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Systematic Creativity, Challenge-Based Instruction and Active Learning: A Study of its Impact on Freshman Engineering Students*

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This research shows an experiment using systematic creativity tools, challenge-based instruction and active learning methods with freshman mechanical engineering students during the course Introduction to Engineering at Tecnológico de Monterrey, Monterrey Campus. The objective is to identify ways of impacting on the creative profile and learning abilities of engineering students during their professional formation. The students were divided into two groups: one experimental group and one control group. The experimental group received an introduction to the Theory of Inventive Problem Solving (TRIZ) and was asked to identify and start working on the solution of challenging engineering projects based on active learning methods, while the control group took the course in the traditional way, typically taught in a lecture-based format. Methods for developing teams and for transitioning from worked problems to independent problem solving skills were also explored. The initial data regarding social and demographic characteristics, background, learning ability, and the creativity profile of both groups were recorded and analyzed, and showed that both groups were very similar at the outset. This allowed us to identify the impact of exposing the experimental group to systematic creativity tools, challenge-based instruction, and active learning methods and compare the evolution of the students belonging to each group. The expectation was that the students in the experimental group would enhance their creative and critical thinking skills during their educational endeavor.

Keywords: creativity; TRIZ; learning styles; creativity profile; challenge-based instruction

INTRODUCTION

GLOBALIZATION and ever-increasing diversification of products in the market are leading to rapidly accelerating technological innovation and a faster pace of change is expected. Breakthroughs will beget breakthroughs leading to ever-shorter product life-cycles and shorter intervals between developments. These facts and the diversification of customer needs are compelling employers to require more from their engineering employees than technical proficiency nowadays [1].

Many authors claim that engineers are not being well prepared for the new situation where knowledge becomes increasingly important to create a viable economy, to generate wealth, and to improve the quality of life. Recognition of this situation is leading engineering education to a turning point: until now engineering education has been focused on providing mainly technical skills in different engineering areas, whereas now engineers and employers aspire to serve the community in a socially responsible manner by developing the ability to acquire more specialized knowledge as the need arises of applying creative solutions to new, emerging engineering challenges [2].

As Stouffer et al. [3] state: 'Choosing to embrace creativity is never a zero-sum commitment that will make technical concerns secondary. Rather, creativity can be a powerful tool to enhance technical efforts to solve engineering problems of all kinds'.

It is necessary to create a distinctive and compelling engineering curriculum that leads to more relevant, vital educational opportunities by blend-

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ing research, innovation, and education in the undergraduate experience to enhance the ability of future engineers to use knowledge to solve critical social problems. Our ability as a society to remain prosperous depends now more than ever on our ability to be creative. To achieve this, engineering curricula must move away from knowledge-based instruction towards a collaborative, creative problem-solving experience [4].

These new systems of learning should contribute to fostering engineering students' abilities for creativity and innovation, to keep up to date in their professional field, and to work in teams with their colleagues. It is especially important to understand how students learn to solve problems that require creativity and innovation. Liu and Schönwetter state in [5] that 'since creativity emanates from problems, it seems more natural for engineering students to gain creativity through practice of problem solving'. Teaching systematic approaches to problem solving is expected to clarify how creativity in students can be activated.

The study was conducted with engineering freshmen who took part in the course Introduction to Engineering. This course is taken by freshmen engineering students from all engineering majors at Tecnológico de Monterrey, Monterrey Campus [6]. This study is an experiment with the aim of looking for ways of impacting on the creative profile and learning abilities required in engineering education. Students from the majors in Mechanical and Management Engineering (IMA), Mechanical and Electrical Engineering (IME), and Mechatronic Engineering (IMT) were selected for the study.

The experiment was conducted to identify ways to transform the entire engineering curricula. It is known that curricular transformation is attainable when it occurs with a specific set of goals, and when change is seen as an ongoing effort that advances a particular part of the curriculum [7]. Key issues to be addressed in formulating a plan for transformation should combine idealistic hopes with realistic expectations and post the right combination of vision, compromise, and commitment.

A major difficulty affecting curricular changes is wrought by the same drawbacks affecting change in all types of organizations, namely, resistance. Therefore, in preparation for making large-scale curriculum changes our research team is studying the experiences of other institutions that are contemplating curricular changes on a similar scale. Especially interesting is the approach developed at Texas A&M described in Froyd *et al.* [8], where they have 'champions' focused on pushing the changes desired in prototypes, and change agents who focus on reducing the resistance to change. The change agents enhance the communication and trust among different people and are a catalyst for action. Based on that experience this experiment is considered a first step and will be followed by successive experiments for constructing the basis for change agents who will catalyze the required changes in the engineering curricula.

