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Searching for the Most Creative Engineer*

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Creativity is one of the skills of our graduates most demanded by working companies, which is directly linked to problem-solving, innovation, and the creation of new businesses ideas or the patents development. The demand for the creativity skill is ever increasing and appears among the five skills most valued by employers at times when resources are most limited. During the last three years, a set of initiatives has been performing at the Industrial Technologies Degree course, at the Universidad Politécnica of Madrid, to enhance creativity as one of the most relevant skills. The goal is clearly to improve the creative skill of the engineers in the industrial field, having focused the activities carried out on the two major players in the educational process, i.e. the teaching staff and the students. The paper describes the process followed to gradually bring on board an ever increasing number of teachers committed to developing their student's creativity.

Keywords: creativity; skills; industrial engineers; educational process; competencies

1. Introduction

Creativity is one of the most relevant skills by employers [1–3] and this paper describes the Development Framework for the Creativity Competence [MDCC] implemented at the Escuela Técnica Superior de Ingenieros Industriales (ETSII) of the Universidad Politécnica de Madrid (UPM). This framework has been in operation for the last three years and its design is in a continuous improvement process. However, its application, as these pages show, is producing measurable outcomes.

Creativity skill in engineering is very closely linked to the product design and development process, problem solving and the innovation and development of new technical or social opportunities, which are fields of action closely tied to the work of engineers; therefore, they need to be educated to develop these competencies. However, many educational programmes for engineers fail to offer specific courses on creativity even though it is a competence that is highly valued by professionals. Back in the 1960s the National Science Foundation sponsored conferences on "Scientific Creativity" [4] although this interest eventually waned and disappeared into the background.

The need for creativity in problem solving and innovation is becoming a global requirement [5]. The need to take creativity on board and encourage it in engineering programmes is real [6]. Creativity and innovation are two of the main skills for professional development in the 21st century [7].

Creativity subjects are to be frequently found in different engineering programmes, particularly in those that encourage setting up companies and developing business or products, but only as subjects promoted by a teacher or group of teachers. However, a coordinated effort to push this skill as part of the program is not frequent.

If creativity is one of the educational aims, it must be defined in a clear and measurable way [8]. Students gain confidence and learn to overcome their creative barriers when their environment offers them an appropriate learning climate [9–10]. The combination of teamwork and PBL boosts creativity according to the works of Zhuo and Kolmos [11]. Tolbert suggests that creativity; especially the number of solutions and originality should be included in the rubrics for students to recognize their importance [12].

Tools for measuring creativity are scarce; the Torrance test, which measures four aspects of creativity, is well known: Fluency (number of solutions), flexibility (number of categories of the responses), originality and elaboration [13].

Companies dedicated to evaluate the skills of management teams and human resources usually design their own tests or measurement tools, but at a high cost [14–15]. Other tests require specialised personnel to interpret them. The University of Ohio has developed the Creativity Engineering Design Assessment (CEDA) [16] related to product development and consists of three design problems to be completed in 25 minutes. Like the Purdue Creativity Test [17] and the Owens Creativity Test, they measure divergent thinking [18].

The process is following a "Pull" approach, which lets to the faculty in charge of implementing the *Creativity Development Framework* activities what supplementary activities they must do. These

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may be basic or advanced workshops, individual or group tutorials, designing pilot projects, challenges or contests for the students even faculty and practical classes. The first step was to teach the faculty what's the meaning of creativity, its principles and techniques and how they can apply them in their classes. To date, 20% of the School's teaching staff has voluntarily taken part and the numbers continue to rise.

As shown by the data in this paper, the progressive changes introduced by the teachers teaching in their subjects from a 'non-routine problems' or 'challenges' point of view are managing to change the way students tackle their work by improving the quality of the answers in terms of the number of alternatives produced and their originality.

The paper describes the process followed to gradually bring on board an ever increasing number of teachers committed to developing their students' creativity.

