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TRIZ 40 Inventive principles classification through FBS ontology

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Abstract

Altshuller screened patents in order to find out what kind of contradictions were resolved or dissolved by the inventors/inventions and the way this had been achieved. From this he developed a set of 40 inventive principles.

Since the first Altshuller's formulation [1], the inventive principles have been largely used and studied by academic institutions and private companies operating in the product innovation field. Research on inventive principles is focused on improving principle definitions by providing a huge list of examples to be used as analogy and customizing definitions for specific domains (i.e. informatics, business, chemical, manufacturing and more others). Meanwhile, many authors worked on classifications and comparisons with other design models or problem solving methods. One of the reasons for this interest can be found in an attempt to reduce the degree of subjectivity in the use of this tool. This problem can be attributed to the high degree of abstraction with which many principles are written, inducing inevitably to a certain freedom of interpretation. In some cases, during the problem approaching, this ambiguity may lead the user-not to fully capture the inventive essence.

The goal of this work is to analyze all 40 principles from a new design perspective, i.e. the FBS (Functional Behaviour Structure theory) [2], in order to overcome their ambiguity and ameliorate their efficacy. New definitions have been conceived to make the user aware if he/she is acting on the function, the behavior or the structure of the device. This analysis has revealed that in many cases there is already a perfect matching between original Altshuller's definitions and FBS logic. That means a large part of the principles forces the user to act both on the function, the behaviour and the structure of the system. Where the matching with FBS is not complete, this classification/reformulation can help to enlarge the range of its interpretation/suggestions broadening the solution space. The potentiality of this work has been tested on a set of industrial case studies solved by 40 mechanical and management engineering students and by a group of TRIZ experts.

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Keywords: TRIZ, inventive principles, FBS;

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1. Introduction

On one hand the 40 inventive principles can be universally applicable in various fields due to their degree of abstraction to describe the problem. On the other hand, their interpretation can be ambiguous because different subjective interpretations can be given.

In literature, most of the authors proposes to classify the principles in order to increase their clarity and applicability. Mann [5] classified the traditional inventive principles on the basis of three areas of intervention: space, time, interface. Guide brainstorming [6] extends the directions of intervention considering the resources use, time, space, structure change and conditions or parameters change. Finally Mann [7] with his matrix has already rethought the traditional inventive principles and has added new parameters.

What the authors propose is different from previous works because they rewrote the 40 principles by a new design perspective based on the Function-Behaviour-Structure theory. FBS is not a novelty in TRIZ, some attempts to combine FBS and TRIZ were proposed by Chulvi and Vidal [3] who used the FBS formalism to better clarify the main function of a device or by Wits and Vaneker [4] who employed the FBS model for better defining TRIZ contradictions.

The paper is structured as follows. Section 2 presents a state of art about traditional inventive principles. It reports on the historical evolution of the traditional inventive principles, the original Altshuller's definitions, the redefinitions of other authors, the classifications and the applications. Section 3 presents the FBS theory, proposing and explaining our reformulation about principles. Section 4 draws conclusions.

2. State of Art

2.1. Inventive principles

The first publication about the inventive principles is dated back to 1956 [8] by Altshuller and Shapiro. It explains the possibility of a limited set of solution directions shared by most of patents. By the end of the fifties, Altshuller and his colleagues isolated eighteen inventive principles. In 1963, at the disclosure of ARIZ [9], principles were classified in seven main groups involving a total of 39 sub-principles. The number of principles continues to increase until the current number of forty in 1971 [10] comprising a series of sub-principles.

In literature, there are still numerous attempts to increase the number of principles following three lines of investigation: some authors propose new sub-principles [11, 12], others add new principles [10], some others instead propose inverted principles [13].

The forty principles have been reformulated several time by Altshuller himself [14, 15] and others [16,17] as shown in Table 1.

