AC 2012-4512: EXPERIMENTAL ASSESSMENT OF TRIZ EFFECTIVENESS IN IDEA GENERATION

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Experimental Assessment of TRIZ Effectiveness

in Idea Generation

ABSTRACT

TRIZ is an idea generation method that identifies conflicting principles in a given problem and then searches for previous solutions that have solved similar conflicts. How effective is TRIZ? This is an important question because it is conducive to a second question: what makes TRIZ (more, or less) effective? Understanding this provides the opportunity to improve the teaching of TRIZ, a more efficient use, and even the possibility of improving the method itself. In this paper we present results from experiments comparing TRIZ against control groups; the experiments were conducted simultaneously at three institutions: University of Texas at El Paso (UTEP), Penn State, and University of Maryland. Besides contrasting results at different institutions, the variety of experiments allows us to contrast participants at the graduate and the undergraduate level (all of them engineering students), working a design problem. In order to have significant results, we followed a rigorous experimental procedure for which a set of guidelines were produced. Such experimental guidelines address (1) Design of Experiment, (2) Execution of the Experiment, and (3) Assessment of Results. With respect to assessment, we used traditional outcome-based metrics (quantity, novelty and variety) and adapted and improved them to solve some of their issues at the conceptual (definitions) and implementation levels. Experimental results indicate that TRIZ improves Variety and Novelty of ideas generated while decreasing the quantity of ideas produced.

1 Introduction

Creativity is a fundamental skill that engineers must develop [1,2] in order to be active participants of the innovative process in engineering; this is crucial for a country that desires to remain competitive in this rapidly changing, technology-oriented world. There is a generalized concern amongst industry and academic leaders about the effects of traditional engineering education on students' creativity. Engineering programs teach key capabilities such as problem solving and analytical skills, but the process of creation and generation of solutions and alternatives remains a difficult task. In response to this, some universities have increased the quantity and quality of design experiences to give students the opportunity to experience open-ended design[3,4]. With this, students apply design strategies and tools (i.e. design theories and methodologies). Through the design process, students learn mostly about external representations of artifacts and how to design them, but students are seldom taught on how to improve their creativity levels; and this is a critical step in the innovation process.

Improving the creativity of the ideation of concepts is as difficult in engineering as it improving the creativity of a painter or sculptor. Every academic institution has a different approach when it comes to teaching creativity. Only some institutions have developed courses that focus only on improving the creativity skills of students; most institutions teach creativity-enhancing tools and methods as part of the conceptual design process (see, for example, Dieter and Schmidt [5]). Instruction on design methods occurs during an introductory or capstone design course under a very strict schedule. Therefore, research on the effectiveness of methods to improve creativity is critical to engineering educators.

In previous research, the authors conducted a pilot study on TRIZ [6](also sketching and smartpen use) that served as the basis for the experimental study presented in this paper. The objective of this paper is to present experimental results of a study of TRIZ (an abbreviation of a Russian acronym of "Teoriya Resheniya Izobretatelskikh Zadatch" meaning theory of inventive problem solving). The hypothesis of this study is: "*Can TRIZ improve the ideation performance of engineering students?*" The authors replicated the experiments at their corresponding institutions: Penn State University, University of Texas-El Paso, and the University of Maryland

2 Background

TRIZ is the name for a design approach developed by Genrich Altshuller [7] during the mid 1900s and reported in the 1960s. The TRIZ methodology developed by Altshuller identified patterns of innovation in devices, articulated heuristic approaches to design problems, proposed an overall algorithm (called "ARIZ") for applying the methods and heuristics. The portion of the TRIZ methodology used most frequently by instructors is the contradiction matrix. Altshuller created a list of 39 engineering characteristics that could be used to define design problems. He also generalized 40 inventive principles from the patents he studied. The contradiction matrix, a table that directs a designer to apply up to four different inventive principles to improve a design in such a way as to overcome any identified contradiction.

There is a thriving consultancy market for TRIZ-enabling software and TRIZ training. The authors' experiences indicate that this is because the TRIZ method is based on patents (implying successful novelty) and that the contradiction matrix gives clear direction to students and practitioners. The contradiction matrix leads users to analogies to be used in design problems, so it is appropriate to summarize representative and recent studies on analogies.