The experiment also addresses the question of challenge-based instruction in the form of project oriented learning (POL) and collaborative learning (CL).

CHALLENGE-BASED LEARNING

The challenge-based team approach to learning is aimed at stimulating the students' creativity, problem-solving abilities, collaboration, and communication skills [9].

To define the challenge projects, the instructor may ask the students to include their personal or group concerns, community needs or issues regarding new products that will fulfill social needs or market opportunities. It is important that the instructors keep the information updated regarding the state of the art of developments in the related area. Inviting students to gain insight into the environment they will enter after graduation will give them self confidence and confront them with the real responsibilities and challenges of a professional engineer [5].

Defining the challenge project is, therefore, the first assignment of the experimental course. Students are invited to build teams to identify and describe interesting engineering challenges with relevant social impact that will lead them to acquire the knowledge needed for working on the conceptual solutions that will contribute to the resolution of those challenges. In this study they were also asked to identify the market opportunities derived from those challenges that could motivate them to continue working on them for the whole of their career, converting the problems into entrepreneurial opportunities.

In fulfilling this first assignment students begin to become aware of their educational demands, and begin to identify their learning objectives not only for this course but for their complete learning venture. In the process of the definition of the challenge projects the students need to use their initiative and develop a sense of commitment. As Williams and Mistree state in [10] 'this marks the first time that students are actively involved in the development of their learning in this class'.

It is known that the engineering design process can be divided into five broad sequential steps: needs assessment/problem definition, conceptualization, preliminary design, detailed design, and production. Commonly, during engineering design courses most student design teams go through the first three stages of the design process: determination of need, conceptualization, and preliminary design [11]. In our experiment, as students are invited to work on real-life, unsolved engineering challenge projects, they are asked only to go to the conceptualization stage. In this stage, the tasks are less certain and require more creativity, emphasizing initiative and risk taking. With this approach the challenge project is intended to become a way of motivating students and inspiring them to continue to acquire the knowledge that they will need during their educational endeavor, allowing them in later semesters to be innovative in their contributions to the solution of the selected challenge project.

The expectation is that this will also allow students to start thinking beyond the immediate limits of their own majors and begin a process that will boost their critical judgment and problem-solving skills continuously throughout their learning endeavors. When they graduate, these students should have experienced interdisciplinary learning challenges with a focus on creativity and innovation issues; they will be more informed, more involved, and more inclined to be effective and engaged innovators who are aware of their power and place within a global society and marketplace.

Students are encouraged to consider the problem definitions formulated during the first assignment only as a first step in the problem formulation process, as the problem definitions would then be refined, applying the tools and methods that they will learn during the course.

As the perception and definition of these kinds of challenge problems have to necessarily occur in information-rich environments, it is especially difficult for students to reduce the definitions to the implicated relevant information. Based on this fact, they were requested to go through a process described as information reduction to filter the relevant information from the irrelevant information for the problem statement [12] until they achieved a definition that was acceptable for starting work on the challenge problem.

FOSTERING CREATIVITY

Creativity for many people is a kind of puzzle, a paradox, and for others, a mystery. Some people have a concept of creativity related to divine inspiration or to romantic intuition. The number of definitions for creativity that can be found is surprising: many theoretical points of view and positions are possible. However, almost all authors agree that creativity is the ability to find new ways to use existing knowledge for solving problems, and when those novel solutions impact in the market successfully, the result of creativity is innovation.

Torrance [13, 14] defined creativity as 'the process of sensing problems or gaps in information, forming ideas of hypotheses, testing, and modifying these hypotheses, and communicating the results'.

Four major aspects for studying creativity can be identified in the literature [15]:

1. the creative process;
2. the creative person;
3. the creative product;
4. the creative situation.

An understanding of these major aspects of creativity can help educators to develop feasible plans to foster student creativity. Studies that consider these aspects tended to describe a creative person in terms of:

1. cognitive characteristics;
2. personality and motivational qualities; and
3. environmental variables

Research performed by Chen and Hsu [16] with professors from two Taiwanese universities concludes that engineering students' creativity may be categorized in five dimensions:

1. exploratory disposition;
2. problem-solving attitude;
3. problem-solving capability;
4. personality traits; and
5. problem-solving approach.

They suggest that a model for fostering creativity in engineering education programs can be developed using these five dimensions.

In [17] some possible ways for enhancing the creativity within the classroom are given. The following aspects are reinforced in this experiment:

- Students should not be restricted to exercises and activities with only one possible correct answer.
- Students should be taught to review and to refine creative ideas.
- Students should be stimulated to present and defend their ideas.
- Activities should be developed that require student initiative and independence.
- An atmosphere of respect and acceptance of student ideas should be promoted.