Alternatively to the definitions, an attempt to improve the understanding of principles is given by the classifications proposed in literature. Ross [18] suggested a matrix to classify principles based on physical attributes and mechanical devices. De Saeger and Claeys [19] distinguished between principles specifying the technology to be used and those specifying the boundary conditions. Cong and Tong [20] and Glaser [21] conducted a detailed study on the connection between principles, patents and patent research. Mann [5] differentiated principles according to the degree of abstraction, showing the correlation with the number of results obtained. Guide Brainstorming [6] links the principles to the type of change made on the system or on the environment.

Furthermore, other authors have compared the principles with other theories. Among them, Yang [22] linked principles with the 36 Strategies while Iyer [23] has investigated the similarities with the Vedic principles.

Many other applications of inventive principles have been found in both academic and industrial world. In particular, we mention business applications [24], microelectronics applications [25], chemistry [26] and computer science applications [27].

However, De Saeger and Claeys [19] advise us about principles applications: the attempt to make principles more user friendly may preclude some solutions.

2.2. Function Behaviour Structure

Compared to the theories from which FBS started [28, 29], the concepts of function and structure were redefined and the concept of behaviour was added [30, 2]. These concepts have been revised several times [31-34]. In some cases, FBS theory redesigned on the basis of the TRIZ theory i.e. [35]. However, design is the natural field of application of this theory and it was not born for problem solving. Consequently the definitions are most oriented towards design. In order to reinterpret the inventive principles according to the FBS logic we have taken into account many authors as Gero, Cao, Sembugamoorthy, who adapted the FBS theory in problem solving. Table 1 shows the reference definitions.

Table 1. FBS definitions

Function	The design intentions or purposes. (Gero [31]) This specifies WHAT is the response of a device or a component to an external or internal stimulus. (Sembugamoorthy [36])
Behaviour	Attributes derivable from structure or expected of structure. (Gero [31]) This specifies HOW the response is accomplished starting from a stimulus. (Sembugamoorthy [36]). The behavior may also be quantified by physical, chemical or geometrical effects describing a transformation of an input-output flow. (Cao and Tan [37])
Structure	The elements (of an artifact/design) and their relationships. (Gero [31])

The links between function, behaviour and structure, are not unique. Indeed, there are several alternative behaviours to realize the same function and also alternative structures for the same behaviour.

3. Proposal

In order to overcome the possible ambiguity in understanding the inventive principles we propose to use FBS logic to better clarify their interpretations. This article aims to make the user more aware about all possible directions of intervention to innovate a system or at which level- he/she is acting on: function, behavior, structure, or all three together.

Some principles already suggest three directions of intervention: changing in a certain manner the function, the behaviour or the structure of the device. An example can be principle #2 Extraction (Altshuller [15]): "*Extract the disturbing part or property from an object*". An example (Altshuller [15]) about the extraction of behaviour is: *"To scare birds from the airport, reproduce the sound known to excite birds using a tape recorder. The sound was separated from birds"*. An example about the extraction of the structure is the equilibration of a disc keyed on a shaft, where we can extract a portion of the material of the disc.

Other principles do not correspond to the FBS logic at all, since they indicate only one of the three possible areas of intervention. An example can be principles such as #18 Mechanical vibrations (Altshuller [15]): *"Make your object or its part vibrate",* focusing only on the structure S. For all these principles suggesting one or two directions of intervention, the authors have reworked them in order to guide the user in modifying the system according to all the 3 levels of FBS. In the following, we propose a limited set of inventive principles according to our reformulation.

3.1. *Principle #1 Segmentation*

If a system cannot fulfil its goal, the traditional principle #1 Segmentation suggests us to divide the system into several parts and recombine them later. By analyzing the principle from an FBS point of view, we can observe that this principle suggests to explicitly work on the structure of the system (e.g. independent parts, object sectionable, segmentation of the object). In fact, this principle does not provide any suggestion on how to achieve the goal by acting on the function or behaviour of the system. From our point of view, we have decided to extend this principle to the other two entities of the theory FBS, without misunderstanding its original essence. With our reformulation, we propose not only "to segment the structure" but also "to segment the behavior" that means "discretize" the operative zone and/or the operative time changing the dynamics of the system. Therefore the physical effects related to the behaviour may occur in a heterogeneous and variable way and they can be also recombined to create new synergies. The "segmentation of the function" suggests to subdivide it into sub-function, dividing them into operative zone and operative time. When we cannot perform the entire function, it could be convenient to realize it partially if we can achieve the same final result, or when it is difficult to perform the function all at once, the partitioning of the function suggests you to realize the sub-functions in sequence. We propose an exemplary case dealing with a toaster. In this case, the function coincides with the need to obtain a slice of baked bread, the behavior is the way of toasting, while the structure is the toaster. Figure 1 shows the application of the segmentation principle based on its original form, while figure 2 presents the application of the same principle according to the FBS ontology.

