the previously known products that are meant to fulfil similar need. Thus, one should know the time line of similar inventions (to identify which product satisfied first the need) and the characteristics of similar products (to assess how this is satisfied). The difference among these characteristics should be the degree of novelty of the recently developed product. We use FBS models for this purpose (Chandrasekaran, 1994, Goel, 1997, Qian and Gero, 1996). If no other product had satisfied the same need before, the new product should be considered of the highest novelty (the maximum value in the scale). If the product is not different from existing products, its novelty should be zero (the minimum value in the scale), otherwise it should be taken as having some degree of novelty, which then needs to be determined. A more detailed model of causality of products is needed for this.

We use SAPPPhIRE model (standing for State-Action-Part-Phenomenon-Input-organ-Effect) model of causality by (Chakrabarti, Sarkar, Leelavathamma and Nataraju, 2005) to assess the relative degree of novelty of products, see Figure 1. It has seven elementary constructs. 'Action' is an abstract description or high level interpretation of a change of state, a changed state, or creation of an input. 'State' refers to the attributes and their values that define the properties of a given system at a given instant of time during its operation. 'Physical phenomena' are a set of potential changes associated with a given physical effect for a given organ and inputs. 'Physical effects' are the laws of nature governing change. 'Organs' are the structural contexts needed for activation of a physical effect. 'Inputs' are energy, information or material requirements for a physical effect to be activated. 'Parts' are the physical components and interfaces constituting the system and its environment of interaction. Parts are necessary for creating organs, which with inputs activate physical effects, which are needed for creating physical phenomena and state change. State changes are interpreted as actions or inputs, and create or activate parts. Activation, creation and interpretation are the relationships between the constructs.

For detection of relative degree of novelty in products that are not 'very highly novel' (i.e., do not satisfy a function for the first time), state change and input constitute the next level of novelty ('high' novelty), physical phenomena and physical effect the next level ('medium' novelty), and organs and parts constitute the lowest level ('low' novelty) at which a product can be different from other products. Based on these, a method for novelty detection has been developed which employs FBS model initially (to find if a product is very highly novel or not) and later SAPPPhIRE model to assess (relative degree of novelty with respect to other products). The method has been formerly evaluated in terms of the degree to which its output (i.e., the degree of novelty of products as determined using the method) matched with the output of experienced designers (the degree of novelty of the same products as perceived/determined by these designers) (Sarkar, 2007, Sarkar, 2007). The results showed high degree of correlation.

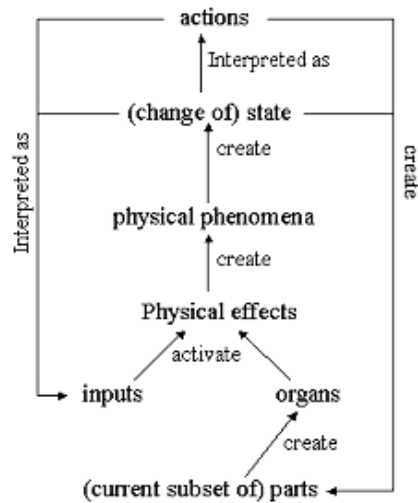


Figure 1. SAPPHIRE Model of Causality

2.3. Measure of Usefulness

We measure Usefulness of a product in terms of the degree of usage a product has or is likely to have in the society. This overcomes other potentially misleading indicators, such as sales, even though a product is not useful. The scale is provided by a combination of several elements to assess the degree of usage: the importance of the product function, the number of users, and how long they use it or benefit from it. Together these give a measure of how extensive the usefulness of the product is to the society. This is explained below.

