Abstract

This article shows a qualitative analysis of the effectiveness of the use of TRIZ, a systematic creativity strategy, as a tool to support the creative competence within the Semester Project in the curriculum of Electronic Engineering. The analysis is based on an experience carried out with second-year students from the Javeriana University in Cali, Colombia. The Semester Project is a pedagogical activity seeking to boost different student competences. The project is based on the formulation of a problem that must be solved by using more than one curriculum course currently taken by the students. The project is evaluated by a set of professors throughout the semester. The results obtained show that the proposal of ideas using TRIZ is higher compared to those generated by trial and error without any creativity technique. TRIZ's potential for engineering work is corroborated because it uses the accrued knowledge of designers over the years helping new generations attain this knowledge. It addresses, from the curriculum, the formation of professionals with abilities to face the new oriented to project enterprises.

Keywords: Creativity, TRIZ, formation competences, integrated curriculum.

1. Introduction

The student formation processes in engineering are currently focused in the development of competences, known as the know-how in a context (Aguilar & Rivera, 2005). On the other hand, it is required that the curricular structures explicitly respond to the new working challenges of the surroundings (Yorke et al., 2006) and that the curriculum must be taken into account as a whole, as opposed to an aggregate of subjects along time guided by academic interests (Koksal & Egitman, 1998). Context recognition and application of pertinent knowledge in this context calls for new teaching methodologies as well as new attitudes of professors and students for these purposes. The Semester Project is one of those new methodologies which seek to look at the curriculum as a whole and form professionals with skills to deal with problem solving, with specific experiences carried out at the university (Aguilar, 2001).
Creativity is a predominant element in product development because it allows the generation of ideas that can then be materialized for the improvement or the generation of new products. There are various techniques that enhance creativity, some focused on a personal internal search for inspiration (brainstorming, analog thinking, lists of attributes, SCAMPER, and many more) and others, such as TRIZ, which invite the design engineer to use a set of knowledge already developed by other designers to boost inspiration (Ogot & Okudan, 2006).

The article begins with the presentation of the Semester Project, then describes in a general way the strategy of systematic creativity - TRIZ and finally presents the pilot experiment conducted with Electronic Engineering students from second year from the Pontificia Universidad Javeriana in Cali, Colombia.

2. The Semester Project

Since the year 1996, the Electronic Engineering undergraduate program of the Pontificia Universidad Javeriana sectional Cali, Colombia, has worked with a pedagogical strategy known as the Semester Project. The Semester Project is a strategy in the training of future engineers that from the enunciation of a practical problem, which is related to the subjects that the student is enrolled in the semester, seeks to develop a set of competences that will be of professional usefulness both in the disciplinary and labor field. The Semester Project is done each semester for three years of the programme, from the fourth to the eighth semester. In the fourth semester, it only involves one subject and it is the preparation of the student for this type of learning, based on project-based learning. In higher semesters it will have a larger number of subjects associated to it.

The Semester Project seeks to promote the following types of competences: the academic, aimed to strengthen the disciplinary formation; the argumentative, which enables the student to propose and defend an idea; the behavioral, which permits the student to recognize the different contexts in order to act properly in them; the communicative, which lets the student interact properly through different means of expression; the conceptual, which recollects the fundamental elements of the phenomena to make proper use of them; and the creative one which enables the student to propose new ideas for finding solutions (Aguilar & Rivera, 2005).

2.1 Characteristics of the Semester Project

The Semester Project stems from the collective work of professors of each academic semester. These professors, before starting the semester, define the problem to be solved and elect a professor as the Semester Project coordinator. This professor is responsible of coordinating the project throughout the semester and acts as the information contact with students on all issues pertaining to the project. Professors act jointly, like a Board of Directors, with the students in three different moments of the project to receive the results. Professors act on individual basis throughout the project in guiding students from their area of knowledge. The following characteristic elements of the Semester Project are recognized:

- Formulation of a project, of average complexity, by the group of professors of the semester.
- Planned solution of the problem.
- Collective assessment of reports on a regular and programmed basis.
• Formal documentation of technical reports submitted by students.
• Practical and oral verification report of the project results.

Table 1 shows how the Semester Project is evaluated based on the instruments used and on the aims of the academic activity.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Instruments</th>
<th>Communicative, argumentative, Behavioural Competences</th>
<th>Academic Competence</th>
<th>Conceptual Competence, Research Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schedule and Presentation of proposed solution to the problem</td>
<td>Written document</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>First and Second Project Submission</td>
<td>Written document, Oral Presentation</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Final Submission</td>
<td>Paper Document, Oral Presentation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 1: Assessment characteristics of the Semester Project.

