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ORIGINAL PAPER

Influence of the type of idea-generation method on the creativity of solutions

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Abstract This paper studies the influence of the type of method, intuitive or logical, used for idea-generation on the final creative results. An experiment was developed in which 16 design teams were asked to solve a design problem using different creative methodologies. Seven of the teams used the SCAMPER intuitive method and another seven teams used the TRIZ logical method. Two groups acted as control. One of these control groups used brainstorming, and other group used no method. The creativity of the results, considered as the combination of novelty and utility, was evaluated using the Analytical Hierarchy Process. Results show the differences in these parameters in the different methods used in the experiment.

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1 Introduction

Market dynamics and the socio-economic environment mean that businesses must respond faster to change by improving their productivity and focussing on the permanent processes involved in the generation of innovative products. As a result, practices focused on creative product design have become key factors in business (Chulvi et al. 2011).

Creativity has been studied from various points of view and includes: factors that motivate product innovation (Francis and Bessant 2005; Tether 2003); the profiles of creative individuals (Nappier and Nilsson 2006; Torrance 1969); and creative problem solving (Rivera et al. 2010). As a result of these studies, numerous contributions have developed techniques for creativity and methods for evaluating the creativity of outcomes. At this point, several authors defend the classifications of the methods (Bahill et al. 1998; Shai et al. 2008; Shah et al. 2003) and studied why these different methods can produce different results (Reich et al. 2012).

Shah et al. (2003) classify the methods for idea-generation in two main groups: intuitive and logical. Intuitive methods are further sub-classified into the following groups: germinal [e.g. morphological analysis (Ritchey 1998)]; transformational [checklist (Thompson and Lordan 1999)]; SCAMPER (Eberle 1996); progressive [635 method (Rohrbach 1969)]; C-sketch (Shah et al. 2001); organisational [mind maps (Buzan and Buzan 1999)]; fishbone diagram (Kaoru 1990); and hybrid [Synectics (Gordon 1961)]. Logical methods are sub-classified in two categories: history-based methods [Pahl and Beitz (1996) and TRIZ (Altshuller 1984)] and analytical methods [SIT (Horowitz and Maimon 1997)].

Although there are many different creative techniques, there has been very little experimental research on product design with multidisciplinary work teams (Peeters et al. 2007; González-Cruz et al. 2008). Moreover, multidisciplinary work teams are said to increase creativity and enable combinations of ideas to be invented that broaden the innovative nature of solutions and which would not have been otherwise invented (Alves et al. 2007).

Numerous contributions have been made in the field of metrics for measuring creativity. Some of them are focused in the creativity of the individual, others are related to the creativity in the design process and the rest are referent to the product creativity. Chulvi et al. (2012b) present a compilation of methods for assessing product creativity, in which the most used parameters for measuring the creativity of a solution are identified as the novelty of the product and its level of utility. Besemer and O'Quin (1989) use the terms 'novelty and resolution'; Moss (1966) uses the terms 'unusualness and usefulness'; Sarkar and Chakrabarti (2008) refer to 'the indicators of creativity as novelty and usefulness'; Justel (2008) refers to 'novelty and utility'; while Shah et al. (2003) discuss 'novelty and quality'.

Previous work in creativity assessment has been carried out recently, like in case of López-Mesa et al. (2011), where the intuitive methods SCAMPER and brainstorming are compared in terms of creativity, and the work of Chulvi et al. (2012a), where creativity is compared when using the methods brainstorming, Functional Analysis, and SCAMPER. Despite the fact that in this last case, the differences between an intuitive technique—SCAMPER—and a logical one—Functional Analysis—that work lacks on terms of number of experiments, since only three solutions are presented for each method analysed, and conclusions are based in a comparison of a limited number of methods analysed.

The aim of this work is to identify the influence that the type of technique (intuitive or logical) has over the level of creativity of solutions generated by multidisciplinary teams during the product design process, where creativity has been defined as the combination of the novelty and the utility. Here, authors try to solve the lacks pointed in the last work, on the one hand by increasing the number of experiences of each kind of method analysed. On the other hand, a different logical method has been chosen in order to see whether similar conclusions are achieved when varying a method analysed. The intuitive method remains the same in order to establish a fix point in the comparison intuitive-logical, so both works could be compared avoiding the dispersion that could cause the change of all methods employed.