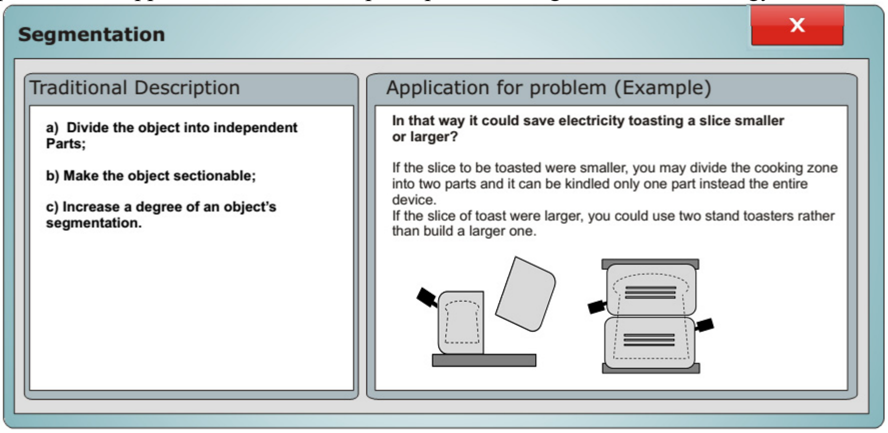

Figure 1. Principle #1 Segmentation (original form)

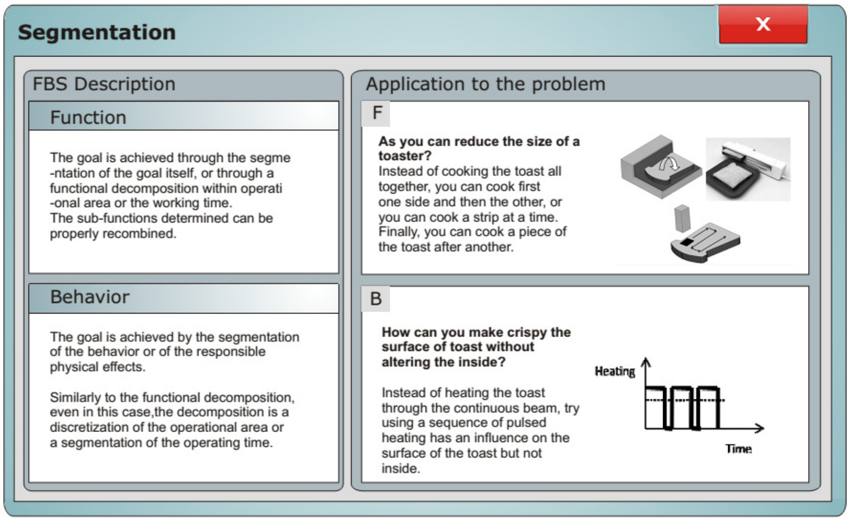

Figure. 2. Principle #1 Segmentation (according to Function and Behaviour form).
Structure form is identical to classical Altshuller's definition in fig. 1

3.2. Principle #4 Asymmetry

Principle #4 Asymmetry suggests to play on the asymmetries of form (S) in order to solve the problem (see figure 3). According to the FBS logic, "asymmetry of the behavior" suggests us to break the possible linearity of the kinematic behavior, making it asymmetric, while the "asymmetry of the function" indicates to perform the function in part or in superabundance within the operative zone or the operative time. The example proposed deals with how tyres of a sport car can maintain the trajectory for a longer time during a curve. In this example, the function of the tyre is the maintenance of the trajectory, the behavior is the physical way through which the wheels maintain contact with the road (figure 4), while the structure is the shape of a single tyre.

