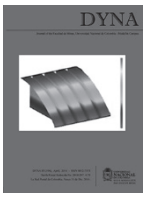
UNIVERSIDAD NACIONAL DE COLOMBIA
SEDE MEDELLÍN
FACULTAD DE MINAS



DYNA
http://dyna.medellin.unal.edu.co/

The influence of design methodology on a designer's emotional parameters and on design results

Vicente Chulvi [a] & Mª Carmen González-Cruz [b]

[a] *Departamento de Ingeniería Mecánica y Construcción, Universitat Jaume I., Castellón, Spain. chulvi@emc.uji.es*
[b] *Dep. de Projectes d'Enginyeria, Universitat Politècnica de València, Valencia, Spain. mcgonzal@dpi.upv.es*

Received: March 24th, 2015. Received in revised form: August 15th, 2015. Accepted: January 15th, 2016.

Abstract
This paper presents the results of an experiment carried out on 21 subjects, all of whom had an engineering background, with the aim of determining the influence of the designer's attitude on the design process and on the finished design. The participants were asked to solve a range of design problems by employing different methods while their emotional response parameters were being registered by a non-invasive neuroheadset. The recorded data was used firstly to compare the different reactions of the subjects when using different design methods. A second analysis was carried out to determine whether the variations in the emotional parameters bore any direct relation to the creativity of the outcomes. The results obtained indicate a relation between emotional parameters, individuals and the design method used. However, there does not appear to be any direct association between emotional parameters and the creativity of the results.

Keywords: Conceptual design; creativity; emotional response; design methodology.

Influencia de la metodología de diseño en los parámetros emocionales del diseñador y en los resultados del diseño

Resumen
El presente artículo presenta el resultado de un experimento llevado a cabo sobre 21 individuos, todos ellos con perfil de ingeniería, con el objeto de determinar la influencia de la actitud del diseñador sobre el proceso de diseño y sobre los resultados finales. A los participantes se les pidió que resolvieran una serie de problemas de diseño utilizando diferentes métodos, mientras que su respuesta emocional fue registrada a través de un casco encefalográfico no invasivo. Los datos registrados fueron utilizados, en primer lugar, para comparar las diferentes reacciones de los individuos al utilizar diferentes metodologías de diseño. Un segundo análisis se he llevado a cabo para determinar si las variaciones en los parámetros emocionales tienen una relación directa con los resultados de creatividad. Los resultados obtenidos apuntan a una relación entreindividuo, parámetros emocionales y método de diseño utilizado. Sin embargo, no parece apreciarse una asociación directa entre parámetros emocionales y creatividad de los resultados.

Palabras clave: Diseño conceptual; creatividad; respuesta emocional; metodología de diseño.

1. Introduction

Designers are directly influenced by many different factors, all of which affect the designs they produce [1]; these include: the environment [2, 3], level of education [4- 6], age [7], personal and cultural values [8], perceptions [9] and even the emotions experienced during the design phase [10] and the way in which these emotions, also known as emotional intelligence [11], are dealt with. It can therefore be inferred that all these variables imply that designers experience different mental processes and have different emotional responses to each design problem, which can affect individual designs.

Creativity is one of the most sought-after results when designing products. Many different definitions of creativity exist in the literature and many of these share common elements [12-15]. One of the most generally accepted definitions maintains that: "Creativity happens through a process by which a subject uses his skills to generate ideas, solutions and products that turn out to be novel and useful". This implies that the creativity of a product is closely tied to the individual and to the design process.

Therefore, on the one hand we can find a large number of studies that focus on defining the individual's creative potential, or creative intelligence, such as those found in [16-20], among others. On the other hand, many authors focus on developing techniques, tools or methods aimed at increasing creativity and innovation in the design process itself [21-23]. Lastly, there are those who prefer to evaluate creativity by its outcomes [15,24,25].

In spite of the fact that responsibility for the results has been divided up between the individual and the process employed, it is not difficult to envisage that a number of individuals will achieve very different results while using the same process or design method, as has been found in previous studies [26,27]. This leads us to accept that different individuals will react in different ways to the stimuli produced by a certain design method. In fact, there are studies that defend different styles of thinking and different reactions during the design process, such as classifying thinking into convergent or divergent, as in [28], or grouping individuals as adaptive or innovative, as in [29], among others.