An experiment has been developed for this proposal in which multidisciplinary teams tackle a design problem using either intuitive or logical methods. The creativity of the outcomes was evaluated using the parameters novelty and utility—as commonly termed by the proposals referenced above. Novelty is understood as the unusual or unexpected quality of an idea, and utility is the nearness of a solution to the design specification.

2 Materials and methods

Generally, design models consider the creative and analytical processes involved in the design of a product. The creative process is associated with the generation of ideas that enable the synthesis of the design proposals; while the analytical process is related to the quality of the design through fulfillment of the design specification. Within the creative methods, the intuitive ones, which are divergent, are easy to learn and rely on internal inspiration for the idea-generation. In contrast, logical methods are convergent and are used to generate new design solutions from knowledge that was compiled by other people (Ogot and Okudan 2006).

The present work uses the SCAMPER intuitive method (Eberle 1996) and the TRIZ contradiction matrix logical method (Altshuller 1984) with the aim of making a comparison. The SCAMPER method, in which the current paradigm is dissected using a series of questions, generates new design ideas (Table 1).

The Theory of Inventive Problem Solving (TRIZ) comes from the idea that there are a set of universal principles of invention that form the basis for all innovative technological creations and that these principles can be identified and codified to make the inventive process more predictable. The evolution of TRIZ has lead to the development of tools for guiding the idea-generation process. The contradiction matrix has been used in the present study. The contradiction matrix is composed of 39 factors (engineering parameters) and helps identify technical contradictions—in which improving one factor worsens another factor. When a contradiction is identified, the matrix helps identify which of the 40 inventive principles must be considered to solve the selected contradiction. The inventive principles are a set of classical approaches for problem solving, and all inventions can be catalogued within these principles (Altshuller and Shulyak 1997).

2.1 Design of the experiment

A design experiment with 48 participants was planned. The participants were designers and engineers enrolled on a PhD design programme or experienced professional designers. The participants were divided into sixteen multidisciplinary teams of three members each: one

Table 1 SCAMPER methodology

SCAMPER
This is a series of questions that help to change an existing solution into a new solution. The starting point is the group of existing solutions, and the task is to generate new ideas by applying the questions below. The questions form part of the idea-generation process, and the most appropriate idea to solve the problem should be selected
Questions
What can be blended, mixed, or included?
What happens if the assembly is reversed?
What are the other ways to use it?
What can be substituted?
What can be combined?
What else is similar to the 'object to be designed'?
What ideas can be combined?
What can be made larger or smaller?
How can the colour, sound, smell, or touch be changed?
Which parts can be eliminated?
Which parts can be repeated, duplicated, triplicated, etc.?
Does its shape suggest other uses?
Can it be turned inside out?
Which parts can be longer or thicker?
Which parts should be added?
What other process of introduction/extraction could be used?
What else is like a classifier?
What if there is no 'product'?
How can it be made more compact or shorter?
Can it be turned upside down?
Does its shape suggest other uses?

designer, one mechanical or industrial engineer, and another designer or engineer.

Each team was asked to work in a 1-h session and apply one of several design methods to solve the same design problem. Seven teams used the SCAMPER intuitive method (A10–A16), while the other seven teams used the logical TRIZ contradiction matrix method (A1–A7). Two groups acted as control groups. One of these control groups was given no guidelines on how to solve the problem and was free to make its own decisions (A8). The other control group was asked to use the brainstorming method (Osborn 1953) (A9) that provides a reduced set of open directives that guide the design process without using a structured methodology. The general guidelines for each methodology can be seen on Table 2.

The problem was to design a new office table for alternating a standing and sitting position. This particular problem was chosen because it was one of the exercises analysed in Chulvi et al. (2012a), so comparison between works will be easier.

The tasks and timings for each session was organised in four steps:

- Step 1: Preparatory meeting with the participants for an explanation of the prescribed design method (10 min).
- Step 2: Solving the problem applying the prescribed design method (30 min).
- Step 3: Evaluation and selection of the best solution (10 min). Neither instructions nor a prescribed method were provided for this step.
- Step 4: Documentation (10 min). During the final 10 min, the participants were asked to prepare the following information: a detailed sketch with major dimensions and materials; description of how it works; explanation of how it solves the problems; identification of the beneficiaries; and why they should buy and use it.

2.2 Development of the experiment

The 48 participants were distributed in four working sessions of four teams of three members each. Each team was conducted to a separate room. Each session followed the previously explained steps.