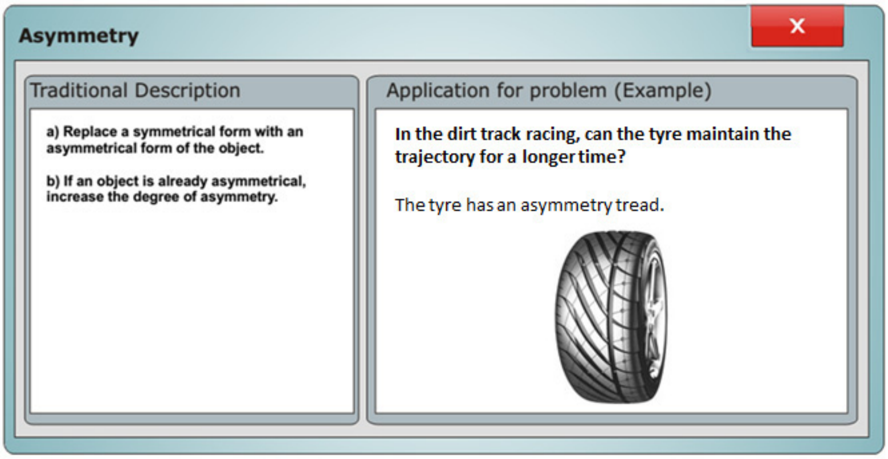

Fig. 3. Principle #4 Asymmetry (original form)

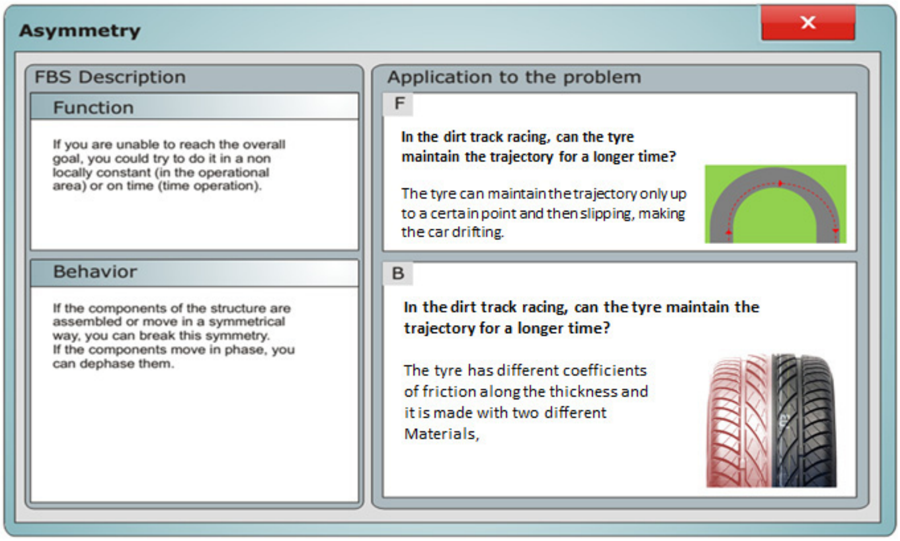

Fig. 4. Principle #4 Asymmetry (FBS form)

3.3. Principle #6 Universality

The principle # 6 Universality suggests to make a part or object perform multiple functions. From an FBS logic, this definition induces the user to change the structure for providing the new function (figure 5). The authors' proposal (see figure 6) is to force the user to reach a new goal and/or a new behavior also without any modification at structure level.