2. Developing the competence of creativity

To develop the creativity competence as part of the study plan, from the very beginning we asked ourselves what was understood as creativity and what we wanted our students to be. This was defined as how to "Solve problems and situations in the field of engineering in a new and original way". We want our students to demonstrate their ability to think creatively, creativity being understood as an aptitude for "Solving non-routine problems with imagination and innovation and generating new opportunities to create value in an imaginative way". These aims are clearly aligned with the educational aims of our qualifications, specifically with the following phrase:

> "Graduates must prove their ability to respond with imagination and innovation to non-routine problems and opportunities [original] [creating value] in the exercise of their profession, in technical roles as well management."

It was considered one of the best ways to achieve this competence was through small challenges that could be included as part of the subject or through non-routine problems, which have been defined as follows: "either not pre-set or badly defined; with more than one possible solution; dynamic, changing depending on the approach chosen to tackle them and/or the proposed solution; often inter-disciplinary".

2.1 Performance indicators

To check the students' performance regarding the creativity skill, the competence can be evaluated in accordance with the following indicators:

- Number of different alternatives proposed for the approach or solutions.
- Originality of the proposed approaches or solutions.
- Value of the approaches and solutions according to their relevance, feasibility and effectiveness.

These indicators are set out in a creativity rubric that teachers adapt as far as possible to the particular features of their subject. Each Performance Indicator is recorded in the document known as the Curriculum Map for each Course and Subject, providing useful information about it:

- Course and subject in which the indicator are explicitly required.
- Level of importance for the subject: The course introduces, strengthens or emphasises the competence.
- Way to demonstrate the competence: tasks, projects, performance tests, etc., or any combination.
- Student's feedback regarding their performance in this indicator [e.g., a mark is given].

3. Training period

For a correct design of the activities, firstly the faculty was trained to different creativity techniques oriented by creativity professionals and later it was applied to the students by the teacher. Following subsections treats the different training points of view.

3.1 Teacher training

One of the major problems when it comes to developing the competence of creativity has been the lack of teacher training in the matter, having been necessary an 8 hours workshop practices given by expert external staff.

During the workshop the teachers were introduced to the basic methods of creativity and how to teach them and stimulate students. These workshops were accompanied by individual tutorials aimed at helping the teacher to incorporate some activity that would interact with the student's creativity. The workshop was followed by periodical meetings with the professional staff as tutors.

The teachers that attended did so voluntarily but took part with the commitment to carry out some "pilot" activity—often called an "experiment"—to encourage creativity in their subjects. The activity was recorded in a wiki host [20] so that teachers can find successful cases and provide feedback on the process. These documented activities let us evaluate a part of the process and set subsequent improvements such as including workshops on more engineering-oriented creative techniques like TRIZ [21].

To date 4 workshops of creativity have been run,

Table 1. Workshops date and level

Course	Workshop	No. of teachers	Level
2011–12	Nov. 2011	15	Basic
	Feb. 2012	14	Basic
2012–13	Jan. 2013	16	Basic
	Apr. 2013	14	Advanced

mainly on the basic contents, and approximately 20% of the teaching staff involved in the qualification (300 teachers) took part on a voluntary basis.

The teacher training process followed is shown in Fig. 1. The objective of this stage is to regularly incorporate non-routine activities or problems for developing this competence into the subjects (standardising the practice). The teachers of these subjects design these activities, finding what the problem is by taking multiple [and original] alternatives of approach, and integrating, if necessary, concepts, methods and tools from different areas of knowledge, identifying multiple [original, relevant, effective, feasible] alternative solutions to the problem.

3.2 Student training

One time the teacher training has been defined, this section will define the student training that have been run to increase the creativity skill.

The degree qualification in Industrial Technologies began in the 2010–2011 academic course and consists of 4 years of training. Activities to develop the competence of creativity have been running since the 2010–2011 academic year. The curriculum map below has been set to develop this competence (Table 2).

On a more informal level, students' associations also promote different activities where creativity is a very important part throughout the course.

There are driven subjects that impart specific knowledge on creativity and apply it to tasks in the subjects, such as Engineering Graphics and other subjects whose job it is to strengthen this knowledge with the activities carried out.

The development of the creativity competence in students is linked to setting up these normal activities and getting them clearly established as part of the program.