In the step 1, the supervisor explains to each team the design method they are going to use. In the first three sessions, two teams use the SCAMPER and the other two teams use the TRIZ contradiction Matrix. In the fourth session, one team uses SCAMPER, one the TRIZ contradiction Matrix, one the brainstorming, and the last one uses no method.

Thirteen minutes are given to each team to problem solving. If the team announces that they have finished before this time, the supervisor encourages them to remain more time in this step. Once the time is over, the supervisor announces the end of the solving problem session and announces that they have 10 min remaining for selecting an option (step 3). Lastly, the teams have another 10 min for elaborating a sketch and/or explanation of the solution.

The sketches of the 16 solutions achieved can be seen in the Appendix 1 of supplementary material. Figure 1 shows four of the solutions achieved as an example.

2.3 Result's assessment

The activities performed to evaluate the solutions provided by the different teams are shown in Fig. 2. The sketches of the generated ideas are evaluated through the variables of novelty and utility using the AHP multi-criteria analysis technique (Saaty 1980). AHP is a widely used instrument of multi-criteria decision-making, which uses pairwise comparisons that allow verbal judgments by capturing both subjective and objective evaluation measures and enhances the precision of the results. Pairwise comparison refers to

Table 2 Brainstorming guidelines

Brainstorming
1. Now carry out a brainstorming exercise on the problem. The steps for a brainstorming exercise are as follows:
At the beginning of the session, write the statement of the problem so that it is clearly visible to everyone, as well as the four rules (see the last part of these instructions)
Ask the participants to raise their hand if they wish to communicate an idea. Have the facilitator write down the idea. Continue until the team has no more ideas
2. Ask the participants themselves to delete silly ideas which have only served as stepping stones and have them cluster the remaining ideas according to similarity
The four rules are:
(a) No criticism is allowed: try not to think of utility, importance, or feasibility, and no critical remarks can be made during brainstorming
(b) Freewheeling is welcomed: the wilder the ideas, the better
(c) Combination and improvement of ideas is sought: add to or build upon ideas of others
(d) Quantity is wanted: think of as many associations as possible

any process of comparing entities in pairs to judge which of each entity is preferred. The pairwise comparisons are used to obtain the exact ratio and to scale priorities by means of the identification and weighting of criteria.

The AHP analysis starts with the decomposition of the main objective in sub-criteria. Every criteria level would be divided in turn up to reaching an appropriate level of the detail, and to every sub-criterion, a weight will be assigned based on its importance, considering that the sum of the weights assigned to the sub-criteria in every level must be equal to 1. Therefore, as more sub-criteria levels are considered, less importance corresponds to each sub-criterion.

Creativity has been defined as the combination of novelty and utility. Novelty is understood as the unusual or unexpected of a proposed idea, and utility is the nearness of a solution to the design specification (Shah et al. 2003).

The first step is the formation of a panel of experts for the evaluation. The panel consists of two engineers, two industrial designers, and two users. The aim of this selection is to include all point of views for the object to be analysed: the engineer provides with the knowledge of new technologies and processes, the designer with the form and style, and the user with the current use of the object. Two experts of each class have been considered in order to promote internal discussion and agreement.