2.1 Analogies and Creative Ideation

There has been a renewed emphasis on the use of analogies for design in general and the use of biology-inspired analogies in particular. Chan et al. [8] conducted a rigorous, full-factorial experiment on the impact of analogies on the ideation process. The study group included 153 seniors in engineering (95% were mechanical engineers). Students generated ideas for a portable, low-cost, energy harnessing device for human use. During the experiment students were given analogies in the form of patents for similar devices. Some students were shown patent art, others were given narrative descriptions. The patents differed in how close they were to the domain of human energy use. The results found that analogies from domains further from the design field were more likely to inspire novelty in generated ideas, but would reduce the number of ideas generated by the student designer.

Chui and Shu [9] studied students doing design generation while being presented with textual (word) stimulus. These researchers discovered that the students tended to use the stimuli as verbs more than nouns, especially as the difference between the domain of the word and the design task increased. Further results included an increase in the novelty (as determined by judges) of concepts when the stimuli was given.

Ahmed and Christensen [10] preformed a protocol study on twelve practicing engineers in the mechanical aerospace industry. Six of the engineers were studied while they worked on a different aspect of a conceptual design task and the others were working on different detail design tasks. It was observed that all the engineers used analogies without prompting. There was a difference in how the analogies were applied; novices used analogies to gain knowledge about the design while more experienced engineers used their analogies for more abstract reasoning.

2.2 Creative Ideation Using TRIZ

There are reports of industry-based engineers using TRIZ with success. Raskin [11] presents studies on the use of TRIZ at Ford and Hewlett Packard. Okudan et al. [12] conducted a study to compare the brainstorming process to the use of TRIZ with brainstorming. Students addressed the task of controlling the air velocity for fumehoods as presented by an industrial sponsor. Students demonstrated improvements in ideation novelty, variety and quality when using TRIZ in addition to brainstorming.

Howard et al. [13] did research on ideation in industry in the United Kingdom. This group worked with practicing designers during their brainstorming process. The designers were given selected TRIZ innovation principles during the design process. Results from the study indicated that the TRIZ principles helped improve the brainstorming process sessions and encouraged the designers to find less obvious ideas.

3 Experimental Methodology

In order to improve the creativity levels of engineering students, first, the creative process must be better understood. In this study, the experiment provides quantitative data to answer the hypothesis: "*Can TRIZ improve the ideation performance of engineering students?*"

3.1 Factors and Treatments

The factor for this experiment is the TRIZ method; it will have two levels: presence and absence. Groups of students working on the same design problem will be asked to use TRIZ (previous training) while other groups will work without a formal idea generation method (i.e. control group).

The treatment for the groups using TRIZ consists of a power point lecture and handouts for TRIZ principles and Contradiction Matrix.

3.2 Responses

Student groups will generate ideas represented as sketches and diagrams; these ideas will be evaluated using a set of effectiveness metrics based on Shah et al. [14]. The responses in this experiment are Quantity (Total number of ideas generated), Novelty (How unusual or unexpected an idea is as compared to other ideas), and Variety (How different concepts are from each other).

3.3 Choice of Experimental Design

Since the experiment involves only one factor (TRIZ), the experimental design model is single comparison; this requires 2 runs, one for TRIZ and one for the control group.

3.4 Participating Subjects

Table 1 shows the composition of the participating subjects at each university. UTEP participants were senior mechanical engineering students, 21 students participated in the control group while 9 students participated in the TRIZ intervention group. A total of 20 students from the University of Maryland participated in the control group while 21 students participated in the TRIZ intervention group.

Table 1.

University	Participating Courses (Fall 2010)	Unit of Analysis	Student Level
UTEP	MECH 4466 (9 in 1 section) MECH 4364 (21 in 1 section)	Individual	Senior
PSU	EDSGN 100 (120 in 4 Sections) QMM 492	Teams	Graduate
Maryland	ENME600 (20 in 1 section) ENME600 (21 in 1 section)	Individual	Graduate

3.5 Design Task

The problem used for this experiment is the Traffic Light redesign shown in the Figure 1.