This paper presents the results of an experiment carried out on 21 individuals who had been asked to find a solution to a variety of design problems by employing different methods while their emotional response parameters were recorded by a non-invasive neuroheadset. The data thus obtained was then used to compare the different individual reactions when using different design methods. A second analysis was also carried out to determine whether the variations in the emotional parameters had a direct relationship with the creativity of the solutions. The aim of the study is to find out if the method used to design affects emotions in the designer, and if the emotions of the designer in his work affect the creativity of the results. As a result, the methods that are more conducive to developing creative solutions could be identified.

2. Tools and Methods

2.1. Methodology

Twenty-one students taking a master's degree in different branches of engineering took part in the experiment. A preliminary session was held to brief them collectively on the design methods they would be asked to use in the tests. Each of the participants was then asked individually to find a creative solution to three design problems, one from each of the design methods used in the tests (Table 1). The third problem was specially selected for its limitations as regards its potential for innovation. This was done in order to determine whether the fact of facing a difficult problem with hidden challenges would also cause variations in the subjects' emotional parameters. The problems, methods and work order were varied to include all the possible combinations (as will be shown in Table 4).

During the entire problem-solving process the subjects wore an EmotivEpoc headset that recorded their emotional parameters. They were allowed 30 minutes to solve each of the problems, after which they were advised that they had to hand in their solution in the form of a sketch, scheme or notes, for which they were allowed an additional 5 minutes.

Table 1.
Statements of the problems to be solved

Problem 1: Design an office desk that can be easily raised or lowered to allow people to work either seated or standing.
Problem 2: Design a suitcase whose size can be altered according to the volume of luggage it contains. The case should be light and easy to use and carry.
Problem 3: Design a rectangular table for use in a practice laboratory including electric plugs for different types of apparatus. Remember that wires must be kept wound up and out of sight so as not to interfere with the work area.

Source: The authors

2.2. Design methods

Three different types of method were chosen for use in solving the design problems, in accordance with the classification proposed in Shah et al. [13]: one was logical, one intuitive and in one they were given carte blanche. The Su-Fields tool from TRIZ [30] was selected for use in the logical method, and SCAMPER [31] for the intuitive method. In one of the exercises the subjects were not given any instructions and were allowed to solve the problem any way they chose.

2.2.1. TRIZ (Su-Fields)

This tool consists of a functional analysis of the problem, which is schematized into substances (physical elements) and fields (function-executing modes), as shown in Fig. 1. The idea is to find all the aspects that can be improved and then act on each aspect individually. Five rules are proposed which are to be applied to each problem:

S2 being a substance that acts on S1 via field F1:

Rule 1 says that substance S2 must be replaced by a new substance S3, which generates a new field F2 over S1.

Rule 2 says that a new substance S3 must be added to act over S2 via a new field F2.

Rule 3 says that that a new substance S3 must be added to act over S1 via a new field F2.

Rule 4 says that that a new substance S3, between S1 and S2, must be added to act over S1 and S2 via a new field F2.

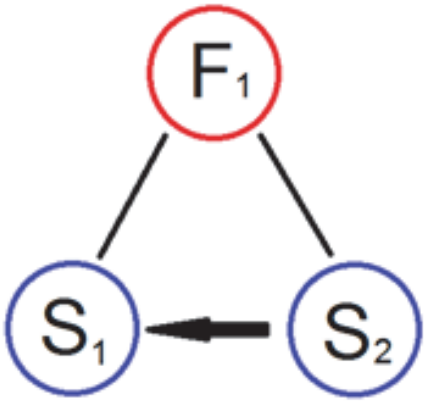


Figure 1. Basic scheme of Su-Field modelling.
Source: The authors

Figure 2. Emotiv EPOC neuroheadset.
Source: The authors

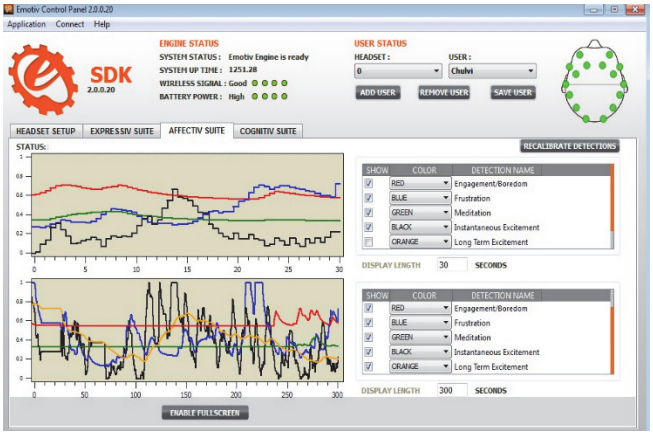


Figure 3. Interface of the affective suite of the Emotiv EPOC Software Development Kit.
Source: The authors

Rule 5 says that that a substance S3, not related to S1 and S2, must be added in such a way that the newly generated field F2 acts over S1 and S2.