As to how important the use of a product is depends on its impact on its users' lives. Some products are indispensable; products that are more important to the society should have a higher value for their usefulness. Five levels of importance of products are used in this measure (Sarkar, 2007, Sarkar, 2007): extremely important (e.g. life saving drugs), Very highly important (e.g. compulsory daily activities), Highly important (e.g. shelter), Medium importance (e.g. machines for daily needs), Low importance (e.g. Entertainment systems). All other parameters being the same, the products that are used by a larger number of people should be more useful to the society. Products that are used more frequently or have longer duration of benefit are likely to have been more useful to the society; assuming that their 'level of importance' and 'rate of popularity' is the same, the rate of their usage increases their usefulness. These parameters are combined using equation 1 below to assess degree of usefulness.

$$U = L (F D) R \quad (1)$$

L stands for level of importance; F for frequency of usage (how often people use it); D for duration of benefit per usage; R for rate of popularity of use (how many people use it). The unit of time for R, F and D should be the same. Formal evaluation of the measure by comparing the ranking of usefulness among various sets of products by experienced designers and that found using the measure showed a high degree of correlation.

2.4. Measure of Creativity

Creativity is measured here as a function of the degree of 'novelty' and 'usefulness' – the only two direct influences on creativity as per the common definition discussed in Section 1.2) That function used is a product of the degree of novelty and usefulness, embodying the notion that absence of either will lead to little creative quality in the out-come (C stands for degree of creativity, N for degree of novelty, and U for degree of usefulness):

$$C = N \times U \quad (2)$$

In order to assess relative degree of creativity of a product in a given set, the following steps are carried out:

1. Assess novelty of each product on a qualitative scale: 'Very high novelty', 'High novelty', 'Medium novelty' and 'Low novelty' using the method in Section 1.2.
2. Convert the qualitative novelty value of each product into quantitative values: Very high novelty = 4 points, High novelty = 3 points, Medium novelty = 2 points and Low novelty = 1 point. Convert these into relative ranks.
3. Assess the usefulness of each product using the method described in Section 1.3.
4. Convert the usefulness value into relative ranking using the following scale: if there are five products that are ranked 1-5, give them 1/5, 2/5, 3/5, 4/5, 5/5 points respectively.
5. Calculate creativity of a product as a product of its degree of novelty and usefulness using Equation 2. Convert the values into relative ranks. Evaluation by comparison of using this measure to rank relative degree creativity among various sets of products and that by using average opinions of experienced designers show a high degree of correlation.

3. Methodology

3.1. Design experiment

To afford these objectives, a design experiment has been carried out in which designers and engineers in a design PhD programme or working as professional Designers participated.

For this study, two teams of three persons each one have been analyzed. Each team started solving a problem applying no prescribed method, and they continued solving another problem applying functional analysis. This allowed us analyzing the relative influence of functional analysis in comparison to with when no method is asked to be applied. The steps for functional analysis method are described in Table 1.

FUNCTIONAL ANALYSIS	
1.	Express the overall function for the design in terms of the conversion of inputs into outputs <ul style="list-style-type: none">• Concentrate on what has to be achieved by the design, rather than how.• Create a black box of inputs and outputs which defines the overall function as broadly as possible widening the system boundary.• Ensure that all relevant inputs and outputs are included, which can be classified as flows of materials, energy or information.
2.	Break down the overall function into a set of essential sub-functions. <ul style="list-style-type: none">• Each function statement should be expressed in the same way (sentence with a verb and a noun).

<ul style="list-style-type: none"> • Each sub-function has its own inputs and outputs, and compatibility between these should be checked • There may be auxiliary sub-functions that has to be added but which do not contribute directly to the overall function.
<p>3. Draw a block diagram showing the interactions between the sub-functions.</p> <ul style="list-style-type: none"> • A block diagram consists of all the sub-functions separately identified by enclosing them in boxes and linked together by their inputs and outputs so as to satisfy the overall function of the design. • It is useful to use different kinds of lines for different kinds of inputs.
<p>4. Draw the system boundary.</p> <ul style="list-style-type: none"> • Decide which part of the block diagram will be satisfied by the system designed so as to define a feasible product. • This may be required in order to narrow down the scope of the product.
<p>5. Search for appropriate components for performing the sub-functions and their interactions. Many alternative components may be capable of performing the identified functions.</p>

Table 1. Functional analysis steps

The problems to solve in the experiment were: the design of a system to bring together and to hide the wires in a table (problem 1) and the design of a table for alternating stand up and sit down position (problem 2). The tasks and timing for each design session was organized in four steps:

Step 1. Preparatory meeting (15 min) with the participants to explain and apply the design method to a short exercise unrelated to the actual problems.