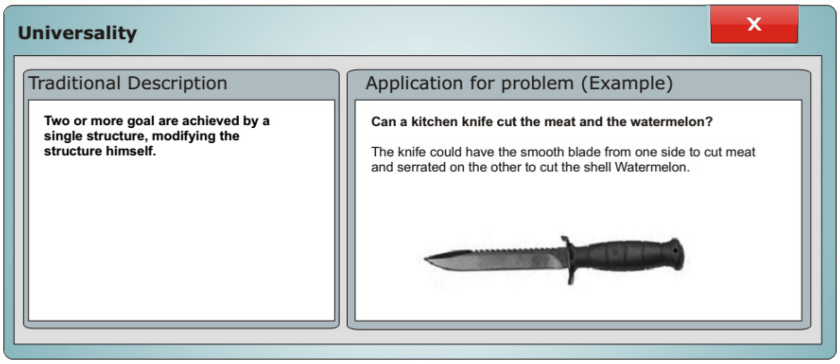

Fig. 5. Principle #6 Universality (original form)

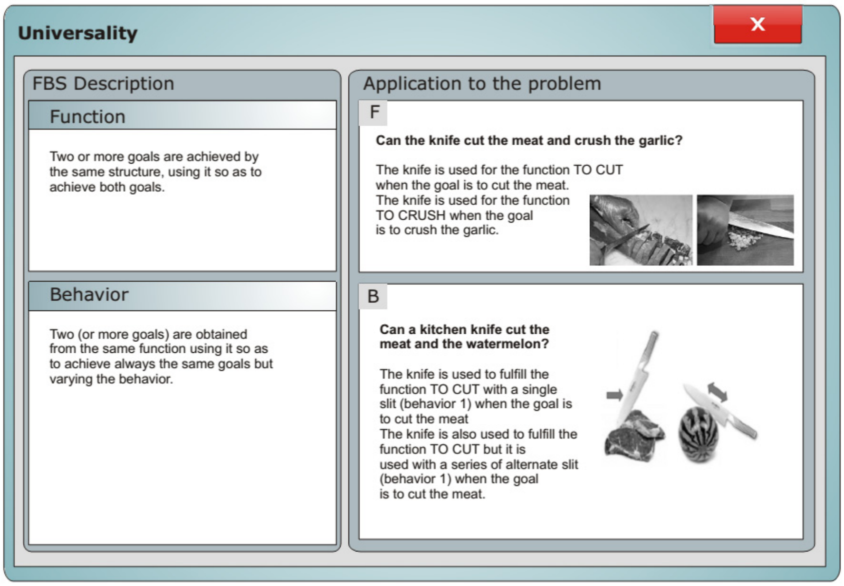

Fig. 6. Principle #6 Universality (FBS form)

4. Test

4.1. Participants

The new FBS version of the Inventive Principles has been tested by 19 Master degree students in Mechanical and Management Engineering. These students have been attending the academic course of "Methods and tools for product lifecycle" (i.e. PLM-Product Lifecycle Management). This course has been followed by two kinds of students: the first group does not have any TRIZ background, while the second received 60 lecture hours on TRIZ theory in the academic course of "Product and Process Innovation". Moreover, also academic researchers and engineers from the industrial field have tested the Inventive Principles proposed by the authors. They come from different areas:

- Academic researchers with any TRIZ experience: researchers and PhD students involved in product and process innovation from different points of view, engineering design, problem solving and CAE methods;
- Academic researchers without TRIZ background: researchers and PhD students belonging to the branch of mechanical engineering and biomechanics working with CAD and FEM analysis;
- Industrial researchers with a narrow TRIZ background: engineers working for mechanical and software industry.

4.2. Case studies

We have considered 4 industrial problems coming from different areas to demonstrate the independence of results from the domain.

- Refrigerated display unit: a supermarket refrigerator should allow the rapid and easy grabbing of products displayed, in order to favor the so-called "compulsive buying". At the same time, it has to preserve the cold temperature inside the refrigerator to save energy.
- Circular saw with adjustable angle: a circular saw has a guide system for inclined cuts with an angle of 45°. We want to add another cutting angle without losing the current option.
- Anodizing bath for aluminum: the process of anodizing aluminum involve by immersing aluminum plates in an acid solution, at high temperature, within suitable tanks. In order to increase the efficiency of the process, the tanks would require special lids for preserving the temperature of the bath, reducing productivity during insertion and ejection of plates.
- Nutcracker: the levers of a nutcracker can easily crack large shells such as nuts, but not small shells such as peanuts. If the distance between jaws is reduced, it will work with peanuts but not with nuts. in this case, we desire a nutcracker capable of breaking the shells of both fruits.