2.2.2. SCAMPER

This method consists of applying the following questions to the design problem:

- What can I Substitute?
- What can I Combine?
- What can I Adapt?
- What can I Magnify?
- Can I Propose other uses?
- What can I Eliminate?
- Can I Reorder or invert any part?

2.3. Emotive Epoc

Throughout the tests, participants wore the Emotiv Epoc non-invasive neuroheadset (Fig.2), which can measure cerebral electrical activity through the scalp. Four emotional variables were directly recorded by the software provided by the manufacturer, consisting of: frustration, meditation, interest and excitement (Fig.3).

2.4. Creativity assessment

Creativity was assessed by a consensus of two specialists in the field (the authors of this work) using the metric developed by J. Moss [24], which estimates creativity by a combination of two parameters: a product's usefulness and unusualness. The former is determined by assessing the degree to which the product satisfies the requirements of a good standard (or teacher's) solution. Creativity is assessed on a scale of zero to three; zero being a design that does not achieve the set requirements, and three being considered better than the teacher's solution

The degree of unusualness is determined by the inverse probability of the idea arising within a homogeneous group of solutions, i.e. by comparing the product with the other products created as solutions to the same problem. This parameter is also assessed on a scale of zero to three; zero for a commonplace solution and three for showing exceptional originality. The overall creativity of the product is then scored by multiplying the above two parameters. The application of Moss's metric can be seen in Table 2.

Table 2.
Moss's scale

		The solution does not satisfy the functional requirements	**The solution barely satisfies the requirements**	**The solution is as good as the standard solution**	**The solution is better than the standard solution**
		0	1	2	3
>10% of similar ideas	0	0	0	0	0
6-10% of similar ideas	1	0	1	2	3
1-5% of similar ideas	2	0	2	4	6
<1% of similar ideas	3	0	3	6	9

Source: [24]

Table 3.
Extract from the compilation of brain parameters

P 1				
Time(s)	**Frustration**	**Meditation**	**Excitement**	**Interest**
781.12	70	33	45	56
782.38	67	33	44	55
783.25	65	33	46	55
784.38	63	33	38	55
785.13	62	33	48	55
786.25	61	33	52	55
787.13	60	33	55	57
788.13	59	34	58	62
788.63	59	35	56	67
789.76	58	36	53	72
790.63	56	36	48	79
792.22	53	36	44	82
793.25	51	37	34	81
794.25	49	38	24	79
795.25	47	38	24	79
796.13	46	39	22	79
797.38	45	38	21	81
798.13	44	39	26	81
799.38	43	38	27	78
800.38	43	37	27	74

Source: The authors

3. Results

A total of 21 solutions were obtained for each of the three design problems. Some examples are given in Fig. 4 together with data on the brain parameters of the participants. Table 3 contains an extract of the parameters of one of the subjects, where frustration, meditation, excitement and interest are judged on a scale of 1-100 where 100 is the max level of an emotion. Unfortunately, data on the parameters from five participants had to be left out of the analysis due to defective contacts and interference. The results and the analysis given below were therefore carried out on the valid data from 16 participants. As it can be observed in Table 3, the values of the parameters show a variation over time tracked. Statistical means are used for data analysis in order to compare the design methods.

As has been described in Section 2.4, the designs were judged by consensus between two specialists using Moss's metric (1966) to obtain values for usefulness, unusualness and creativity. Table 4 gives a summary of the results obtained, the emotion averages over time obtained by direct measurement during the tests, and the values awarded by the judges for usefulness, unusualness and creativity.