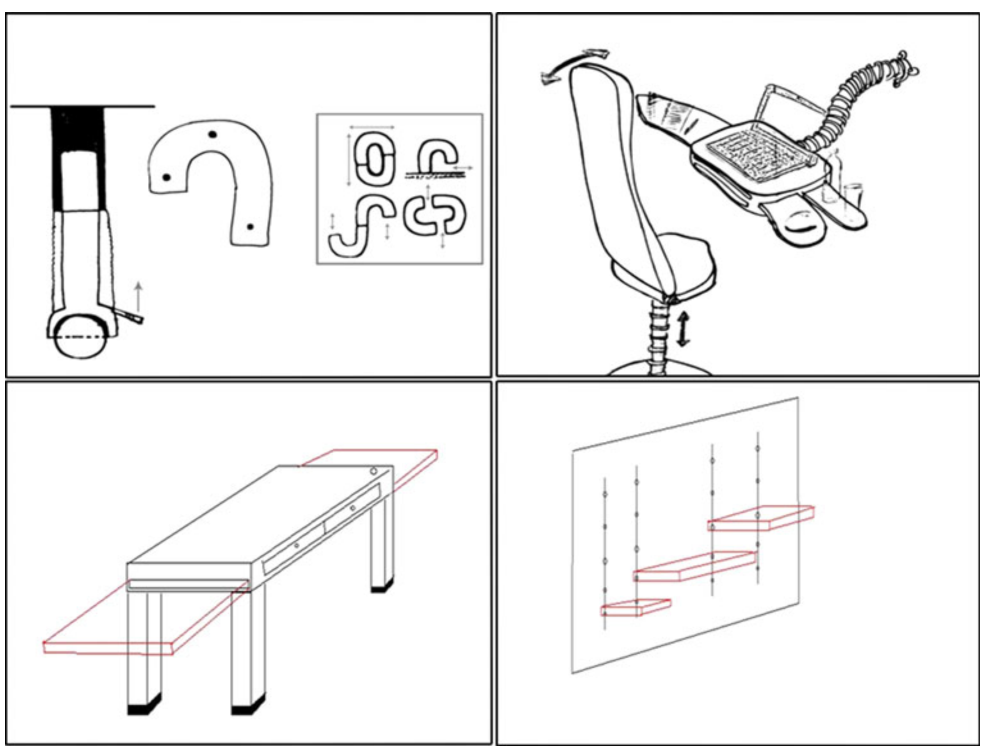

Fig. 1 Four solutions achieved by the design teams. All solutions are presented on Appendix 1 of supplementary material

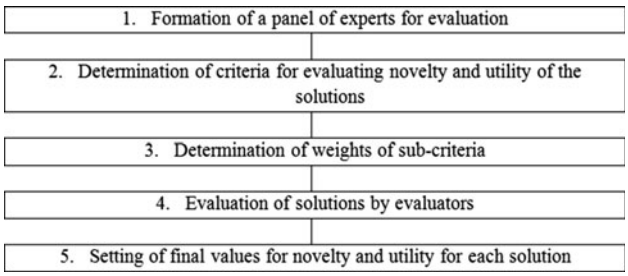

Fig. 2 Process for the evaluation of the creative product

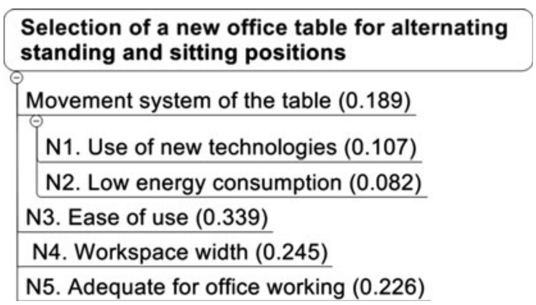

Fig. 3 Hierarchical diagram with the weights obtained for evaluating the novelty of the solutions

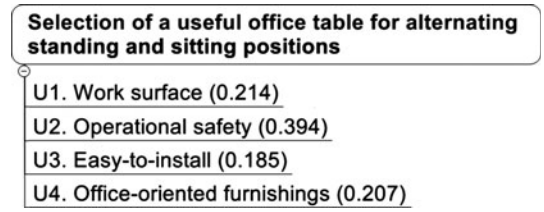

Fig. 4 Hierarchical diagram with the weights obtained for evaluating the utility of the solutions

The second step is the determination of criteria for evaluating novelty and utility of the solutions and is carried out from the hierarchical modelling of each variable (see Figs. 3 and 4). Four sub-criterions were defined for novelty that relates to the main characteristics of the problem: the movement system of the table (which is sub-divided into use of new technologies and low energy consumption); ease of use; workspace width; and suitability for office use. The utility sub-criterions were defined as work surface, operational safety, ease of installation, and suitability for offices—which are all characteristics associated with engineering and design.

In the third step, the weights of the sub-criteria have been determined. Each expert makes a pairwise comparison of the relative importance of the criteria. The results of all the experts are then weighted using the geometric average. Expert Choice (EC 2000) software was used as a support in the process of measurement and comparison. Expert Choice is a software to assist on calculations related to AHP, including to build models, make assessments in, synthesise, and perform sensitivity.

The fourth step, the evaluation of the solution, requires the experts to complete a questionnaire in which each sub-criterion for each solution is evaluated in a bi-polar scale of seven points. The full questionnaire is shown in the Appendix 2 of supplementary material, and an example question is shown on Table 3. The results of the questionnaires answered by the six experts are analysed using AHP with ratings. As in the case of sub-criterion weightings, the results of the preferences of the experts are integrated using the geometric average.