These problems have been formulated more or less explicitly in form of a contradiction. In this way, we try to prevent the use of inventive principles like a simple creativity tool (e.g. a trigger of creative ideas).

4.3. Test execution

The students were divided into two groups:

- group A (12 students)
- group B (7 students): with some students having a TRIZ background.
- group C - Professionals

The above mentioned problems have been assigned to users in 3 different sessions (see table 10) . In all sessions users could use only a set of inventive principles (#1 Segmentation, #3 Local quality, #4 Asymmetry, #6 Universality, #10 Prior action) but in different versions:

- "Classical session" used the original definition of Altshuller's inventive principles;
- "FBS session" used a new definition of the inventive principles based on FBS, without any training
- "FBS advanced session" used the same definitions of FBS sessions but after a theoretical explanation (1h).

Two questionnaires were given to all users in order to consider their own feedback.

Table 2. Text execution

Round	Group A-Students		Group B-Students		Group C-Professionals	
	Classical session	**FBS session**	**Classical session**	**FBS session**	**Classical session**	**FBS session**
1st		*-Refrigerated display unit -Circular saw*	*-Refrigerated display unit -Circular saw*		*-Refrigerated display unit Circular saw*	*-Refrigerated display unit -Circular saw*
2nd	*-Anodizing bath -Nutcracker*			*-Anodizing bath -Nutcracker*	*-Anodizing bath -Nutcracker*	*-Anodizing bath -Nutcracker*
	Questionnaire					
Training	**FBS Advanced Session**					
3rd	*-Anodizing bath -Nutcracker*		*-Refrigerated display unit -Circular saw*		*-Anodizing bath -Nutcracker*	
	Questionnaire					

4.4. Results and discussion

4.4.1. Evaluation criteria

This test allowed the evaluation of:

- The utility of FBS principles in comparison with traditional inventive principles;

- The influence of experience regarding the traditional inventive principles and the FBS theory.
- For the evaluation of the aforementioned aspects, the following criteria have been considered:
- Type of the solution obtained: solution directions or effectiveness of solutions;
- Number of solutions.

4.5. Questionnaire evaluation

The use of FBS principles allows us to obtain a solution space larger than the one obtained with the original principles. This is possible because the FBS based principles guide the user to work on different aspects of the system, using the suggestions acting on all 3 levels: function, behavior and structure. Both the tests conducted by students and professionals confirm the usefulness of the integration of FBS ontology. However, the main difference between the two groups of students derives from the personal background: in the first 2 sessions, experienced people obtained better results, but after the training on FBS based IP definitions all differences are quite insubstantial. Also, looking at the total number of solutions obtained through the use of the FBS principles we can observe that an introduction to the FBS theory is useful (if not necessary) to better exploit the FBS principles. The feedback questionnaires used at the end of the second round and at the end of the test confirm these results. Answers analysis shows:

- the FBS principles are better appreciated if they are introduced by a theoretical introduction; they are harder to use but they help to find a larger set of solutions;
- the FBS principles are generally perceived as less general but more accurate in finding solutions.
- the FBS principles force the user to work on function and behavior of a system, and they also require a more detailed analysis of operative zone and operative time;
- FBS principles generally lead to better quality solutions;
- Some users suggested to start using only the inventive principles in their traditional form; if results are not satisfying, we can use FBS principles in order to broaden the solutions' space.