In our experiment, similar to the experience of Overveld *et al.* [18], we seek to foster creativity in an engineering curriculum by stimulating positive attitudes regarding creativity and innovation, as they are vital for the future of engineering and engineering education. Commonly, studies for teaching creativity look for the use of traditional methods such as brainstorming, mind mapping, attribute listing, Synectics, morphological syntheses, and lateral thinking, among others [5, 18]. In this study we focus on fostering creative thinking skills that enhance students' problem-solving attitudes and problem-solving capability by using a strong problem-solving approach like TRIZ, as it is now widely recognized that it is an important amplifier for idea generation and problem resolution phases [11].

THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ)

Created by Genrich Altshuller in 1946 [19], TRIZ (pronounced trees) is a Russian acronym for Теория Решения Изобретательских Задач, which means Theory of Inventive Problem Solving.

It is a systematic approach for breakthrough solutions to difficult engineering problems and challenges based on systematically finding a creative solution, if one is possible. TRIZ is a process based on science that is used as tool for the solution of contradictions in technical systems. TRIZ allows the prediction of the evolution of systems while it is based on databases of creative solution methods that have been applied to past similar contradictions.

Initially, TRIZ was used exclusively in the former Soviet Union, providing engineers with effective ways to face technological challenges. During the last decade TRIZ has been used by many leading corporations from all over the world to increase their competitiveness.

The main TRIZ axiom is that evolution of technological systems is governed by objective laws, what Altshuller called Laws of Technological System Evolution. Altshuller discovered, after an extensive analysis of thousands of successful innovations, that the evolution of a technology included apparently accidental or risky steps; nevertheless, he realized that in the long term the technological evolution repeated certain patterns. The application of these patterns allows the systematic development of new generations of technologies and products. In other words, TRIZ is based on the premise that the evolution of technological systems is governed by certain laws that allow for anticipating the evolution of technological systems and it helps to design more efficient systems of problem resolution [20].

Altshuller developed the concept of system conflict: a problem requires creativity when attempts to improve some system attributes or goals lead to deterioration of other system attributes. TRIZ assumes that the degree of difficulty of a problem depends on the way in which it is formulated; as problems are formulated more clearly, reaching a solution for them will be simpler. Formulating problems by identifying the underlying conflict is an important step toward their solution. Two types of conflicts have been typified: technical contradictions and physical contradictions.

A technical contradiction exists when two systems' attributes or goals, such as weight versus strength or energy loss versus quantity of a substance, lead to system conflicts. A physical contradiction exists when the same attributes, such as temperature, energy, pressure, etc., embrace conflicting requirements. Traditionally, when facing conflicting goals, engineers tend to determine which goals have higher priority for establishing compromise or trade-off solutions. Creative solutions, however, mean surmounting the conflict by satisfying all colliding requirements. This approach is a guide to a new, different way of thinking in engineering challenges that leads to the vision of transforming system conflicts into opportunities for innovation.

Commonly TRIZ beginners do not understand how it is that in defining a problem by 'what gets better and what gets worse', one can identify a solution through an inventive principle. This is easier to understand by stating it in following way: Altshuller, while analyzing the patents' databases to find how inventors solved problems, postulated the thesis that an analogy may be established between two problems by discovering the underlying contradiction that impedes resolution. Those solutions generalized as 'inventive principles' could then be applied to any other problems having the same typified or generalized contradiction.

This process should be understood as an abstraction that eliminates other details that may be impeding identification of the underlying contradiction. The stronger the contradiction, measured in the degree of the deterioration of the parameter or feature we do not want to deteriorate, the greater the impact on a solution that avoids that deterioration.

The Theory of Inventive Problem Solving (TRIZ) rests on a chain process that reformulates the initial problem until it is sufficiently clarified: ARIZ is a logical group of processes for reinterpreting the initial problem through consecutive reformulations. Solving a problem using ARIZ involves beginning with an initial definition of the problem formulated under the following rule: 'Everything in the system stays without change, but the required function is performed' [20]. The next step in the formulation is to simplify the conflict scheme and, later, considering the available material, the space energy and time resources.