3. The strategy of systematic creativity -TRIZ

The theory of inventive problem solving TRIZ was developed by Genrich Altshuller and his colleagues in the former Soviet Union in the year 1946. This methodology, which combines principles and algorithms, is now used worldwide. The investigation of TRIZ assumes that there are universal principles of invention which are the basis for creative innovations that promote the advancement of technology (Salamatov, 1999). When these principles are identified and codified, the invention processes can be more predictable. The Altshuller’s research team has analyzed through 50 years over two million patents. They have classified them by their level of inventiveness and they have analyzed them to identify the principles of innovation. The key concepts in TRIZ theory are Ideality, ARIZ, Contradictions, Substance-Field Analysis, Laws of systems evolution, and Knowledge Base of the Effects and Inventive Principles (Goel & Singh, 1998). At present, there are various works of effective use of TRIZ with other design engineering methodologies such as Axiomatic Design (Kang, 2004; Shin & Park, 2006) that help engineers in problem solving.
Altshuller's work presents a set of tools to solve problems where the notion of contradiction is a key aspect in TRIZ theory. It is affirmed that through a careful analysis of a problem its inherent contradictions can be identified. The tools that TRIZ provides should be applied every time a contradiction has been identified (Cavallucci, 2002). Figure 1 shows an overview of Altshuller’s work.

Using TRIZ methodology, a design team changes its specific design problem into a general design TRIZ problem (see Figure 2). The general TRIZ design problem derives from the analysis and classification of a large number of problems in various engineering fields and suggests a set of general design solutions. From the general design solutions, the design team can derive particular solutions for their specific problem. Therefore, the power of TRIZ is in its inherent ability to bring solutions from different and seemingly unrelated fields of knowledge to use them in a particular design problem of innovative characteristic.

Salamatov [6] states that "engineers usually think concretely but not systemically. After establishing a problem often they focus their attention on a particular object that must be improved. For example: if the problem describes a tree, they only consider the tree. In systems thinking, it is necessary to imagine not only the tree itself but simultaneously the forest (supersystem) and separate the branches and leaves (subsystems). Possibly, he must consider the wood, climate, the cells of the leaves too ". Regarding this aspect, which doesn’t permit to have a broad vision of the problem, appears the concept of mental inertia which refers to the internal and external characteristics of people which don't permit them to overcome a
predetermined way of conventional thinking to have access to non-conventional mental operations.

Figure 2: Characteristic of TRIZ methodology for solving a problem (Cavallucci, 2002).

Figure 3 shows the nine windows diagram or multi-screen that gives a broader vision of a problem and it is a strategy that is suggested by TRIZ theory to overcome mental inertia. The horizontal axis is associated with time, where the problem is analyzed, and the vertical axis with the structure of the problem. It is suggested to follow the strategy according to the numbers indicated in the windows so that the contradictions associated with the problem can be identified (Cavallucci, 2007).
3.1 The Contradiction Matrix

A contradiction is a situation in which a parameter is affected negatively when wanting to improve another parameter in the analysis of a problem. For example, if one wants to make a very fast measuring device, the accuracy of the measurement is affected by the traditional methods. In this case, the parameter wanted to be improved is speed, but the one which would negatively be affected is accuracy.

Altshuller suggested a matrix of parameters that allows finding inventive principles of problem-solving from the identification of contradictions in those parameters resulting from the analysis of a problem. The parameters originally proposed were 39 and the inventive principles, 40. The parameters can be classified into three groups (Savransky, 2000): Common physical and geometric parameters, negative parameters independent of the technique and positive parameters independent of the technique. Contradictions are classified into technical contradictions and physical contradictions. A technical contradiction is one that has two different parameters and a physical one, the one that has two equal parameters.

To use the Contradiction Matrix, the Main Function of the system which is going to be designed must be identified first and the contradictions arise from the analysis of that function. When the contradictions have been identified, the cell which contains the inventive principles suggested to overcome such contradictions is identified in the matrix. The cell is the intersection of the parameter that is improved (column 1 in Figure 4) with the parameter that is worsened (row 1 of Figure 4). The nine windows allow the identification of both the Primary Function of the system as well as the contradictions of the problem. Contradictions are found analyzing state transitions at the time. For example, between window 1 and 9 (see Figure 3), it is possible to find a contradiction because to reach a new state (window 9) one or more contradictions must be overcome from the previous state (window 3).
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With the contradictions identified, particular ideas must be generated from the inventive principles suggested. Figure 4 shows an example of the use the Contradiction Matrix. A contradiction is found analyzing a problem that could be the design of a sturdy table of low weight. The parameter you want to improve is the strength (14), but the parameter that worsens is the weight of the stationary object (2) for the case of a traditional table. In the cell of the intersection are the principles suggested to overcome the contradiction and help in the design process. For example, the suggested principles are: 40, 26, 27 and 1 for the use of composite materials (40), Use copies (26), disposable Objects (27), and Segmentation (1). The order of the suggested principles is associated with the highest use frequency in similar situations in other types of problems. One possible solution could be to build a table with composite materials like fiberglass which has high resistance and is of low weight, taking into account the suggestion of the 40th principle.