4.5.1. Results

Analyzing the solutions, the following considerations can be made:

- Feedback from the questionnaires is clearly confirmed by results;
- the testers previous background has not been shown to be particularly relevant. The knowledge and experience in TRIZ and FBS has not proven significant results in terms of quality/quantity of found solutions;
- the new definition of FBS based principles allows the achievement of solutions which are not found with the traditional inventive principles. Results show that every time the user has to systematically face a function, behaviour or structure at least one new solution is found.
- Almost all inedited solutions found with the FBS based principles deal with functional and behavioral aspects, while no differences are found by comparing methods a structural level. For example: comparing solutions obtained by applying #1 Segmentation in the problem of the anodizing bath for aluminum we noted that both Altshuller's version and FBS/structure definition suggested to divide the lid introducing a series of floating balls; on the contrary, only the FBS behaviour version pushed to think about laying down the acid on the plate using a spray application, as shown in fig 7.

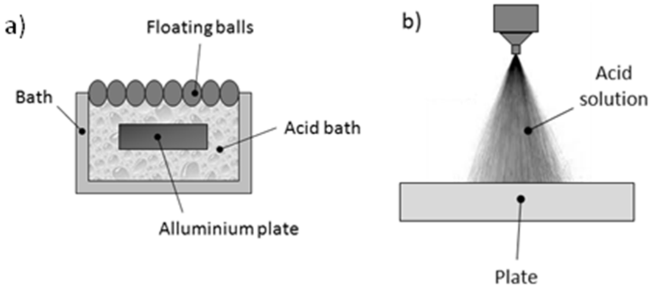

Fig. 7. Two example of solutions found by the application of the principle #1 Segmentation: (a) solution found by traditional form of segmentation; (b) solution found by FBS form of segmentation

The same observation can be done for the application of the principle #6 Universality on the problem of nutcracker, see figure 8. The traditional version of the principle only some small geometric changes of the structure are suggested. Modifying the behavior, the user is challenged to change the physical effect; this modification affects also the structure in a radical way. Moreover, the FBS principle based on the function suggests the changing of the function of the nutcracker into the function of "hammering" when it has to crack peanuts.

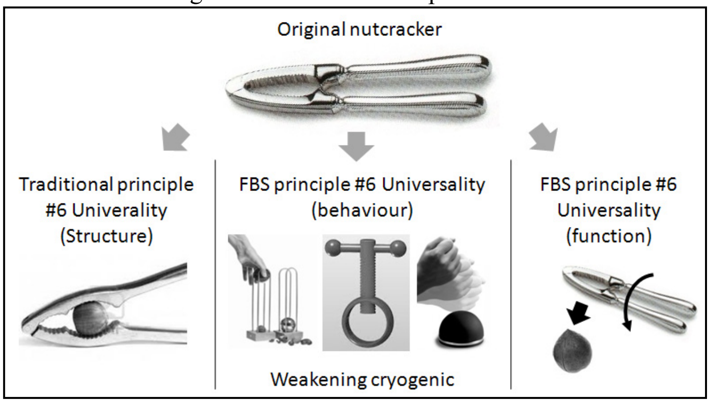

Fig. 8. Solutions found by traditional inventive principles and solutions by FBS principles

5. Conclusion

This paper presents a revision of the traditional TRIZ inventive principles through the FBS theory. All original Altshuller's definitions have been divided in three parts. Accordingly, they have been rewritten according to Function, Behaviour and Structure changes. Indeed, it has been observed that some Altshuller's definitions guide the user to modify only a part of the system, often only the structure, ignoring other important aspects like the goal (F) and the way this goal is achieved (B). This lack of becomes evident in people with little experience in TRIZ or in Design. On the contrary, other TRIZ principles leave too much freedom to the user, without clearly suggesting where to apply the given principle.

The aim of this work is to systematically take into account all the above mentioned aspects (F, B and S) and to specify the element to be considered. Therefore, leading to less ambiguity in the application of these principles. An exemplary test conducted both on students and professionals has clearly confirmed that, after a short training of 1 hour, FBS integration provides more and better solutions. About 30% of these solutions have not been reached reached by just applying classical inventive principles (with Altshuller's definition). This result has been further confirmed by two self-evaluation questionnaires filled by users during the test.

The main limit of this approach is that FBS based definitions of TRIZ principles seem more difficult than the original ones and they may not be effective without a previous training session.

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