The TRIZ content used is based on a previous experience at Pennsylvania State University by Ogot and Okudan [11]. This content has a pilot character and has been under evaluation prior to proceeding to the following stages of expansion of this experience to more freshman engineering courses. The subjects of the course were as follows:

- Introduction to TRIZ
- Definition of Problems
- Concepts of Ideality and Ideal Final Result
- Definition of Technical Contradictions
- Altshuller Inventiveness Principles
- Altshuller Parameters
- Technical Contradictions Matrix
- Physical Contradictions
- Principles of Separation
- Introduction to Substance–Field Diagrams

As creativity is the ability to use knowledge to solve problems and produce novel works valued by society, freshmen students normally lack sufficient domain knowledge, which results in low levels of creativity. Drawing from solution patterns and general design principles synthesized from inventive knowledge contained in thousands of patents, TRIZ supplements the limited knowledge the designer may have by suggesting possible solution directions that may be applicable to the current engineering problem.

TRANSITIONING TO INDEPENDENT PROBLEM SOLVING

As stated by Jonassen *et al.* [21], the kind of problems most often encountered in engineering courses are those problems for which the parameters are specified in the statement, and that have predictable, exact solutions that are achieved by applying algorithmic solution methods that imply using 'correct' rules and principles. When learning to solve this kind of problem, engineering students commonly learn to obtain the unknown parameters from equations starting from the known or given parameters. The process is most often reduced to solving the equations and rules for finding the required answers. This type of algorithmic process implies that solving problems is a procedure to be memorized and practiced, in which the instructor assesses if the answers are 'correct' or not. This leads students to think that there is a right answer and a wrong answer, while in real life there are many ways to do things and it is not a matter of getting a 'right answer' but of achieving the best solutions for customers.

Workplace engineering problems are commonly very different from the types of problems that engineering students most often solve in the classroom; therefore, learning to solve classroom problems does not necessarily prepare engineering students to solve the kinds of problems that they will have to face during their professional lives. Real life engineering problems are ill-structured, complex, ambiguous, and inherently difficult, as they commonly contain conflicting goals. Very often workplace problems are assessed with non-engineering success standards, possess non-engineering constraints, and frequently their solution process leads to new unanticipated problems.

Workplace problem solving mostly require engineers to be able to first identify and formulate the problem using multiple forms of problem representation, and then to manage distributed knowledge, and also to recognize the importance of working in collaborative teams. Real life problems do not have unique 'correct' solutions and the assessment often stems from success or failure criteria, not from engineering standards.

To give engineering students the most comprehensive preparation, they should be involved in solving those kinds of problems that require resolving the complexities and ambiguities of workplace problems consistently throughout the curriculum.

For this study already worked out classroom examples were obtained from TRIZ literature [22–25] and were combined with real life challenge problems, the selection process of which is described later in this chapter. A classroom TRIZ example is a fully solved example problem that consequently allows the student to examine the methods, concepts, and the steps leading to possible solutions of an inventive problem. Unlike other classroom problems no 'unique correct solutions' are given, only 'possible solutions', which are provided to the students as a means to self assessment of the solutions they implemented.

The following example illustrates the type of classroom TRIZ problems used in this course.

Classroom TRIZ example [25]: History of the 'Russian light'

In the second half of the 19th century, streets of European capitals were illuminated by arc lamps—the so-called 'Russian light' (see Fig. 1). The electrodes are carbon rods in free air. To ignite the lamp, the rods are touched together, thus allowing a relatively low voltage to strike the arc. The rods are then slowly drawn apart, and electric current heats and maintains an arc across the gap. The tips of the carbon rods are heated to incandescence, creating light. The rods are slowly burnt away in use, and need to be regularly adjusted to maintain the arc. The question is what should be done to maintain the same distance between the carbons irrespective of the burn-out of the rod ends?

Many ingenious mechanisms were invented to do this automatically. A clock-operated device (see Fig. 2) was invented that brought the rods

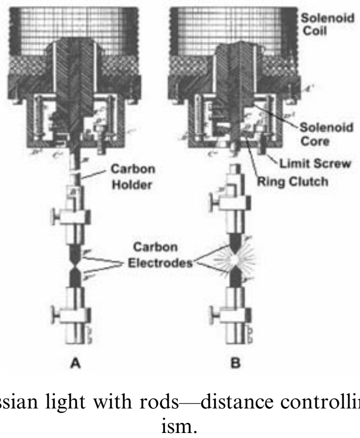

Fig. 1. Russian light with rods—distance controlling mechanism.

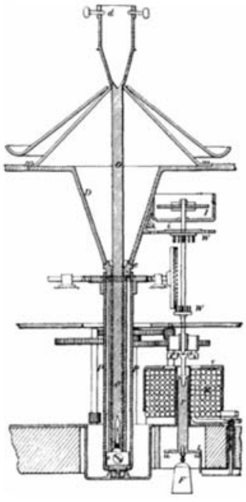

Fig. 2. Staite–Petrie lamp.

together. Gear wheels, springs, rockers, a driving mechanism . . . all those components needed adjustment, lubrication and repair. How could it be made reliable and less expensive?