Step 2. Solve the actual problem (30 min) applying the design method prescribed.

Step 3. Evaluate and select one solution (10 min). Neither instructions nor any prescribed method were provided to do this.

Step 4. Documentation. (10 min). During the last 10 minutes, the participants were asked to prepare the following information: detailed sketch with major dimensions and materials, describing how it works, explaining how it solves the problems, who the beneficiaries are, and why they should buy and use it.

Each design session was recorded for further analysis

Tables 2 to 3 describe the design outcomes for each experiment run analyzed in this study.


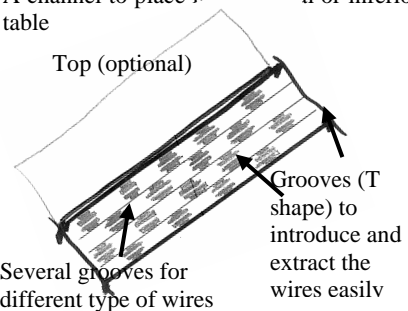
No method (NM)	Functional analysis (FA)
<p>The wires are tight by velcro on the inferior face of the table and are lead to the leg. There is a plug in the leg to connect the wires</p> 	<p>A channel to place in the top or inferior surface of the table</p> 

Table 2. Design solutions obtained for problem 1.

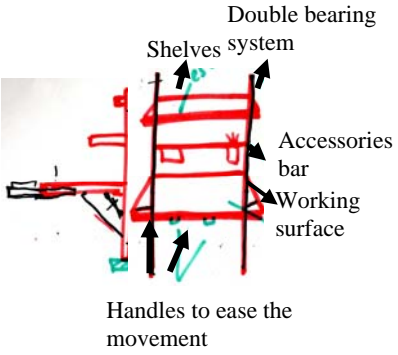
No method (NM)	Functional analysis (FA)
<p>A metallic structure holds the table to the wall. It allows changing easily the height and the angle of tilt. It can be used for different purposes</p> 	<p>There are no sketches for this solution. The proposed components and their respective functions:</p> <ul style="list-style-type: none"> - Bearing (to enlarge the board surface) - Wheels (to move) - Hydraulic system (to stand up the board, to change its position) - Two legs (to support) - Rack. (to keep pencils and objects in the board, avoiding these to fall down)

Table3. Design solutions obtained for problem 2.

Next, the relative degree of creativity of each design outcome from the experiment is assessed in two ways: by means of experts' evaluation and by applying the measurement method explained in section 2.

3.2. Experts evaluation

A questionnaire was designed to evaluate the degree of novelty, usefulness and creativity. For each design problem, the questionnaire asks for ranking each one of the 2 solutions from 1 to 2, with 1 being the most novel, useful or creative of the two, and 2 the least one. For each solution, a sketch and an explanation are provided.

The questionnaire was then offered for survey to experts. Here an expert is taken as a person with at least eight years of professional experience in the design of furniture and similar products. Seven experts answered the questionnaire. The responses from these questionnaires are analyzed and the median, mode and standard deviation were obtained. The experts' responses present a significant dispersion, and therefore one expert has been excluded from the study because his answers were very different from any others' one and the mode was used to assess the relative degree of novelty, usefulness and creativity.

3.3. Evaluation of novelty

In this sub-section the degree of novelty was measured applying the SAPPhIRE Model, thus comparing the differences in action, state change, physical phenomenon (PP), physical effects (PE), organ, parts and input between the obtained solutions and the previously known solutions for each problem. Table 4 shows the FBS and the SHAPPhIRE constructs for one existing solution for problem 2.