Table 4.
Summary of the results obtained

Sub.	Prob.	Method	Frustration	Meditation	Excitement	Interest	Unusualness	Utility	Creativity
1	1	SCAMPER	52.06	37.54	32.35	59.55	1	2	2
	2	TRIZ	67.65	33.28	64.08	56.23	2	1	2
	3	No method	67.66	35.02	41.93	70.27	0	2	0
2	1	SCAMPER	49.32	36.77	67.73	63.37	0	2	0
	2	TRIZ	60.12	34.52	19.48	58.25	0	2	0
	3	No method	59.53	29.80	69.19	50.63	0	2	0
3	1	SCAMPER	44.72	36.92	28.00	65.34	0	2	0
	2	TRIZ	46.96	35.61	35.61	59.77	3	2	6
	3	No method	42.42	27.76	35.41	51.09	0	2	0
4	1	SCAMPER	21.68	33.00	20.32	55.00	0	2	0
	2	TRIZ	78.56	32.95	54.14	55.15	2	1	2
	3	No method	33.72	23.64	42.89	46.09	0	2	0
5	1	SCAMPER	54.60	33.10	33.99	61.28	1	1	1
	2	TRIZ	5.10	34.28	29.76	56.16	2	1	2
	3	No method	5.67	31.47	37.71	68.87	0	2	0
6	1	SCAMPER	60.60	38.24	29.29	59.62	1	0	0
	2	TRIZ	66.52	33.49	37.86	54.21	1	1	1
	3	No method	59.10	30.29	32.89	64.13	0	2	0
7	1	SCAMPER	62.52	39.31	33.58	62.54	1	0	0
	2	TRIZ	66.40	33.14	36.13	56.61	1	2	2
	3	No method	62.70	33.86	25.21	69.95	0	2	0
8	1	TRIZ	44.67	35.53	33.12	67.65	0	2	0
	2	No method	41.61	36.22	27.74	66.48	0	2	0
	3	SCAMPER	39.11	38.70	23.10	65.83	0	2	0
9	1	TRIZ	61.20	36.68	38.60	62.89	0	2	0
	2	No method	49.48	38.23	39.80	70.97	1	2	2
	3	SCAMPER	47.53	40.72	79.86	64.84	0	2	0
10	1	TRIZ	48.47	35.29	42.90	67.18	3	2	6
	2	No method	39.14	33.22	33.33	69.28	0	2	0
	3	SCAMPER	36.23	37.48	49.88	68.52	0	2	0
11	1	TRIZ	47.06	34.11	68.53	64.43	0	2	0
	2	No method	42.87	37.18	39.80	61.47	0	2	0
	3	SCAMPER	45.24	40.24	52.51	68.11	0	2	0
12	1	TRIZ	52.29	36.25	34.67	64.22	0	2	0
	2	No method	31.93	34.27	32.37	64.20	0	2	0
	3	SCAMPER	21.06	36.37	39.74	61.84	2	2	4
13	1	No method	46.22	33.82	33.83	71.52	0	1	0
	2	SCAMPER	50.70	30.17	38.33	55.04	0	2	0
	3	TRIZ	35.25	32.61	27.05	53.11	0	2	0
14	1	No method	41.86	34.32	35.53	68.35	0	1	0
	2	SCAMPER	46.92	32.08	16.67	57.59	0	2	0
	3	TRIZ	47.88	35.92	37.95	54.01	2	2	4
15	1	No method	38.49	33.91	26.70	72.07	0	1	0
	2	SCAMPER	46.43	32.03	33.30	57.04	2	1	2
	3	TRIZ	47.71	35…05	28.18	53.29	0	2	0
16	1	No method	47.34	33.58	37.89	69.32	2	1	2
	2	SCAMPER	47.23	33.36	30.79	54.49	2	1	2
	3	TRIZ	39.69	32.62	30.32	52.75	0	2	0