For this example students are asked to use two TRIZ tools: Ideal Final Result (IFR) and Technical Contradiction Table.

- IFR: The best mechanism performs the required function without even existing. How could it be made reliable and less expensive? The bottleneck is the clock device. But we already know that the best mechanism is the one that is absent. Let us fantasize a little—let carbons adjust the distance between each other, without any clock device . . .
- Control Solution: This is how Russian engineer Pavel Nikolayevich Yablochkov solved the problem with the 'Yablochkov candle' (see Fig. 3). The carbons stood upright, parallel to each other—this meant that the candle did not require complex regulating mechanisms. It was the first arc lamp that was put to wide practical use and that greatly accelerated the development of electric lighting. It was cheap and simple compared with previous arc lamp designs, and it was far brighter than gas lamps. The solution is simple, like all works of genius. What looked impossible at first sight, turned out to be the Ideal Final Result of the inventive problem.

After working in teams to look for solution ideas, students post their responses on a 'Discussion Board' in the Blackboard Academic Suite of the course. Randomly selected students present their solutions for open discussion. Afterwards the 'control solution' is presented by the instructor. The whole group is then invited to compare the control solution with their own solutions. The next step is comparing this solution with other lighting devices that were developed after the Yablochkov candle, such as the Edison lamp, CFL, HID, LED lamps, and so on. This discussion helps students better understand the IFR concept and its relationship to the technology available at the moment of facing the problem solution. This step is also especially useful for helping them to understand the patterns or laws of evolution of technological systems. These presentations and discussions provide students with the opportunity to articulate their learning.

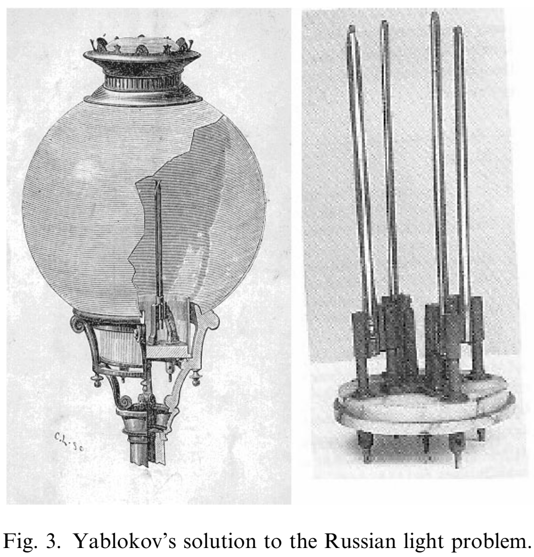

Fig. 3. Yablokov's solution to the Russian light problem.

Example of a challenge problem

It should be recalled that in this experiment, practice challenge problems are formulated as the result of the first assignment, in which the student teams were asked to identify and formulate problems they perceived in society.

The process of how to most effectively shift the learner from studying worked out examples to independently solving challenge practice problems has been identified as an essential question [26]. The approach used in this case was to start working on both types of problems in parallel and, later, after the problem solving methods had been applied to classroom problems, continue working only on the challenge practice problems.

An aspect emphasized for students in project selection and definition is the challenge posed to engineering in this century because of the ecological damage caused by non-sustainable technologies in the past. This situation creates an obligation to find solutions that not only give answers to the specific problems, but that also assure that the implementation is sustainable from environmental and social points of view. These circumstances increase the degree of difficulty and, therefore, require more structured and efficient methodologies for the search for solutions. With this in mind, the course combined the contents of TRIZ with the e-learning tutorial Chronos [27]. The following is a briefly described example of one challenge problem formulated by student teams and the definition refinement process.

Initial definition

The number of automotive accidents is increasing. New technologies for reducing car crashes and/or for reducing the severity of such accidents should be developed. (two student teams have simultaneously chosen this challenge problem definition). All initial definitions were presented by each team to the whole group. The instructor assumed the role of discussion facilitator and advised the teams on how to further refine their challenge project definitions. After their second research process to obtain more precise information, these teams came up with the following summarized problem definition.

Refined definition 1: An important percentage of automotive accidents occur due to the following causes:

- insufficient driver attention due to sleepiness, tiredness, exhaustion;

- reduced driving capability because of alcohol or drug consumption;
- speeding;
- reduced visibility due to smog, rain, and other weather related causes;
- reduced friction between tires and roadway due to rain, snow, and oil spills.

Using this refined definition, the teams came to the following differentiated challenge problem reformulations:

Team A challenge problem 1st reformulation

The existing technology may be used for avoiding accidents due to insufficient driver attention caused by sleepiness, tiredness and exhaustion. By using sensors it is possible to detect inadequate driver conditions and produce alerts and other measures for avoiding accidents resulting from these causes.