Existing solution	FBS	SAPPhIRE
<p>Sitting/standing desks</p>  <p>SISstand 2 (1230)</p> <ul style="list-style-type: none"> • extension surface for keyboard • pivoting mouse-pad on right or left side • compact • continuously variable height adjustment 	<p>Function: to support both sitting and standing working positions</p> <p>Behaviour: a bearing system allows changing the height.</p> <p>Structure: legs and board. A bearing system in the legs to change sitting/standing position. Bearing system to extend the board.</p>	<p>Action: to change the board height</p> <p>State Change: supporting at a different height</p> <p>PP: a human force is applied to enlarge the legs</p> <p>Organ: rigid solid</p> <p>Parts: legs, board, bearing system</p> <p>Input: human force</p>

Table 4. FBS and SHAPPhIRE analysis for problem 2 existing solution

Problem 1 solutions	Number of differences		Degree of novelty	Novelty rank
	In terms of parts			
FA	More differences		Low novelty	1
NM			Low novelty	2
Problem 2 solutions	Number of differences		Degree of novelty	Novelty rank
	In terms of PP	In terms of organ and parts		
FA	-	Not new	Not new	2
NM	-	2	Low novelty	1

Table 5. Analysis of differences using SAPPhIRE Model Constructs

3.3. Evaluation of usefulness

It was observed that some of the factors that influence the degree of usefulness considering the method explained in Section 2 has the same value for the three solutions obtained for every design problem. Then, only those having a different score are indicated in this subsection.

For problem 1, four issues concerning the level of importance and the rate of usage have been identified to be different for the three solutions obtained in the experiment: ease to change and expected lifespan (FA>NM), flexibility to connect in many different points (FA and NM are very similar) and capability to hide the wires (NM>FA). Finally, equal ponderation for the four factors has been applied and the final usefulness rank is: FA>NM.

For problem 2, the rate of usage and the popularity of use (R) are considered to be very similar for the two solutions obtained. A slightly higher level of importance is assigned to the solution obtained with no method, because it has more additional uses.

4. Results

In this section we present the data analysis for the evaluation of novelty, usefulness and creativity made both with data collected from the experts' evaluation and the assessment with methods proposed by the research community when functional analysis and when no prescribed method are applied. Table 6 illustrates the cumulative sum of the rank values assigned to novelty, usefulness, and creativity. The lower the sum of the rank values, the higher novelty, usefulness and creativity.

	Experts' evaluation cumulative sum of ranks for problem 1 and problem 2		Research metrics evaluation cumulative sum of ranks for problem 1 and problem 2	
	Functional Analysis	No Method	Functional Analysis	No Method
Novelty	28	29	3	2
Usefulness	21	23	2	3
Creativity	25	29	3	3

Table 6. Relative degree of novelty, usefulness and creativity

As it can be seen, the design outcomes provided by functional analysis and provided with no prescribed method present a quite similar degree of novelty, usefulness and creativity with both evaluation methods. The most significant difference is observed in the degree of usefulness, when functional analysis is better evaluated than with no method is used.

Figures 2 and 3 show the cumulative sum of the ordinals assigned to novelty, usefulness and creativity with the experts' evaluation and with the metric respectively.

