A METHOD FOR ASSESSING CREATIVITY AND INNOVATION OF INDUSTRIAL PRODUCTS BY ENGINEERING STUDENTS

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Abstract
In this paper experiences about the implementation of creative activities in industrial engineering degrees are related. These activities were used in engineering courses to improve the creative skills of the students. Thus, the main goal was to make them capable to design innovative products using ideation methods and working in groups. Although there are some works in the literature about the implementation of creative methods in engineering degrees none of them have established well defined approaches which are able to assess the creativity and innovation level of products in an effective way. Indeed, one of the main problems that have been found by instructors during the classes is how students can evaluate their own creative solutions and the degree of innovation of the designed products. There are no many works in the literature focusing in this topic and all of them have been developed to be applied by engineers with long experience in design. These methods measure the innovation of products by the quantification of a number of factors. However, these factors present some difficulties for students who are not used to work with them. In fact, one of the main problems found by instructors in implementing creativity procedures at university level is that students do not have enough experience about the assessment of engineering products and their degree of innovation.

This paper describes a new procedure for the measurement of the level of creativity that new ideas provide. It can be also used for the measurement of the innovation of products. A case study is presented to illustrate the method and evaluate its effectiveness. In this activity an engineering design problem is proposed to the students and they have to find the best solution. Brainstorming is used as idea generation method and they have to measure their creativity using the proposed approach. The main advantage of the method is that it can be easily used by students and instructors. In this way the students can evaluate their own ideas in order to sort them and select the most creative ones. The method works with a three dimensional scale which are level, scope and goals. The comparison of the proposed method with other existing approaches allows highlighting the easier understanding of the factors to be evaluated.

Keywords: Assessing creativity, Engineering Innovation, Design activities, Usefulness of products.

1 INTRODUCTION

Engineers with creative capacities are more demanded by industry because they are able to generate competitive products and open new business opportunities. For this reason capabilities in creativity and innovation are included in training programs for engineers. Furthermore, these capabilities are included in the form of competencies in our universities and they are supposed to be acquired by our students. In fact, many subjects in engineering curricula include one or more competences including creative skills and the capacity for innovation in students. However, few curricula establish specific activities focused on improving creativity and innovation. In many cases it seems that teaching science to our students implies generating professionals with potential for developing creative products and innovation. However, assuming this fact is to make a mistake because a user of science and technology is not necessarily a creative person.

Creativity in a person can be defined as the ability to look at the problem in a different way than others have looked before. In this way it is possible to open up new possibilities and ideas [1]. Some authors use the term functional creativity to refer specifically to creativity in engineering and distinguish it from the same concept applied in other fields [2] as for example art. As a definition of functional creativity it can be said that it is a procedure that allows the study and evaluation of problems from different or unusal points of view in order to generate innovative products, processes or methods. On the other hand, innovation is the capability of the creative idea to generate products that are sustainable and
profitable over time. Thus, one idea could be creative (it is new and original) but not profitable and sustainable which are important factors in engineering. Engineers search for ideas and products which can find a niche in the market.

Although some of the earliest works on creativity in engineering and its implementation in university curricula appear in the second half of the twentieth century [3], it is not until the last decade that works presenting methodologies begin to appear [4]. Recent studies have shown that the innovative behaviour of engineering students can be improved if creative methodologies are incorporated in undergraduate courses. These additional activities are complementary to other activities in technical subjects. Despite the many works published in the literature there are no clear idea and concise criteria for methodologies encouraging creativity in engineering and how these activities should be carried out in our classrooms. In fact, the improvement of creative capabilities in our students is currently a research field which requires the introduction of new teaching methodologies, or modify existing ones. It is necessary to educate students with a capacity to think differently generating innovative solutions.

Currently [5] there are two fields of research in engineering education related with creativity. They are the following: 1) the use of methodologies to enhance creativity and 2) the evaluation of the degree of creativity of ideas, methods and products. Both aspects present a challenge of investigation where numerous authors have proposed different models in the bibliography [6,7,8]. The work presented in this paper is focused in the last one. We use a well-known method for the generation of ideas which is Brainstorming. Thus, the paper presents a methodology for the evaluation of the creativity of products in engineering degrees. To this aim, the new methodology use terms that are very familiar to engineering students because they have used them in many other fields. The new methodology is also simple trying to reduce the complexity of other methods which have been developed to be used by experienced engineers and professionals. These methods are analytical and require experience and knowledge that students do not have [9].

2 ASSESSING CREATIVITY IN ENGINEERING STUDENTS

An important problem that is generated in the implementation of the development of creativity in engineering students is how the student's creative performance is evaluated [10,11]. However, to find an answer to the question of “How” it is necessary to take into account “What” is going to be assessed. Creative could be a person, a methodology, an idea, product or the environment. When the creativity of a person is evaluated many factors should be considered. Although the creative capabilities of the person can be enhanced, each individual has innate creative abilities. Evaluating people's creative capabilities belong to the field of psychology and therefore it is outside of the scope of this work. Furthermore, the instructor must accept all students with their best or worst creative capabilities and enhance them as well as possible.