Team B challenge problem 1st reformulation

The existing technology may be used for avoiding accidents due to reduced visibility. By using sensors, actuators, and communication technology it is possible to detect and warn about potentially dangerous situations to avoid or at least reduce the severity of accidents.

Because of space limitations only some highlights of Team A will be further described in this paper.

Team A challenge problem 2nd reformulation: Driver Alerting Systems

'According to the National Highway Traffic Safety Administration, driver drowsiness causes more than 1500 traffic deaths (about 4% of all fatal crashes) every year in the United States. Our project is intended to develop a system of devices that alerts drivers to prevent possible accidents because of driver distraction due to fatigue, sleepiness, tiredness or similar causes. The system of devices is aimed at sensing different situations that may endanger safe driving to save the driver as well as other people who are in the danger zone and can be affected by a possible accident'.

The following relevant information has been found during the patent search:

- U.S. Patent 6,426,702: Driver fatigue detector
- U.S. Patent 5,689,241: Sleep detection and driver alert apparatus
- U.S. Patent 5,585,785: Driver alarm
- U.S. Patent 5,570,698: System for monitoring eyes for detecting sleep behavior
- U.S. Patent 5,508,685: Vehicle and device adapted to revive a fatigued driver

From this information, the following directions for solutions have been identified: Detecting drowsiness by means of different factors as effects of early imminent sleep, hand pressure on the steering wheel, acceleration changes in the vehicle for detecting abnormal behaviors in driving patterns. Different types of alerting signals may be activated such as turning on the radio to its highest volume, an alarm buzzer, strong vibrations of the seat belt and/or of the seat, or the spraying of a fluid on the driver's face, which may be deactivated afterwards. If these alarm measures do not work, it would be necessary to use sensors and actuators to reduce the vehicle's speed until it stops while simultaneously warning other vehicles until aid can be received.

What is the challenge? Implementing a safe system that does not lead to inadequate effects nor cause false alarms while keeping the system costs at a reasonable level.

At the end of the course, students submit a major document: a report on their challenge project with an explanation of how they used TRIZ and the conceptual solutions proposed, and how their solutions take into account the Chronos tutorial. This document includes a reflection on their learning experience throughout the semester and how they intend to continue learning how to develop solutions to the challenge problems.

SETUP OF THE EXPERIMENT

For the experiment, two groups of students were selected. One of them (called experimental) was exposed to this experimental course. The students in this group were organized in teams that were encouraged to identify interesting, motivating engineering challenges for application of the TRIZ systematic creativity tools.

Creativity testing is used in addition to product and performance evaluations in order to ensure that creative potential, as well as creative productivity, is assessed.

As a measure of the degree of student motivation in the experimental group, an anonymous initial survey was carried out. The results are shown in Table 1.

As 11 students chose answers 3, 4 and 5, students in this group were given the opportunity to change to a different group if they preferred.

Table 1. Initial survey regarding motivation for participating in this experiment

	For me, participating in this experiment is:	Number
1	A lucky opportunity to learn and become a better 21st century engineer	22
2	An opportunity to learn something new	34
3	I accept it, but can live without it. I give you the benefit of the doubt.	7
4	It means an additional effort that I would rather not make.	2
5	Something I don't want to do. Why me?	2
	Total	67

The course was taught under the following scheme:

- Team-teaching
- Challenge-based instruction
- Project Oriented Learning and Collaborative Learning

TEST RESULTS

Several instruments for identifying the learning styles and abilities for self orientation and self regulation and for measuring creativity were applied to the students who took the course Introduction to Engineering in both groups for the purpose of measuring their creative profile and innovation abilities.

These tests were administered at the end of the course to measure the impact on students' creative and innovation abilities and their creative profile. The set of tests applied measures intrinsic to student characteristics related to creativity, such as socio-demographic data, learning styles, self orientation, self regulation, and creativity.

The following measurement tests and tools were applied:

1. a survey for collecting socio-demographic data;
2. VARK questionnaire [28, 29] to obtain the learning style, since it is believed that this may be related to promoting creativity;
3. questionnaire for Research of Self Orientation Profile (CIPA from its Spanish acronym) [30];
4. a creativity test: Are you a creative person? [31],

The VARK questionnaire was developed in 1987 by Neil Fleming, Lincoln University, New Zealand [29]. This test was the first to systematically present a series of questions with help-sheets for students, teacher and employees. The VARK questionnaire aims to find out how people process information. The VARK questionnaire allows people to identify their own learning style. The questionnaire has 13 items that reflect the learning style: Visual (V), Aural (A), Read or Write (R) and Kinesthetic (K). A visual person usually takes advantages of images. They try to see all of the information and then draw their own maps and use symbols. People that are Aural usually take in the information by hearing. They attend lectures and tutorials; they discuss topics with lecturers and other students and explain new ideas to other people. Those that are Read or Write obtain information by writing lists, glossaries, definitions, handouts; they usually read lecture notes, essays and manuals. Kinesthetics use all senses: sight, touch, taste, smell and hearing. They enjoy laboratories, field trips, and field tours, examples of principles, applications, and hands-on approaches.