Source: The authors

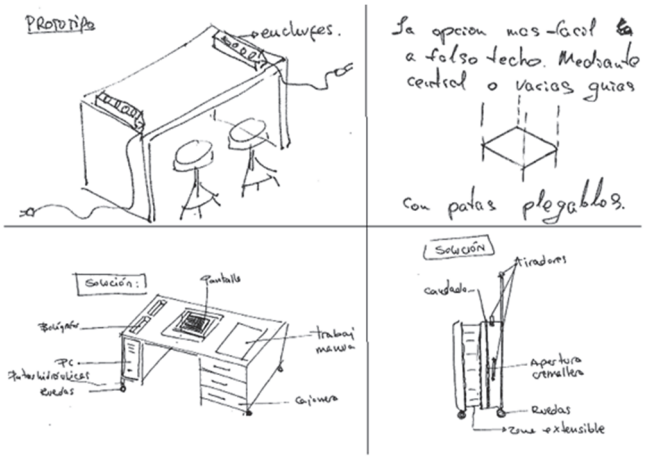


Figure 4. Some of the solutions provided by the students.
Source: The authors

3.1. Influence of design method on the emotive response

ANOVA was utilized in the first analysis to discover whether the emotional variables (frustration, meditation, excitement and interest) were influenced by the method used and the problem to be solved, or whether the variations in these variables could be attributed to individual subjects, regardless of the problem to be solved or the method employed to solve it. The results of this analysis are given in Tables 5, 6 and 7. In Table 5 it can be seen that method appears to have an influence on meditation and interest, while the variations in frustration and excitement are non-significant. Table 6 shows that the type of problem to be solved does not affect any of the emotional parameters and in Table 7 it can be seen that the individual seems to bear a certain relationship with frustration, but has no significant effect on the other variables.

However, as both method and individual do seem to influence the emotional response, a joint statistical analysis was performed using Tukey's proof [32] to find out whether there was any interaction between these elements. The results are given in Table 8, where it can be seen that there does not appear to be a significant difference between method and subject. However, after eliminating the noise that a significant factor can cause on another, certain aspects showed a significance that was not previously apparent. In this case, method was seen to significantly affect the emotional responses of frustration, meditation and interest, while the individual had an effect on frustration and meditation.

Table 5.
Influence of method on emotional response.

Emotional Response	F-critic = 3.20
Frustration	F(2, 45)=2.69, p=0.079
Meditation	F(2, 45)=**4.45**, p=0.017
Excitement	F(2, 45)=0.06, p=0.943
Interest	F(2, 45)=**3.97**, p=0.025

Source: The authors

Table 6.
Influence of problem on emotional response.

Emotional Response	F-critic = 3.20
Frustration	F(2, 45)=1.18, p=0.317
Meditation	F(2, 45)=1.42, p=0.252
Excitement	F(2, 45)=0.64, p=0.534
Interest	F(2, 45)=3.07, p=0.056

Source: The authors

Table 7.
Influence of the individual on emotional response

Emotional Response	F-critic = 1.99
Frustration	F(15, 32)=**2.36**, p=0.020
Meditation	F(15, 32)=1.60, p=0.130
Excitement	F(15, 32)=1.45, p=0.182
Interest	F(15, 32)=1.18, p=0.333

Source: The authors

Table 8.
Effect of interaction between method and individual on emotional response

Emotional Response			F-critic
Frustration	Method	F(2,29)=**4.29**, p=0.023	3.33
	Subject	F(15,29)=**2.82**, p=0.008	2.03
	Interaction	F(1,29)=0.57, p=0.455	4.18
Meditation	Method	F(2,29)=**5.94**, p=0.007	3.33
	Subject	F(15,29)=**2.06**, p=0.047	2.03
	Interaction	F(1,29)=0.27, p=0.609	4.18
Excitement	Method	F(2,29)=0.06, p=0.938	3.33
	Subject	F(15,29)=1.32, p=0.250	2.03
	Interaction	F(1,29)=0.02, p=0.898	4.18
Interest	Method	F(2,29)=**4.49**, p=0.020	3.33
	Subject	F(15,29)=1.42, p=0.202	2.03
	Interaction	F(1,29)=0.50, p=0.485	4.18

Source: The authors

3.2. Influence of emotive response on the creativity of the outcomes

As seen in Table 4, we now had the values of unusualness, usefulness and creativity for each of the designs obtained. As in the preceding section, here it was advisable to check whether the method used, the problem to be solved or the individual subjects had influenced these results. Tables 9, 10 and 11 present the results of the ANOVA analysis of these three factors on the unusualness, usefulness and creativity of the solutions. From these tables it can be seen that the method used to solve the problem does have an influence on unusualness and creativity, that the problem to be solved influences usefulness, and that the individual has no influence on any of these three aspects.