Cummulative sum of experts' rank

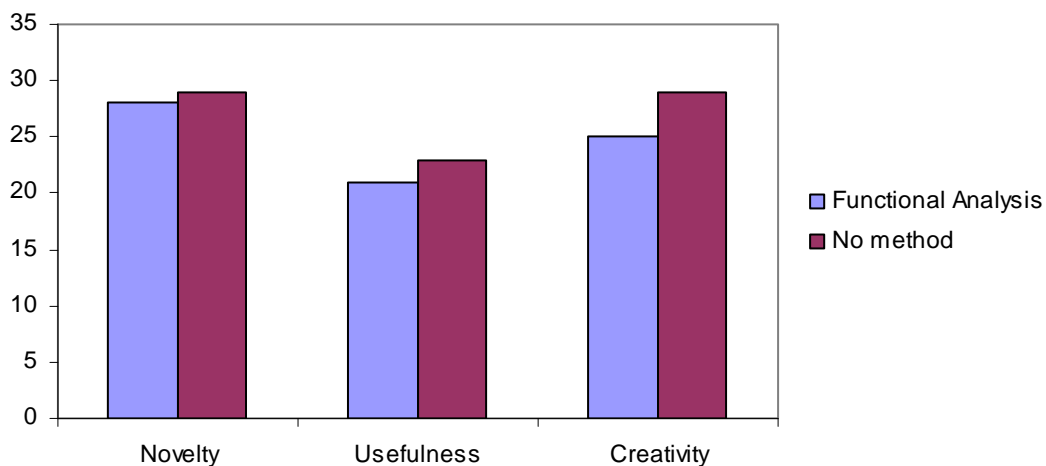


Figure 2. Experts' evaluation for novelty, usefulness and creativity

Cummulative sum of research metrics rank

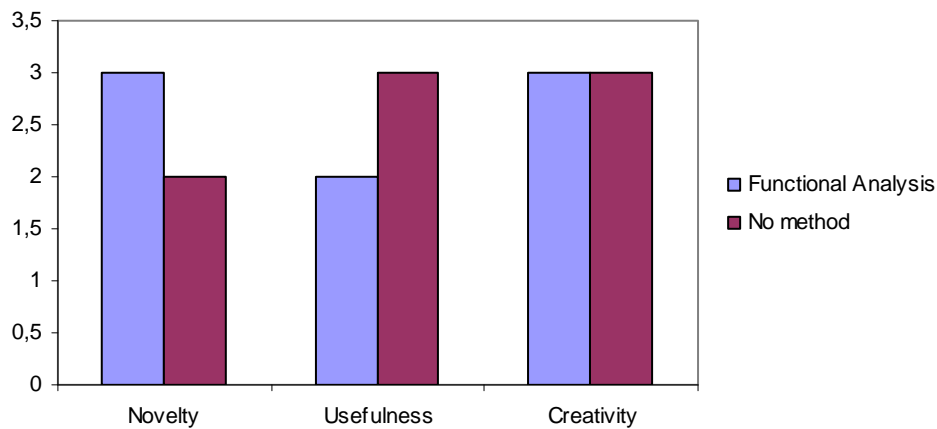


Figure 3. Metric evaluation for novelty, usefulness and creativity

As it is observed, the most novel results according to the experts' opinion are those obtained with functional analysis, while according to the metric, the most novel are the no method solutions. We argued that this difference can be due to the fact that the design solutions generated differ only in secondary functions, and while SHAPPhIRE metric takes into account these minor differences in relation to the existing solutions, it is probable that the experts have not considered these secondary differences relevant.

As it has been mentioned, the most usefulness outcomes are those obtained applying functional analysis. From the point of view of the degree of creativity, the same degree is obtained applying the metric, but considering the experts' opinion, functional analysis is slightly more creative than when no method is used.

5. Conclusions

This study provides an analysis of the degree of novelty, usefulness and creativity of the design outcomes for functional analysis method in comparison to when no method is applied.

It is observed that functional analysis does not provide much difference in the degree of creativity in comparison to when no method is asked to be applied. On the other hand, Functional analysis seems to provide more useful solutions than when this method it is not used.

We argue that since the design problems used in the experiment have a small number of functions, it is possible that the degree of novelty and creativity could be higher when functional analysis is applied to a design problem with a larger number of functions. So, future works will analyze if the same results are obtained even when functional analysis is applied to a design problem with a higher number of functions to satisfy.

The low number of experiment runs and the involvement of few teams that vary across the problem and method may also have influenced the results. Also, the experimental runs have

been relatively short (40 mins); this gives little scope for substantial variation in time spent on problem exploration and solution consolidation.

In future work it would be interesting to analyze in which other way functional analysis may produce better solutions, as for example, more feasible solutions in comparison to other methods.

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