Table 2. Comparative socio-demographic data

	Age (years)	%	Gender %
Control group N = 51	17	9.8	Males 94
	18	56.8	Females 6
	19	29.4	
	20	3.9	
Experimental group	17	8.3	Males 93
N = 60	18	51.6	Females 7
	19	38.3	
	20	1.6	

The CIPA test [30] is aimed at identifying the self orientation and the self regulation levels. The inventory used contains 41 items that are divided in four components: 1. Planning and selecting strategies; 2. Self regulation and motivation; 3. Interdependency and autonomy and 4. Use of experience and critical conciseness.

The results of the VARK test in Fig. 3 show that both students groups have higher scores in the 'kinesthetic way', which means that they prefer to learn by experience and practice. At least at the beginning of their college education, all the students show a similar profile.

Tables 2 and 3 show the socio-demographic data of the students in both groups. It can be observed that there are no big differences between groups. The majority are 18 years old, male, natives of the state of Nuevo León, single, and full-time students.

As for the capacity for self orientation in these two groups (Fig. 4), it was found that in the experimental group the highest average was obtained in component 3: independence and autonomy, which means that the students show willingness to learn and/or to obtain what interests them. They show willingness to assume responsibility for their acts, besides having a suitable concept as apprentices and individuals. Component 1: planning and selection of strategies was the second place in preference. Component 4: use of experience and critical conscience was in third

Table 3. Comparative socio-demographic data

	Birthplace	%	Marital status	Currently employed
Control Group	Monterrey, Nuevo León	58.8	Single 100%	Yes 4%
N =51	Another state of the Mexican Republic	41.1		No 96%
	Other countries	0		
Experimental Group	Monterrey, Nuevo León	66.6	Single 100%	Yes 15%
N = 60	Nuevo León	5		No 85%
	Other states in Mexico	23.3		
	Other countries	3.3		

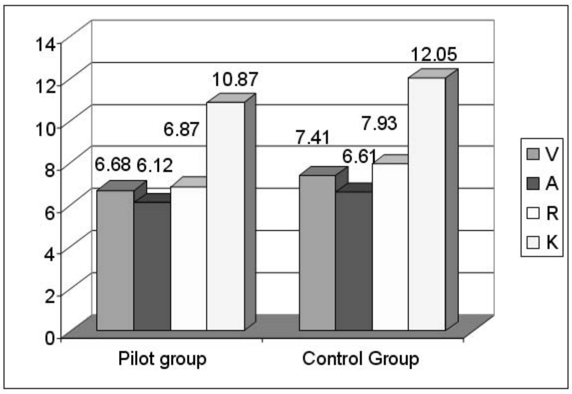

Fig. 4. Comparison of the VARK questionnaire results.

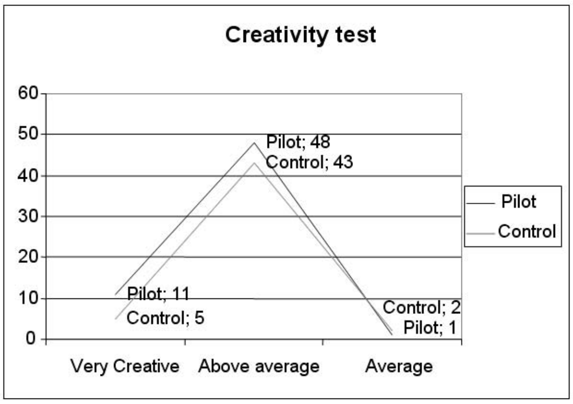

Fig. 5. Comparison of the creativity test.

place and component 2: self regulation and motivation was in last place.

The values of the Creativity Test are measured in three different categories: very creative (when the value obtained is 65 or higher), above average (when the value obtained is between 40 and 64), and average (when the value obtained is between 30 and 39) (Fig. 5). In the control group only 5 students obtained values of 'very creative', while 43 students had values 'above average'. Of the 51 students in the control group, only 3 students received average values (39, 38, and 31 points). When the results of the test of creativity as percentages are compared, it is possible to determine that only 9.8 % of the students in the control group were in the 'very creative' category whereas in the pilot group this category included 18.3 % of the students. The category 'above average' was reached by 84.3 % of the control group and by 80 % of the pilot group. Of the students in the control group, 5.3% were categorized as 'average', compared to only 1.6 % in the experimental group.