The initial pilot group started in the 2010–2011 academic year, with 75 first year students, developing activities in the subject of *Engineering Graphics*. These activities were fully implemented for the first course students (450 persons) in the following academic year (2011–2012); during this academic year a second subject was included too (*Environmental Engineering*), affecting 550 students. Finally, in the 2012–2013 academic year, the previous subjects were kept together with their activities. Other subjects have been incorporated (e.g. *Chemistry, Design Thinking*) where it is also aimed to encourage creativity.

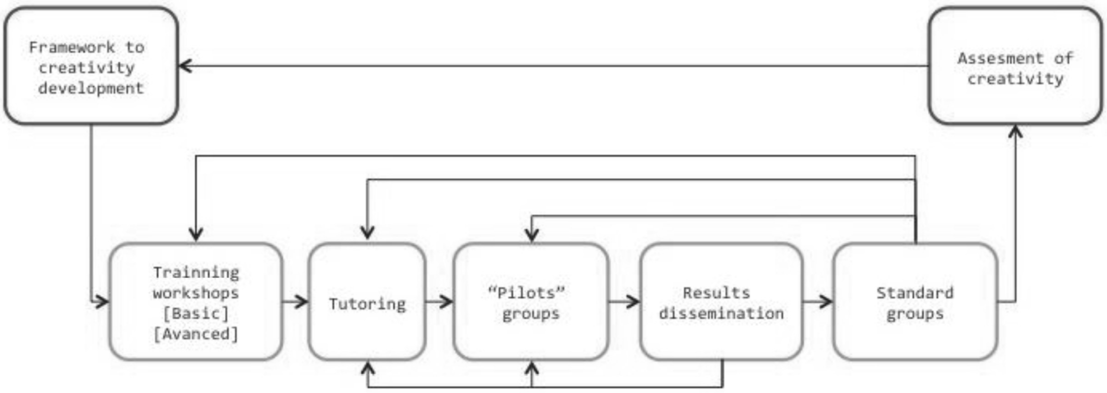

Fig. 1. Teacher training process for creativity development.

Table 2. Training experiences resume

Year	Creativity contents to be taught	Main subjects	Main activity	Reinforcement subjects	No. students affected
1st	Basic methods: brainstorming, splitting up and combining	*Engineering graphics* (12 ECTS)	Subject Assignments	*Chemistry* (12 ECTS)	428
2nd	Basic methods: brainstorming, splitting up and combining	*Environmental Engineering* (6 ECTS)	Creativity Challenges		450
3rd	Design thinking	3 day challenge (1 ECTS)/subject on creativity			125
4th	TRIZ method	1 subject per speciality	Creativity challenges		350