Concept Generation Assignment
Energy-Efficient Traffic Lights Can't Melt Snow

Traffic accidents are blamed on energy-efficient traffic lights getting covered with snow.
By Dinesh Ramde

Cities around the country that have installed energy-efficient traffic light are discovering a hazardous downside: The bulbs don't burn hot enough to melt snow and can become crusted in a storm – a problem blamed for dozens of accidents and at least one death.

"I've never had to put up with this in the past," said Duane Kassens, a driver from West Band who got into a fender-bender recently because he couldn't see the lights. "The police officer told me that new lights weren't melting the snow. How is that safe?"

Many communities have switched to LED bulbs in their traffic lights because they use 90 percent less energy than the old incandescent variety, last far longer and save money. Their great advantage is also their drawback: They do not waste energy by producing heat.

Short of some kind of technological fix, "as far I'm aware, all that can be done is to have crews clean off the snow by hand", said Green Bay, Wis., police Lt. Jim Ringe. "It's a bit labor-intensive"

Illinois authorities said that during a storm in April, 34-year-old Lisa Richter could see she had a green light and began making a left run. A driver coming from the opposite direction did not realize the stoplight was obscured by snow and plowed into Richter's vehicle, killing her.

Authorities said dozens of similar collisions have been reported in other cold-weather states, including Iowa and Minnesota.

Not every storm causes snow to stick to the lights, but when is night and the snow is wet, drivers should beware, said Gary Fox, a traffic engineer for the city of Des Moines, Iowa.

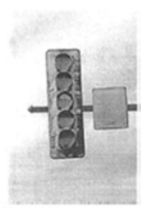
Exactly how much a technological fix will cost is unclear, but it will surely cut into the savings and the energy efficiency many cities are enjoying.

Wisconsin, which has put LED bulbs at hundreds of intersections, saves about $750,000 per year in energy costs, said Dave Vieth of the state Transportation Department. LEDs installed seven years ago are still burning, while most incandescent bulbs have to be replaced every 12 to 18 months, he said.

One reason there have been so few deaths is that drivers know they should treat a traffic signal with obstructed lights as a stop sign, traffic experts say. "It's the same as if the power is out," said Dave Hansen, a traffic engineer with the Green Bay Department of Public Works. "If there's any question, you err on the side of caution"

Associated Press writers Patrick Condon in Minneapolis and Melanie Welte in Des Moines, Iowa, contributed to this report.

This Dec. 2009 image made from video provided by WLUK-TV Green Bay (AP)



This photo provided by the Oswego Police, was taken after a fatal crash in Oswego, Ill. (AP)

Figure 1. Design Task: Traffic Light Redesign.

3.6 Other Variables

Ideally, the factor (TRIZ), and the responses (Quantity, Novelty and Variety) are the only variables of interest. In real life, multiple variables exist that must be addressed in order to obtain the main effect of the factor in the responses. Some of these variables can be blocked or minimized and others can be ignored. An effort was made for all runs to follow a similar process, in similar classrooms. The subjects bring several variables to the experiment (e.g. personality, skills, background, motivation, experience, etc.). The subject variability was addressed by having a homogeneous group (i.e. students taking the same course, same major) with the expectation that existing differences can be averaged out. Another important element of variability in the subject is motivation; this was addressed by assigning course grade credit (between 2% and 5%) to students for their completed participation.

4 Experimental Setup

The experimentation sequence followed by the three institutions was as follows:

Warm-Up: students were asked to work on a preliminary ideation task. UTEP students worked on an unrelated ideation task for 20 minutes without a formal ideation method. UMD students worked on the standardized task to generate "unusual uses of tin can" for 10 minutes. Penn State students didn't work on a warm-up task.

Introduce Design Task: The experiment facilitator introduced the design task to the students; students had a chance to ask questions about the design task (i.e. traffic light redesign). This step took 10 minutes at each of the 3 institutions.

Ideation Session 1: Students generated and recorded their ideas for 20 minutes without using a formal ideation method; this was repeated at the 3 institutions.

TRIZ Training Intervention: A common TRIZ PowerPoint presentation lecture was given to the TRIZ intervention groups (not to the control groups). Students received a list of TRIZ principles and the Contradiction Matrix handouts; this was repeated at the 3 institutions.