Finally, to determine if there were noteworthy differences between the groups, an ANOVA test was applied for the most important variables related to the creativity profile in the two groups. The results are shown in Table 4 [32].

It is important to note that the socio-demographic characteristics of both groups are very similar: the students, in the majority, are male, between 18 and 19 years old, single, and most do not yet have job experience. The highest percentage indicates that their parents have higher education. The preference for engineering was the priority when choosing which major to study. These freshman students are highly motivated: they want to become engineers.

With this first analysis we determined that compared with the control group, the pilot group showed a higher self-orientation profile in the use of experience. The students in this group have a critical conscience that shows they make use of their accumulated experience in solving problems in daily life and other areas. Besides valuing their own experience, they are also able to appreciate the experience of others. They practice critical reflection that may enhance creativity and that could have been influenced by the types of projects on which they worked during the course as well as by the use of systematic creativity tools.

Although most of the students in the control and pilot groups obtained values of 'above average' in the Test of Creativity, the results of the pilot group show a greater percentage of students with values in the 'Very creative' and 'Above average' categories. At this time, in the first semester of their college education, these are the only variables in which the students showed a significant difference. A possible interpretation is that the activities in the experimental group contributed to enhance their creativity. The rest of the variables are very similar in both groups. In future research it would be worthwhile to apply this instrument again to determine if there have been changes in the values of the 'very creative' category in both groups.

Regarding the comparison of the final grades for the course, the control group obtained a slightly better average than the pilot group, nevertheless, both averages can be classified as very satisfactory as both were over 9.5 (on a scale where the maximum is 10).

Table 4. Variance analysis

Variable	GF	F	Sig.	Determinant factor
Experimental group	1	33.0	0.000	0.226
Age of student	1	0.558	0.644	0.010
Sex of student	1	0.591	0.444	0.004
Program	1	0.229	0.633	0.007
Creativity score	2	0.078	0.925	0.017
Learning style	3	1.24	0.296	0.007

Tests b, c and d will also be applied in the following academic years to the students in both groups to follow up on their evolution.

CONCLUSIONS

To remain competitive, colleges and universities must foster creativity in their faculty and students. The next generation of engineers will need a creative outlook to approach technical problems in new ways. Comprehending creativity and the creative process in the framework of engineering is crucial for fostering creativity in engineering students. The instructors can use systematic creativity methods to foster student creativity through teaching strategies oriented towards challenge problem solving.

The approach used in this experiment seeks to contribute by using systematic creativity tools, challenge-based problem solving, and active learning methods, and tools for measuring the creativity of the freshman engineering students at Tecnológico de Monterrey's Monterrey Campus.

This study did not prove that this type of instruction is better than a traditional approach, as the statistical comparisons were made only between two groups and the effect after only one semester is not enough for ultimate conclusions.

Nonetheless, the results of this study suggest that interesting differences were observed between the experimental group and the traditional control group in the percentage of students in the category 'very creative', and this was the only variable that showed a significant difference in the tests. However, the results may be considered similar at the beginning of their college education, and it will be important to apply this test again in later semesters.

If the particular use of systematic creativity methods such as TRIZ increases the creative potential of students, from a learning styles perspective, it is not demonstrated by a measurement made in a particular case. However, it appears that methods of systematic and knowledge-based creativity tools like TRIZ, compared with the sole use of traditional methods, should produce an increase in the creative potential and output of the students. This conclusion coincides with those of the experiment performed by Ogot and Okudan [11], who state that they found that teams exposed to and using TRIZ methods were able to produce an average of 35 unique solutions per section, a 115% increase over non-TRIZ sections that averaged 16.3 unique solutions per section.

The use of challenging workplace engineering problems that are complex, ambiguous, and ill structured and often with conflicting goals has important implications for engineering education as these problems are similar to the ones that engineers have to solve at their workplace. Extending this inference to the design of the engineering curricula requires more research within the engineering education community.

This experiment has proven to be an appealing way to teach an engineering course, with traditional lectures replaced by a combination of classroom examples and challenge problems that require the students to search for and acquire new knowledge, skills, and abilities to solve nonclassic classroom problems. The experiment has also shown that fostering creativity in the engineering classroom provides better student–professor interaction. It is a way of engaging modern engineering students who otherwise may not be motivated by the traditional lecture-based format and note-taking approach to education.

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