Table 9.
Influence of method on unusualness, usefulness and creativity

	F-critic = 3.20
Unusualness	F(2, 45)=**3.48**, p=0.039
Usefulness	F(2, 45)=0.61, p=0.550
Creativity	F(2, 45)=**3.40**, p=0.042

Source: The authors

Table 10.
Influence of problem on unusualness, usefulness and creativity

	F-critic = 3.20
Unusualness	F(2, 45)=2.93, p=0.064
Usefulness	F(2, 45)=**5.05**, p=0.010
Creativity	F(2, 45)=1.27, p=0.292

Source: The authors

Table 11.
Influence of individual on unusualness, usefulness and creativity

	F-critic = 1.99
Unusualness	F(15, 32)=0.56, p=0.887
Usefulness	F(15, 32)=1.14, p=0.365
Creativity	F(15, 32)=0.50, p=0.922

Source: The authors

Table 12.
Pearson coefficients of the interaction of emotional response with creative factors

	Unusualness
Frustration	r=0.205, n=47, p=5.05e-32
Meditation	r=0.074, n=47, p=2.14e-50
Excitement	r=0.059, n=47, p=2.72e-24
Interest	r=-0.171, n=47, p=5.03e-47
	Usefulness
Frustration	r=-0.339, n=47, p=5.25e-31
Meditation	r=-0.078, n=47, p=1.40e-49
Excitement	r=0.072, n=47, p=9.15e-24
Interest	r=0.011, n=47, p=2.89e-47
	Creativity
Frustration	r=0.039, n=47, p=1.30e-31
Meditation	r=0.087, n=47, p=2.92e-49
Excitement	r=0.056, n=47, p=3.80e-24
Interest	r=-0.100, n=47, p=1.21e-46

Source: The authors

Pearson's correlation coefficient was used to determine whether emotional response had any influence on the creativity of the results. The values of the coefficients thus obtained are given in Table 12, in which it can be seen that all the values are quite low, except in the case of frustration, which only showed low values for unusualness and usefulness. This would seem to indicate that a direct correlation cannot be established between the designer's emotional response during the design process and the creativity of the results obtained.

4. Discussion

This paper deals primarily with an analysis of aspects of the design process that could somehow influence the subject's emotional response. One of the aspects considered was the problem to be solved, which was found to be non-significant (see Table 6) in spite of the fact that a purposely difficult design problem with little room for innovation was included in the experimental design.

Another aspect considered was the method used by the subjects to develop their designs; in this case, significant variations were found in the emotional parameters meditation and interest (see Table 5). In other words, the method selected affects the way in which the designer approaches the problem and, according to its difficulty, requires varying amounts of interest and meditation, or concentration.

The third factor considered was the individual subject (as regards level of education, culture and personal characteristics) and his special reaction to the design process. Here we found that the subject causes significant variations as regards frustration level (Table 7). This means his ability to find the right solution while working under pressure will largely depend on his personal characteristics and not on the method used or the problem to be solved.

None of the factors considered in the study was found to significantly affect the emotional parameter excitement.

We also studied whether the subject's emotional variables during the design process had any influence on the creativity of the results. First, we looked at the effect of the three factors mentioned above on creativity. As expected, we found method to be significant, in agreement with previous studies in this field that have shown that the design method affects creativity and its associated parameters [26, 27, 33]. However, we were somewhat surprised to find that the problem had a significant effect on the usefulness parameter; this may possibly have been due to including Problem 3 (which gave little room for innovation) in the tests, forcing the subjects to resort to standard, well proven solutions. As can be seen in Table 4, all the solutions to Problem 3 were given a usefulness score of 2 by the judges. Dunnett's post hoc analysis subsequently revealed that Problem 3 showed significant deviation (see Table 13).

As regards the relationship between emotional parameters and the creativity of the design, the Pearson's coefficients obtained were low enough to rule out this possibility. The only one of these parameters that proved to be a little higher than the rest was frustration in relation to unusualness and usefulness, with coefficients of 0.205 and -0.339, which, even though comparatively low, still indicate that the frustration level during design may have a slight positive influence on unusualness and a slight negative influence on usefulness.

5. Conclusions

From the results of the tests carried out in the course of this work it can be concluded firstly, that both the individual and the method used have a significant effect on emotional response during the design phase. However, both these factors affect the emotional response in different ways; or, in other words, they each affect different emotional parameters. Firstly, the subject's individual personality appears to influence his frustration level, regardless of the problem to be solved or method used. Secondly, method appears to significantly influence meditation and interest. Also, even though no significant relationship was found between the individual subject and method, the joint analysis of these factors shows that the individual also affects the meditation and frustration levels, and that method seems to affect frustration, meditation and interest.

Therefore, even though the analysis showed no direct relationship between individual and method as regards emotional response, a rather more complex underlying reality can be perceived that will require further studies on a larger scale and on a greater number of emotional and personal variables in order to identify the factors to be considered when analysing the relationship between individual and method.