In the fifth and final step, the final weighted values of novelty and utility are calculated from the sub-criterion values achieved on step four and the weighting ratings calculated on step three. The final value of Creativity is calculated by combining the values of novelty and utility. Same importance has been given to both parameters, since it is suggested by several authors of metrics for creativity, as shown in the recompilation work of Chulvi et al. (2011).

3 Results

This section shows the results of the evaluation of novelty and utility, as calculated from the application of AHP to the responses from the experts. The weighted values for each sub-criterion of novelty and utility calculated in Step 3 are shown in Figs. 3 and 4.

In the analysis of the expert assessment of the 16 solutions (Appendix 1 of supplementary material) using AHP with ratings, it was considered that all steps within the seven-point bipolar scale are equal. The normalised values of the scale are shown in Table 4.

Table 5 shows the weighted values for each criterion and sub-criterion of each analysed solution from the expert assessment. Here, each N_i value corresponds to the mean of the expert's responses to the correspondent novelty sub-criteria, normalised as seen in Table 3. Equally, each U_j value corresponds to the correspondent utility sub-criteria. The correlation coefficient between the responses of the six experts is shown in Table 6. Experts 1 and 2 are the engineers, experts 3 and 4 are the designers, and experts 5 and 6 are users.

Table 7 shows the Anova statistical analysis for novelty results. Here it can be seen that the value of F is greater than the critical value of F, so it means that the design method has a significant effect on the value of novelty.

Table 3 Extract from the questionnaire for solution's evaluation

	Well-known technologies				Totally new technologies		
N1.—Regarding the *use of new technologies in the movement system* of a *NOVEL* table for alternating standing and sitting positions							
Alternative 1	0	0	0	0	0	0	0
Alternative 2	0	0	0	0	0	0	0
Alternative 3	0	0	0	0	0	0	0
Alternative 4	0	0	0	0	0	0	0
Alternative 5	0	0	0	0	0	0	0
Alternative 6	0	0	0	0	0	0	0
Alternative 7	0	0	0	0	0	0	0
Alternative 8	0	0	0	0	0	0	0
Alternative 9	0	0	0	0	0	0	0
Alternative 10	0	0	0	0	0	0	0
Alternative 11	0	0	0	0	0	0	0
Alternative 12	0	0	0	0	0	0	0
Alternative 13	0	0	0	0	0	0	0
Alternative 14	0	0	0	0	0	0	0
Alternative 15	0	0	0	0	0	0	0
Alternative 16	0	0	0	0	0	0	0

Table 8 shows the Anova statistical analysis for utility results. In this case, the value of F is higher than the critical value of F as well, so the design method has a significant effect on the value of utility too.

The graphical representation of the novelty and utility values can be seen in Fig. 5. Lastly, Fig. 6 graphically shows the result of the addition of the two terms, which, by definition, can be interpreted as the global creative value of the solutions (Chulvi et al. 2011).

4 Discussion

An analysis of the results requires discerning the variations in the level of novelty and utility in the design problem outcomes with respect to the type of design method used by each team. The ANOVAs analysis showed in Tables 7 and 8, for novelty and utility, respectively, will be used for that purpose.

The teams that used the SCAMPER intuitive technique (A10–A16) produced a novelty mean of 0.279, so they presents less novel results than teams using the TRIZ's contradiction matrix logical technique (A1–A7), which have a novelty mean of 0.404. It can also be seen that the outcomes of the logical technique of TRIZ are more novel than the outcome obtained using no method (A8), 0.247, but they are lower than when using brainstorming (A9), which has produced the better results in terms of novelty, 0.836. The outcomes of SCAMPER are slightly better than in case of no method is used.

On the other hand, the utility of the results achieved with the intuitive technique SCAMPER were only slightly better than those of the teams that used the logical technique TRIZ, with a mean value of 0.693 and 0.683, respectively. However, both of them present better results than the two control groups: Brainstorming was rated with 0.549 and no method with 0.479.

Designing without a specific method provided the worst outcomes, both in novelty and in utility. Brainstorming, which was the other control category, produced the most novel solution. However, the utility value for the brainstorming outcome was lower than when using other design method. These results coincide with previous experiments, where problems solved using brainstorming are highly novel but not very useful (Chulvi et al. 2012a). Moreover, the problems solved using SCAMPER achieve better outcomes in terms of utility than brainstorming (López-Mesa et al. 2011).