Ideation Session 2: Students were asked to generate and record ideas for 50 minutes (UTEP) or 20 minutes (UMD and Penn State) following the TRIZ method while the control group was asked to generate ideas without following a formal ideation method.

Ideation Homework: Students were asked to generate and record ideas with a two-hour limit during the following week (UTEP and UMD) or 4 days (Penn State); these ideas were collected after this period.

5 Assessment

The ideas generated by the students during the experiments were collected; only those ideas from ideation session 1 (after the intervention) were assessed. The metrics used and the assessment approach was adapted from Shah et al. [14].

5.1 The Genealogy Tree

The first step in the assessment process is to characterize the ideas collected. The Genealogy Tree (GT) allows this by defining a common origin for all ideas addressing functions of the design process. The braches follow the concretization of the ideas from Physical Principles (PP) and Working Principles (WP). This GT allows two objectives (1) to have a common structure to categorize each idea, and (2) the GT is used to calculate Quantity, Novelty, and Variety.

A GT can be defined for a set of ideas; these ideas may come from one individual, one group, or more groups. GTs can be defined for different groups and then merged. Merging is necessary in order to allow comparison between groups. Merging refers to having aligned names for the branches of the GT; after merging each group can have its own GT based on the definitions aligned in the merging for Physical Principles and Working Principles.

5.2 Measuring Quantity

Quantity of ideas generated is directly counted as the leaves of the branch in a GT. The total number of ideas in a GT can be divided then by the number of subjects in the corresponding group to obtain an average quantity of ideas per person.

5.3 Measuring Novelty

Novelty is calculated for the subset of ideas in each branch (WP) as follows:

$$Novelty = \frac{\left(\frac{Total\ number\ of\ ideas\ at\ a\ given\ WP\ branch}{Total\ number\ of\ ideas\ for\ GT}\right)}{Number\ of\ WP\ branches\ for\ the\ GT}$$

Comment [Noe1]: Numerator is inverted

The Novelty Score is assigned to all ideas in the given WP branch. An overall Novelty Score for a given group can be calculated as an average from the novelty score of the ideas in that group.

5.4 Measuring Variety

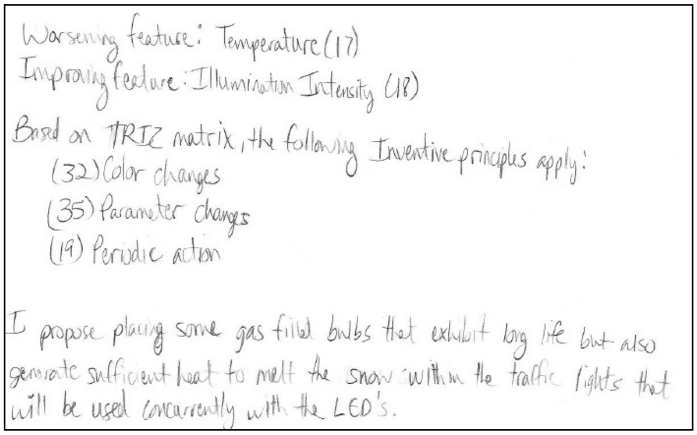
Variety is calculated for a given group represented in a GT as follows:

$$Variety = \frac{(Number\ of\ PP * Weight\ for\ PP + Number\ of\ WP * Weight\ for\ WP)}{Total\ number\ of\ ideas\ in\ the\ GT}$$

Through this formula, Variety is calculated for the whole group represented in a GT, hence, each idea in the group, regardless of branch, obtains the same Variety score. For this study, Physical Principles were assigned a weight of 9 and Working Principles were assigned a weight of 3; this means that the branches at higher levels have more weight relative to braches at lower levels.

6 Experimental Results and Analysis

Figure 2 presents a sample TRIZ solution generated at UTEP that shows the use of TRIZ principles.


Worsening feature: Temperature (17)
Improving feature: Illumination Intensity (18)
Based on TRIZ matrix, the following Inventive principles apply:
(32) Color changes
(35) Parameter changes
(19) Periodic action

I propose placing some gas filled bulbs that exhibit long life but also generate sufficient heat to melt the snow within the traffic lights that will be used concurrently with the LED's.