Since it has been shown that the design method does have an effect on the designer's emotional response, the next step will be to

Table 13.
Result of Dunnett's post hoc test using Problem 1 as control.

	Mean (Mi)	Control mean (Mc)	Mean square error (MSe)	n	t'	t
P 2	1.65	1.44	0.26	16	1.04	2.32
P 3	2.00			16	3.12	2.32

Source: The authors

determine the methods that positively and negatively affect this response, the design process and its outcomes. One of these outcomes, the creativity of the solutions, was analyzed in the present study and its conclusions indicate that the subject's emotional response during the design phase has no effect on the creative aspect of the results. This has important implications for design methods that promote creativity, since it helps to confirm their validity and utility regardless of whoever uses them. However, our intention is not to isolate the designer from the final results, as there are additional factors that impinge on creativity, including: creative intelligence, training, experience, tools available, surroundings, and a long list of other factors currently under in-depth study or scheduled for future studies [2-10, 19, 34, 35].

Future work will examine the whole range of variables that influence creativity in design, with the aim of optimizing all possible aspects of the design process and to rule out the factors that play no part in the outcome of the creative process.

References

[1] Lidwell, W., Holden, K. and Butler, J., Universal principles of design: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design. Rockport Pub, 2010.

[2] Gerard, R.M., Differential effects of colored lights on psychophysiological functions, PhD Thesis. University of California, USA, 1958.

[3] Soler, L.C.T., Creativity in computer systems. Ingeniería e Investigación, 23(2), pp. 25-30, 2003. DOI: 25-30 2248-8723 0120-5609

[4] Sheppard, S. and Jenison, R., Examples of freshman design education. International Journal of Engineering Education.13(4), pp. 248-261, 1997.

[5] Chulvi, V., Rivera, J. and Vidal, R., Creative experience in engineering design: The island exercise. DYNA, 81(185), pp. 86-93, 2014. DOI: 10.15446/dyna.v81n185.36570

[6] Aizpun, M., Sandino, D. and Merideno, I., Developing students' aptitudes through University-Industry collaboration. Ingeniería e Investigación, 35(3), pp. 121-128, 2015. DOI: 10.15446/ing.investig.v35n3.48188

[7] Atman, C.-J., Cardella, M.-E. and Turns, J., Comparing freshman and senior engineering design processes: An in-depth follow-up study. Design Studies 26(4), pp. 325-357, 2005. DOI: 10.1016/j.destud.2004.09.005

[8] Kumar. K. and Bjorn-Andersen, N., A cross-cultural comparison of is designer values. Communications of the ACM. 33(5), pp. 528-538, 1990. DOI: 10.1145/78607.78613

[9] Manchado-Pérez, E. and Berges-Muro, L., Sistemas de retículas: Un método para diseñar nuevos conceptos de producto hacia el usuario. DYNA 80(181), pp. 16-24, 2013.

[10] Norman, D., Emotion & Design: Attractive things work better. Interactions. 9(4), pp. 36-42, 2002. DOI: 10.1145/543434.543435

[11] Salovey, PP. and Mayer, J.-D., Emotional intelligence. Imagination, Cognition and Personality. 9(3), pp. 185-211, 1989. DOI: 10.2190/DUGG-P24E-52WK-6CDG

[12] Sternberg, R.-J. and Lubart, T.-I., The concept of creativity: Prospects and paradigms. Handbook of Creativity. 1, pp. 3-15, 1999.

[13] Shah, J.-J., Smith, S.-M. and Vargas-Hernandez, N., Metrics for measuring ideation effectiveness. Design Studies. 24(2), pp. 111-134, 2003. DOI: 10.1016/S0142-694X(02)00034-0

[14] Sarkar, PP. and Chakrabarti, A., Development of a method for assessing design creativity. International conference on engineering design, ICED'07 28 - 31 august 2007, cite des sciences et de l'industrie, Paris, France 2007.

[15] Sarkar, PP. and Chakrabarti, A., Studying engineering design creativity-developing a common definition and associated measures. In: Gero J., (Ed.). Invited paper in the Proceedings of the NSF Workshop on Studying Design Creativity. 2008.

[16] Hocevar, D. and Bachelor, PP., Handbook of Creativity. Springer, 1989, pp. 53-75.