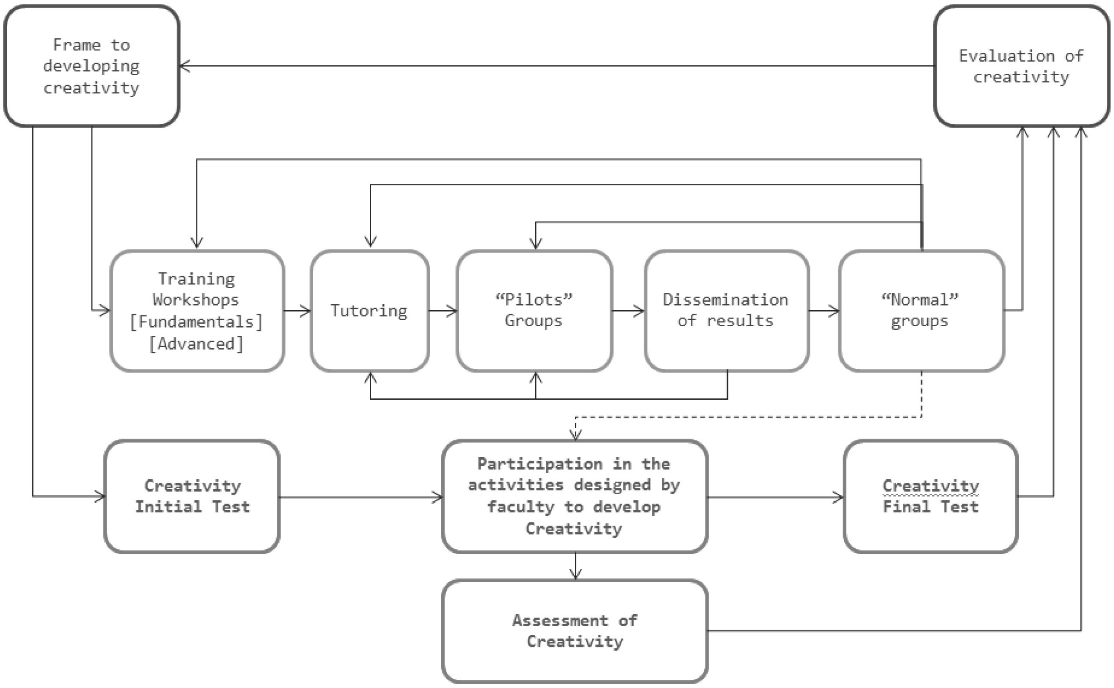

Fig. 2. Overall process for creativity development.

Table 3. Subjects and students involved in the training process

Driven subjects	Year 2010–2011	Year 2011–2012	Year 2012–2013	Total
Engineering Graphics	75 (Pilot Group)	450	450	975
Environmental Engineering	–	550	550	1100
Design Thinking			25 (Pilot Group)	25
Sum by Year	75	1000	1025	2125

4. Assessment of the creativity activities

During 2012–2013 academic term, a creativity test were done on the first day of class for the newest students. Therefore, these students had not received any prior teaching or activity at the university, apart from what they had done in their secondary education. In addition, the same test was also given to second year students, who had done activities during the previous year as part of the *Engineering Graphics* subject.

The test is very simple and enables two of the indicators appearing in the creativity rubric to be evaluated, i.e., number of solutions and originality.

Students are asked to write the different uses of a common object in a given time (3 minutes). As more uses (solutions); as more creative he or she is. Solutions were checked and rewritten to avoid orthographic or mistyped mistakes and were sort in categories with the same use. For us "Join papers" or "Join A4 sheets" were the same solution. Finally we counted the solutions given by each student.

4.1 Number of alternatives

After the creativity development process of students during the first and the second academic year, if we analyse the results, we observed that the second year students show more alternative solutions, existing an average of 9.12 solutions per student. Listed below is the statistical data resulting from the analysis test.

By performing a variance analysis it can be seen, with a 95% confidence level, that the groups are not

Table 4. Alternative solutions presented by students

Students	Number	Average	Variance	St deviation	Min	Max	Range
Freshers	312	7.82692	9.75773	3.12374	3	20	6.68329
2nd year students	298	9.12081	14.4298	3.79866	2	22	6.62638

Table 5. Variance analysis (ANOVA)

Source	Square sums	GI	Mean Square	F-Quotient	P-Value
Between groups	255.171	1	255.171	21.19	0.0000
Intra groups	7320.3	608	12.04	–	–
Total (Corr.)	7575.48	609	–	–	–

Fig. 3. Tag clouds, (a) Fresher students tag cloud, (b) 2nd year students tag cloud.

homogeneous and so there are clear significant differences between the new students and these students since the P-value of the F test is less than 0.05.

4.2 Originality

In order to evaluate originality indicator, and faced with a lack of resources, a tag cloud was used [22, 23]. If is taken that a solution is more original the fewer times it appears, the tag cloud would reflect the concepts that were least original. In order to prepare the tag cloud, the solutions suggested by students were pre-processed (accents, capital letters, spelling mistakes, etc.).

Figure 3 shows the result obtained after applying this solution to the first and second year students solutions.

The tag cloud enables the most frequent words to be counted and thus the least original ones. The size of the letters and the number of words that are repeated mean that a mere glance can help us decide the originality of the groups. The ten most repeated words that are not prepositions or articles, etc., are randomly removed from this list. In principle these words are associated with the proposed solutions, so if we eliminate the most frequently repeated words from the total number of alternatives we will obtain the least frequent number of solutions.