The idea, the method and the product can also be evaluated. The creative idea is one that presents a different approach to solve a known problem. An idea can be considered creative when it is far away from other previous ideas used to solve the same problem. Creative idea can be evaluated using the concepts: quality, variety, novelty and quantity [12]. The creative method is one that leads to the creative idea and product. There are many methods in the literature to produce creative ideas and products [13]. The well-known Brainstorming is one the most used along the world. However, there are many others based on brainstorming including variations to improve their efficiency [14]. The creative product is the innovation that is obtained from the creative idea. Encouraging the creative idea and the innovative product is the ultimate goal, but do not forget the process that enhances this idea. The environment is creative when it fosters the generation of ideas. In the case of students, it is the teacher who favors this creative environment in order to improve student performance.

It seems evident that in an engineering course the teacher should focus on the evaluation of the idea and the product, encouraging the creative environment and accepting the students with their creative capabilities. It is important do not make the mistake of considering that if the final idea is creative or the product is innovative the student or students will get a better mark. In an academic environment, it is necessary to take into account that many restrictions exist and students have to achieve innovative solutions with these limitations (i.e. technological means, professional experience, time, technical knowledge, etc.). Therefore, students’ evaluation focused only on the final result leads to an incomplete and even unfair assessment. This can also be demotivating for the student. The evaluation should therefore consider the whole creative process from the approach of the problem and the
generation of ideas (divergent thinking) to reduction of ideas (convergent thinking) and proposal of an innovative product that solves the problem. The whole process used in this work is shown in Figure 1.

Therefore the evaluation of the students must be continuous and divided into different parts throughout the process of creativity. At the end of the process the goals are focused on the student and their behavior when using creative tools. It is important to point out that the students must become aware that when they encounter a technical problem, it should not be seen as a difficulty, but as an opportunity to improve a product.

2.1 Teaching methodology

It is clear that instructors must fight against the reaction to change that involves implanting new methodologies for fostering creativity. Engineering instructors tend to follow known teaching techniques where the solution of a given problem is unique (closed-ended problem). In these cases, if the solution provided by the student coincides with that expected by the instructor, the student will be evaluated satisfactorily. If the solution does not match the solution expected by the instructor, the assessment tends to be negative. Thus, the more the difference between expected values and the results obtained the lower the mark. It has been shown that this way of acting is a barrier in the creative development of students [15,16]. Open-Ended Problems (OEP) should be a standard form in engineering education. In methodologies using OEP unexpected ideas are well considered by instructors and they are also valued. In other words, not only the quality of the solution provided by the students is assessed but also the student's initiative to create new approaches to solve the problem must be evaluated.

At the educational level, the first problem generated when fostering creativity in students is how to encourage the generation of new ideas. That is, it is necessary to teach the student to face the problem by looking for unusual solutions and getting rid of prejudices fomented by existing solutions. In this aspect the selection of methodologies to enhance the creativity of students plays a fundamental role. In creative studies these tools are known as methods of generating ideas or methods of ideation [17,18]. In the bibliography there are experiences that show the results of incorporating in engineering curricula methodologies of ideation to promote the generation of innovative ideas in the students. They have been applied in Project-Based Learning (PBL) format or open-ended problems (OEP) [19,20,21].

Fig. 1 Methodology for the creativity process in classroom.
Some of these methods have proven effective in the professional context of engineering design. In addition to the Brainstorming method, C-Sketch [22], Design by Analog, and TRIZ [23] are other alternatives to be used. In any of these methods students working in groups are essential to improve efficacy. In general, working in groups should be encouraged in order to find the most innovative ideas but also to generate a synergy in the group that allows all members to improve the ideas proposed by one of the individual. It is a proven fact that the difference of personalities of each member of the group provides and fosters creativity.

### Table 1. Methodology for the assessment of creativity and innovation.

<table>
<thead>
<tr>
<th>Function (x3)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavior (x2)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Satisfaction</td>
</tr>
<tr>
<td>Structure (x1)</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Creativity</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>Effectiveness</td>
</tr>
</tbody>
</table>

Figure 1 shows the methodology used in this work to foster creativity in students. It includes the steps followed by students and instructors in order to obtain a new product and evaluate its creativity and innovation. The methodology uses Project-Based learning (PBL) to obtain the results. Previous to the steps presented in the flowchart of Figure 1 a seminar about creativity is given to the students. The main goal of this seminar is to prepare them for the use ideation techniques and to avoid the barriers to the creativity that always appears during the creativity process. The central boxes in Figure 1 represent the process from the beginning to the end. The boxes on the left show important task carried out by students. Boxes on the right column contain the tasks performed by instructors. The first step is the identification of the problem which is provided by the instructors to the students. Then, students have to deeply understand the details of the project, the goals and constraints. An important task of the instructors is to explain these details. Once the students have studied the problem divergent thinking step begins. In this step students have to generate new ideas without the help of instructors. The more ideas they generate the better assessment they obtain. Thus, instructors work in this step is to evaluate the number of ideas and their originality (i.e. how far are they from the previous solutions). After that, they have to assess the ideas reducing their number until only one is selected. This step is known as convergent thinking. In convergent thinking technical knowledge is necessary and help is provided by instructors to the students. In the next step this idea should be materialized in a real product using the students’ technical knowledge and the support of instructors. Finally, the evaluation of the product determines if the solution is innovative. Otherwise they have to repeat the process until a valid solution is obtained.
2.2 Assessment procedure