[17] Corbalán, F., Martínez, F. and Donolo, D., CREA. Inteligencia Creativa. Una medida cognitiva de la creatividad. Madrid: TEA eds, 2003.

[18] Guilford, J., Personality. McGraw-Hill, New York, 1959.

[19] Torrance, E.-P., Reynolds, C.-R. and Riegel, T., Your style of learning and thinking, forms A and B preliminary norms, Abbreviated technical notes, scoring keys, and selected references. Gifted Child Quarterly. 21(4), pp. 563-573, 1977.

[20] Otis, A., Otis-Lennon School ability test-(OLSAT 8). The Psychological Corporation, San Antonio, TX, USA, 2006.

[21] Altshuller, G., Creativity as an exact science: The theory of the solution of inventive problems. Gordon and Breach Science Publishers, 1984.

[22] Kwak, Y.-H. and Anbari, F.-T., Benefits, obstacles, and future of six sigma approach. Technovation, 26(5-6), pp. 708-715, 2006. DOI: 10.1016/j.technovation.2004.10.003

[23] Thompson, G. and Lordan, M., A review of creativity principles applied to engineering design. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering. 213(1), pp. 17-31, 1999. DOI: 10.1243/0954408991529960

[24] Moss, J., Measuring creative abilities in junior high school industrial arts. American Council on Industrial Arts Teacher Education, 1966.

[25] O'Quin, K. and Besemer, S.-PP., The development, reliability, and validity of the revised creative product semantic scale. Creativity Research Journal. 2(4), pp. 267-278, 1989. DOI: 10.1080/10400418909534323

[26] Chulvi, V., González-Cruz, M. and Mulet, E., Influence of the type of idea-generation method on the creativity of solutions. Research in Engineering Design. 24(1), pp. 33-41, 2013. DOI: 10.1007/s00163-012-0134-0

[27] Chulvi, V., Mulet, E. and Chakrabarti, A., Comparison of the degree of creativity in the design outcomes using different design methods. Journal of Engineering Design. 23(4), pp. 241-269, 2012. DOI: 10.1080/09544828.2011.624501

[28] Guilford, J., Cognitive styles: What are they? Educational and Psychological Measurement. 40(3), pp. 715-735, 1980. DOI: 10.1177/001316448004000315

[29] Kirton, M., Adaptors and innovators: A description and measure. Journal of Applied Psychology. 61(5), pp. 622-629, 1976. DOI: 10.1037/0021-9010.61.5.622

[30] Belski, I., Improve your thinking: substance-field analysis. TRIZ4U, 2007.

[31] Eberle, B., Scamper on: More creative games and activities for imagination development. Prufrock Pr, 1996.

[32] Tukey, J.-W., One degree of freedom for non-additivity. Biometrics. 5(3), pp. 232-242, 1949. DOI: 10.2307/3001938

[33] Chulvi, V., Sonseca, Á. and Mulet, E., Assessment of the relationships among design methods, design activities, and creativity. Journal of Mechanical Design. 134(11), pp. 111004-111004.11, 2012. DOI: 10.1115/1.4007362

[34] Kim, M., Kim, Y. and Lee, H., An underlying cognitive aspect of design creativity: Limited commitment mode control strategy. Design Studies. 28(6), pp. 585-604, 2007. DOI: 10.1016/j.destud.2007.04.006

[35] Artola-González, T., PIC-A: Prueba de imaginación creativa para adultos. Manual. Madrid, 2012.

V. Chulvi, is professor at the Department of Mechanical Engineering and Construction at the Universitat Jaume I of Castellón, Spain. Chulvi earned a BSc in Mechanical Engineering (2001), an MSc in Mechanical Engineering (2007) and a PhD in Engineering (2010). His main research focuses on design and creativity within the research group DACTIC of the Universitat Jaume I of Castellón, Spain. ORCID: orcid.org/0000-0002-0708-3852

M.C. González-Cruz, holds a PhD in Industrial Engineering from the Universitat Politècnica de València, Spain. After working in several engineering companies, she now works as an associate professor/senior lecturer in Project Engineering (undergraduate), and Project Management (graduate). She is currently the Head of the Department of Project Engineering and she is also in charge of the MSc in Project Management at Universitat Politècnica de València, Spain. She has conducted research on the use of design methodology in industry, creativity and innovation management, and currently, she works in analysis and development of forecasting and bid models on procurement.
ORCID: orcid.org/0000-0002-6987-5732