By last, the number of original solutions per student, i.e. the originality index to correctly categorize the creativity skill of the students can be obtained dividing the total number of alternatives by the number of students, having excluded the ten most repeated alternatives.

$$\text{Originality index} = \frac{\text{Total number of alternatives} - 10 \text{ most repited alternatives}}{\text{number of students}} \quad (1)$$

From the results obtained by the first and the second academic course students, we are in conditions to have a look to the increasing or decreasing competence skill (Table 6).

Doing a quick analysis we observe that the number of presented alternatives per student is highest at the second academic course. In addition, analysing the number of most repeated alternatives, they are highest at the first academic course. From the previous data we observe a clear correspondence between the originality and course, existing more not repeated alternatives at second course, which could be linked to the training techniques applied to the students at the different subjects. From the results, it can be seen that the second year students showed themselves to be more original.

Table 6. Originality index analysis

	Fresher students	2nd year students
Number of most repeated words	959	824
Number of alternatives	2442	2718
Number of students	312	218
Originality index	4.75	8.69

5. Conclusions

An institutional framework has been designed to develop the competence of creativity at the Escuela Técnica Superior de Ingenieros Industriales (ETSII). Under this policy of encouraging creativity as one of the most relevant competencies for their students, specialised training in creativity has been given to the faculty. A curriculum map has been established where the students receive training and undertake activities to develop this competence in an orderly and progressive way by setting driven courses and challenges to reinforce it.

Around 2000 students have received training and done some kind of activity. This method has been backed up by the results obtained in a creativity test that shows that students who have completed the second year are more creative and come up with more original ideas than new students.

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Appendix: Creativity Rubric

	Indicator	Description	Evaluation Scale			
Knowledge Understanding	**Knowledge of creativity techniques**	Demonstrates knowledge of the existence of creativity techniques. Can name them and describe their use	Can quote no creativity technique	Can quote up to N different techniques and describe their use	Can quote up to N+X different techniques and describe their use	Can quote N+Y techniques of creativity and describe their use
	Understanding the principles that are behind the effective use of the different techniques	Demonstrates they know which technique or techniques are better suited to the context. Through an effective use they demonstrate the basic principles that make a technique work.	Cannot choose a technique suited to the context.	Can identify at least one technique suited to the context. Cannot use it in an effective way.	Can identify different techniques suited to the context. Can use at least one in an effective way.	Can identify different techniques suited to the context. Can use any of them in an effective way.
Quantity	**Number of approach alternatives or solutions proposed**	Contributes different approaches and/or solutions to the problems set.	Cannot suggest a valid approach to the problem.	Can suggest different approaches to tackle the problem.	Can suggest different approaches to tackle the problem. Contributes at least one valid solution to the problem.	Can suggest different approaches to tackle the problem. Can contribute different solutions [three or more]
Originality	**Originality of the proposed approaches and solutions**	Originality understood as the frequency with which an idea or alternative appears among the total of proposals in the reference group: most repeated, least original and vice versa.	The alternatives proposed by the student are repeated with a high frequency in the reference group, either in the same way or with slight variations.	The alternatives proposed by the student are repeated with a certain frequency in the reference group, either in the same way or with slight variations.	The alternatives proposed by the student are repeated with little frequency in the reference group, either in the same way or with slight variations.	The proposed alternatives are unique in the reference group.
		Application of different methods. Integrates methods from other contexts to generate ideas.	Their ideas are based on "habitual" knowledge of the matter. Is limited by their social, technical, financial conventions, etc.	Finds it hard to think of other methods although they understand that the solution may be "outside".	Has the ability to see beyond their limits. Has few ideas that let others come up with new solutions.	Student understands the problems from multiple perspectives and from the "outside". They do not limit themselves to conventional solutions. They develop ideas in varied and complex contexts.
		New uses found. Originality of the new use. Can find different uses or purposes for the objects, entities/organisations in an original way.	Cannot find any purpose or use other than the habitual ones for the elements available in the situation.	Can find various different uses apart from the usual ones for the elements available in the situation, by putting their properties to their usual use.	Can find various different uses apart from the usual ones for the elements available in the situation, or either use their least used properties.	Can find various different uses apart from the usual ones for the elements available in the situation and take advantage of their least used properties.