Considering that the proposals for assessing the creativity of a product involve the variables of novelty and utility (Chulvi et al. 2011), as has been defined previously in point 2.3, the analysis of these two variables acting together in each solution (Table 9) shows that brainstorming generally provides the most creative solutions. The solutions achieved using the TRIZ logical tool provide more creative outcomes than the intuitive SCAMPER method. As a final observation, any method provides better results than no method.

These findings produce some reflexions. Regarding to the differences between the structured, represented by TRIZ, and the intuitive methods, represented by

Table 4 Normalised ratings achieved with the AHP with ratings technique

	1	2	3	4	5	6	7	Geometric mean	Normalised rating
1	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.296	0.143
2	2.00	1.00	0.67	0.50	0.40	0.33	0.29	0.592	0.286
3	3.00	1.50	1.00	0.75	0.60	0.50	0.43	0.888	0.429
4	4.00	2.00	1.33	1.00	0.80	0.67	0.57	1.183	0.571
5	5.00	2.50	1.67	1.25	1.00	0.83	0.71	1.479	0.714
6	6.00	3.00	2.00	1.50	1.20	1.00	0.86	1.775	0.857
7	7.00	3.50	2.33	1.75	1.40	1.17	1.00	2.071	1.000

Table 5 Weighted values for each criteria and sub-criteria of the analysed solutions

Alternative	Weighted values										
	N1	N2	N3	N4	N5	Novelty	U1	U2	U3	U4	Utility
A1	0.031	0.018	0.129	0.128	0.124	0.430	0.178	0.310	0.163	0.187	0.838
A2	0.079	0.053	0.258	0.152	0.145	0.687	0.117	0.235	0.128	0.128	0.608
A3	0.036	0.021	0.153	0.047	0.054	0.311	0.082	0.319	0.150	0.133	0.684
A4	0.043	0.029	0.153	0.117	0.102	0.445	0.153	0.272	0.119	0.163	0.707
A5	0.056	0.037	0.097	0.088	0.070	0.348	0.133	0.263	0.119	0.148	0.662
A6	0.059	0.023	0.097	0.058	0.065	0.302	0.102	0.263	0.101	0.163	0.629
A7	0.033	0.035	0.121	0.058	0.054	0.302	0.092	0.263	0.132	0.168	0.654
A8	0.025	0.023	0.081	0.053	0.065	0.247	0.092	0.188	0.101	0.099	0.479
A9	0.102	0.041	0.291	0.187	0.215	0.836	0.102	0.225	0.123	0.099	0.549
A10	0.069	0.020	0.153	0.053	0.070	0.364	0.082	0.253	0.137	0.138	0.610
A11	0.028	0.023	0.081	0.058	0.054	0.244	0.143	0.310	0.150	0.128	0.730
A12	0.036	0.023	0.073	0.053	0.048	0.233	0.138	0.272	0.123	0.128	0.661
A13	0.041	0.033	0.113	0.058	0.075	0.321	0.143	0.328	0.132	0.158	0.761
A14	0.023	0.018	0.073	0.047	0.043	0.203	0.092	0.328	0.154	0.148	0.722
A15	0.025	0.020	0.097	0.053	0.059	0.254	0.097	0.310	0.141	0.158	0.705
A16	0.025	0.033	0.105	0.076	0.092	0.331	0.117	0.263	0.159	0.128	0.667

Table 6 Correlation coefficient between the responses of the experts

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Expert 1	1.00					
Expert 2	0.59	1.00				
Expert 3	0.54	0.64	1.00			
Expert 4	0.63	0.59	0.80	1.00		
Expert 5	0.41	0.58	0.62	0.55	1.00	
Expert 6	0.57	0.63	0.86	0.76	0.65	1.00

Table 7 ANOVA analysis for novelty

	Items	Mean	Variance	
TRIZ	7	0.404	0.019	
SCAMPER	7	0.279	0.004	
No method	1	0.247	–	
Brainstorming	1	0.836	–	
F				8.748
Critical value for F				3.490

Table 8 ANOVA analysis for utility

	Items	Mean	Variance	
TRIZ	7	0.683	0.006	
SCAMPER	7	0.693	0.003	
No method	1	0.479	–	
Brainstorming	1	0.549	–	
F				4.488
Critical value for F				3.490

SCAMPER, it has been found that structured methods provides with better novel outcomes than intuitive ones, and no difference has been found in case of utility. Nonetheless, the brainstorming outcome, which was selectioned as a control one, presents the best outcome in novelty, and its utility is lower than both TRIZ and brainstorming. Moreover, the brainstorming method can be considered in the group of the intuitive ones. In fact, Shah et al. (2003) considers it in that group, with high level of intuitiveness. Since only one experiment has been made using brainstorming, this result is not conclusive, despite the fact that this result coincide with the conclusions of previous work (Chulvi et al. 2012a).