![Table showing the Contradiction Matrix](image)

Figure 4: Example of the use of the Contradiction Matrix.

4. The use of TRIZ in the Semester Project

A pilot experiment was conducted in order to assess TRIZ’s potential in supporting the creative competences within the Semester Project. There wasn’t any previous work with creativity strategies and students used intuitively knowledge drawn from textbooks, Internet and brainstorming. The first experience was carried out with second year Electronic Engineering students who for the first time are participating in this pedagogical experience and only involves one subject, Electric Circuits. The proposed project was the manufacturing of equipment which could pour and weigh ground coffee in definite weights. The problem arises from a real necessity of small organic coffee producers in Colombia, who require of automatic systems for

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this type of work and who have few monetary resources to buy an automatic machine for such purpose.

Students participated in a short TRIZ training, basically in the use of the Contradiction Matrix and the nine windows, and the instruction was complemented with the use of CREAX Innovation Suite software. The training was done in a remote way through video conference from Valencia, Spain.

To guide the work in the use of the Contradiction Matrix, students were asked to carry out an activity consistent with the scheme of problem-solving by TRIZ following these steps:

- Problem Clarification. Each group had to adjust the requirements of the proposed system in the Project Semester.
- Reformulation of the problem. Identification of contradictions. Each group had to identify three parameters that could favor the fulfillment of the requirements of the problem and from them the ones that will be worsened. It was suggested the use of the nine windows in order to broaden the vision of the problem and identify contradictions.
- Generic Solution. From the contradictions, the groups had to find the solution principles using the Contradiction Matrix.
- Specific solution. With the principles identified, each group had to generate at least two ideas per group for the solution of the problem.

5. Results

Sixteen students, organized in four groups, participated in the experience voluntarily. The groups carried out the proposed tasks, identified the contradictions based on the analysis of the problem, selected the principles suggested by TRIZ and generated a set of solutions to their problem.

To illustrate the results, one of the groups presented the analysis that is shown in Table 2.

Some of the students’ ideas generated using the principles were:

- Principle 2. Separation. The circuit must be separated by functions of power supply, switch control, signal reception of the balance scale, visualization, and reception of other signals of administration and control.
- Principle 5. Combination. A solenoid valve must be used that works together with data from the balance scale to control the flow of the ground coffee.
- Principle 35. Parameter Changes (physical states). For an industrial implementation, the material which the prototype should be built must be stainless steel and also a drying system must be added in order to prevent the coffee from accumulating and thus impeding the normal flow through the main funnel.
After the groups submitted the results of the experience with TRIZ, a discussion group was held in order to assess their experience. The discussion was focused on the following aspects:
- The understanding of the functioning of the TRIZ Contradiction matrix
- The assistance of TRIZ to the Semester Project work.
- The difficulties in using the TRIZ principles.

The results show that there is an easy understanding by engineering students of the strategy of systematic creativity TRIZ, particularly of the Contradiction matrix. Regarding the support that the tool gives to the Semester Project, the students consider it worthy but that they require more time to fully understand the extension of the principles. According to this, it was verified that students restricted the use of the principles to generate ideas for aspects associated with electric circuits rather than the overview of the problem.

Likewise, the results have helped generate a reflection about the importance of providing tools to enhance creativity in engineering students such as TRIZ. However, a training course with more examples is required in this particular case of the Semester Project so that students can understand the meaning of the inventive principles and can use better its potential, since in the results mental inertia was detected. Despite the fact that some authors consider that little knowledge makes less effective the use of these techniques in first year students, the authors of this paper consider that they should be used to favor creative competence.

Currently, the authors are conducting empirical studies with TRIZ with multidisciplinary design teams, which will analyze the specific characteristics of manipulation of the nine windows and the identification of contradictions in these teams.

### 6. Conclusions

In a qualitative way, comparing this experience with the experiences of authors in past years with the Semester Project, it is verified that the proposition of ideas using TRIZ is higher and of greater variety than with the absence of techniques to promote creativity. Students using the TRIZ methodology make better use of information they have obtained from the review of similar systems and information available on the Internet and a greater variety of proposals between the different groups involved can be achieved.

The knowledge and use of strategies for generating ideas in engineering courses help strengthen the creative competence of students. An additional asset, when using TRIZ, is the
change that occurs in the way of generating new proposals for solutions in a guided and convergent manner that deviates from the traditional form of trial and error.

For engineering students, accustomed to procedures and techniques, TRIZ is a strategy of easy assimilation that allows them to generate new concepts using the experience of many inventors throughout history. However, unlike other strategies of more intuitive creativity, TRIZ requires a process of training accompanied by examples to appreciate better its convenience.

The Semester Project has been enriched with the use of this methodology that fulfills an absence detected within the creative competence that was not explicitly worked with students.

The integrating educational activities such as the Semester Project, which have clearly defined its working structure and are supported with adequate tools for their execution, address from the curriculum the formation of professionals with skills to face the new oriented to project enterprises.

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