The assessment procedure proposed in this work measures the creativity of the product and the degree of innovation. Students can assess these issues using the matrix shown in Table 1. The creativity is assessed in two dimensions: level and scope. Level indicates the quality of the change that the idea supposes in the new product. They are the following:

1. Physical principle: used to satisfy the goals of the product. This is the most significant extent of finding differences between ideas.
2. Concept: in this case the idea shares the same physical principle however the product’s performance is carried out in a completely different way.
3. Design: changes in the design of the product affects the general layout, geometry, weight and size, etc.
4. Detail: this the lowest level of change. In this case only local elements are modified.

The scope is classified in the matrix using three items: function, behavior and structure. Function refers to the goals carried out by the product. Changes improving the function are considered the most significant. Normally, these changes increase the function or functions of the product having an important impact on innovation. Behavior refers to the way in which the product works to achieve the goals. Structure changes are considered less important but it is necessary to consider the influence in some aspects such as weight and size.

The measurement of the degree of innovation is done by the assessment of three items which are defined as: users’ satisfaction, efficiency and effectiveness. Users’ satisfaction measures the users’ comfort and the improvement obtained in this sense with respect to previous products. This item assesses the positive (or negative) attitudes of the users towards the product when they are using or manipulating the product. The efficiency factor measures the resources used by the product to complete the task. Examples of variables contributing to the efficiency are the completion time, the consumption of energy (e.g. electric, human, etc.), the time necessary and complexity to learn how to use the product, etc. Effectiveness factor measures the accuracy and completeness of the task performed by the product. Indicators of effectiveness include the quality of the task performed by the product.

These factors are evaluated using a Likert scale which varies from 1 to 5 where 1 is the worst value and 5 the best. Thus, in this scale marks 1 and 2 mean two levels indicating that the new product is worse than previous one. Levels 4 and 5 stand for two marks indicating improvement whereas level 3 means that there is no improvement at all.

Fig. 2 Genealogical tree of ideas.
Students working in groups generate ideas using the Brainstorming method. These ideas are developed following a genealogical tree of ideas which compares previous ideas with the new ones. Figure 2 shows the scheme generated by a group of students during the creativity process. In this figure letters in black stand for previous designs whereas letters in red stand for the new ideas generated in the project. These ideas are classified in the aforementioned four levels. Changes in physical principle involve changes in the lower levels (i.e. concept, design and detail). Each branch of the tree needs to be reflected in the Table 2. Students have to classify the ideas and products by marking the corresponding box in the table and the marks are obtained using the weighting sum of these marks. Weighting parameters are indicated in Table 1 but they can be changed by the user depending of the product.

3 RESULTS

Three groups of students worked with the assessment method proposed in this paper, other three groups worked with the analytical method proposed in [9] and other three groups were free to choose the method for the assessment. They had to evaluate their ideas and products and after the project was finished a questionnaire was completed by the students. For the two first groups of students the questionnaire had three questions (Likert type with 5 levels) about the assessment of the ideas and products using the assigned method. The questions were the following:

1. Indicate the level of difficulty in the assessment of the creativity.
2. Indicate the level of difficulty in the assessment of the innovation.
3. Indicate the level of difficulty using the method proposed.

For the students who had the opportunity of selecting the method the questionnaire included the following question:

4. Which method did you select?
5. Why did you select this method? Options: accurate, easy to use.

Figure 3 shows the results obtained from the statistical analysis (ANOVA) of the questionnaires. In all cases the method proposed in this paper was less difficult to use (method 1 in Figure 3) than analytical method for the students (method 2 in Figure 3). This fact is clear when students are asked about the assessment of the creativity (Figure 3a). However, the dispersion of the results is significant in the case of innovation. Better results are obtained about the level of difficulty on using the method (Figure 3c). The majority of the students selected the new method as the best one (67.7%) and the indicated “easy to use” as the main reason for selection.
4 CONCLUSIONS

Creativity is an important issue in engineering education and universities should include its application in their graduate schedules. The incorporation of creativity and innovation require special teaching methodologies that must be assumed by the instructors in the classrooms. These methodologies are different from those using in industrial companies by professional engineers because at educational level some constrains exists. The lack of experience is one of the main difficulties that students have to confront with. This fact makes difficult the evaluation of new ideas and products by students which is an important step in the use of creativity methodologies. This paper proposed a new methodology for the evaluation of creativity and innovation of ideas and products generated in engineering education. The method is simple and easy to use by students. The words and concepts used in the assessment of ideas and products are used by the students in other fields and they are familiar with them. For this reason it is very easy to understand their meaning. The results of the experience described in this paper demonstrate the positive main features of the method.

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