Differences between intuitive and structured results can be caused due to time devoted to each of the activity phases: problem understanding and problem solving (Chakrabarti 2003). In this study, Chakrabarti shows how the intuitive methods, like brainstorming, devote more time

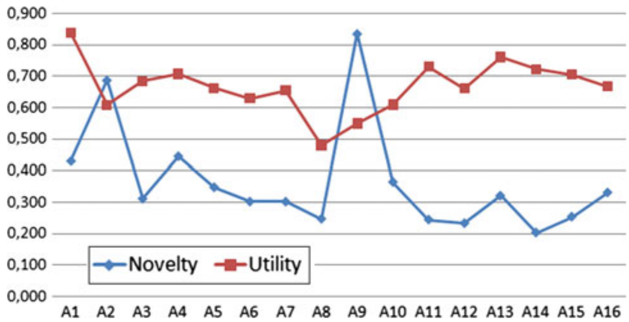

Fig. 5 Weighted values of novelty and utility

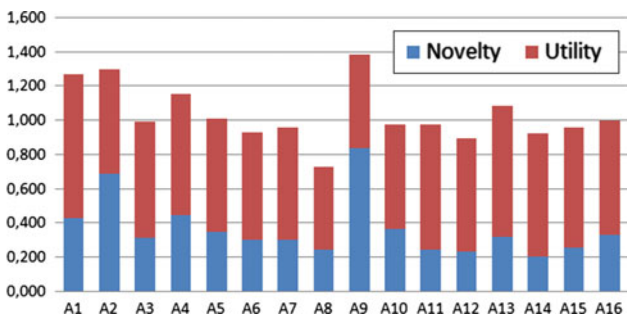

Fig. 6 Added values of novelty and utility

Table 9 Creativity as the combined value of novelty and utility

	Novelty	Utility	Creativity
TRIZ	0.404	0.683	1.087
SCAMPER	0.279	0.693	0.972
No method	0.247	0.479	0.726
Brainstorming	0.836	0.549	1.385

to the problem-solving phase, and how the structured or logical methods, like Functional Analysis, devote more time to problem-understanding phase. More research in this direction is needed to advance the adequate conclusions regarding to this aspect.

Another cause of difference can be the property of convergent–divergent of the methods where structured methods are considered convergent, as they drive to more knowledge accumulation in the early phases (problem-understanding phase), while the intuitive ones are divergent since they start to generating concepts very soon, as they spent less time in the problem-understanding phase. This idea of the effect of working with knowledge and concepts and transforming them is defend in Reich work on the C–K theory (Reich et al. 2012).

5 Conclusions

In the present work, it has been experimentally demonstrated that:

The TRIZ logical method obtained solutions that were more novel than using the SCAMPER intuitive method.

- Both TRIZ and SCAMPER produced solutions of similar usefulness.
- The intuitive method brainstorming produced a solution with more novelty than TRIZ and SCAMPER, but its solution was rated with less usefulness than TRIZ and SCAMPER.
- Using no method produced less novel and useful solutions than any formal method.

Also, as creativity as been defined as the combination of novelty and utility, it can also be said from present results that:

- Brainstorming produce the best creative outcomes, TRIZ produces better creative outcomes than SCAMPER, and using no method provides with the worst creative outcomes.

Thus, regarding to the two methodologies compared as a representation of intuitive and logical methods, which are SCAMPER and TRIZ, it may been concluded that logical methods provide with better creative outcomes because of the better novelty achieved, but the control experiment by using brainstorming refutes that statement. As only one design test was made using brainstorming, more research is needed in this aspect.

This experiment complements and expands the previous related work (López-Mesa et al. 2011; Chulvi et al. 2012a) by adding more experiences and considering more different methods of each class in order to give more consistency to previous conclusions. Anyway, it is necessary to compare more different methods of both groups, intuitive, and logical, in order to provide more solidity to the comparison between these kinds of methods and how affect the way that they manage the knowledge and concepts, and the times devoted to design phases to the level of creativity of the outcomes.

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