Figure 2. Sample Idea Generated at UTEP Showing the Use of TRIZ Principles.

Every university first created a Genealogy Tree for the Traffic Light redesign problem for the function "Counter Snow". Since the objective was to compare results across institutions, the three GTs were merged to identify and align into similar terms for the branches (WP and PP). Through the merging process the authors noticed that the individual trees shared most of the terms on branch even before merging, this facilitated the process since few changes were required. This indicates that the design problem was well understood and that the differences in the ideas produced among institutions weren't too large. The merged Genealogy Tree for the three universities is shown in Figure 3, the main function assessed for the Traffic Light redesign problem is "Counter Snow".

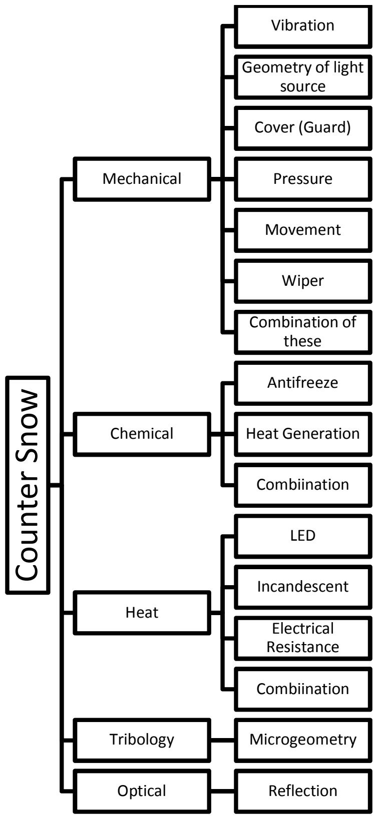


Figure 3. Merged Genealogy Tree for the Traffic Light Redesign Problem.

Figure 4 presents the data collected at UTEP and Maryland for both groups: Control and TRIZ. The numbers indicate the total number of ideas at each branch in the Genealogy Tree.

Root	Category	Subcategory	UTEP Control	UTEP TRIZ	UMD Control	UMD TRIZ
Counter Snow	Mechanical	Vibration	2	0	6	10
		Geometry	5	1	11	5
		Cover	7	1	12	13
		Pressure	2	2	2	5
		Movement	0	1	0	4
		Wiper	3	0	13	7
		Cover + Movement	0	0	1	2
		Cover + Geometry	0	0	0	1
		Cover + vibration	0	0	0	1
	Chemical	Antifreeze	2	3	3	5
		Heat Generation	0	0	0	0
		Combiination	0	0	0	0
	Heat	LED	2	1	0	2
		Incandescent	1	0	7	5
		Electrical Resistance	14	4	21	14
		Combiination	0	1	0	0
	Tribology	Microgeometry	3	1	6	5
	Optical	Reflection	0	0	0	2

Figure 4. Idea Counts for UTEP and UMD with Reference to the Genealogy Tree.

Tables 2, 3 and 4 present the numerical results for comparison for the experiments for Quantity, Novelty and Variety respectively.

Table 2. Quantity Numerical Results from Experiment.

	Quantity		**ANOVA**
	Control (μ,σ)	**TRIZ (μ,σ)**	**Two Tail t-tests**
UTEP	(2.050, 0.999)	(1.667, 0.500)	0.2879 $s_1 \neq s_s$
UMD	(4.100, 1.119)	(3.800, 2.067)	0.5409 Paired t-test
Penn State	(15.000, 5.215)	(16.286, 3.817)	0.6291

Table 3. Novelty Numerical Results from Experiment.

	Novelty		ANOVA
	Control (μ,σ)	**TRIZ (μ,σ)**	**P-value for Significance**
UTEP	(0.241, 0.127)	(0.560, 0.301)	0.0004 $s_1 \neq s_s$
UMD	(0.095, 0.0794)	(0.186, 0.1044)	0.0145
Penn State	(0.683, 0.115)	(0.651, 0.086)	0.5786

Table 4. Numerical Results from Experiment.

	Variety	
	Control (μ)	**TRIZ (μ)**
UTEP	1.610	4.200
UMD	0.805	1.111
Penn State	0.912	0.920

As it can be seen from Tables 2, 3 and 4, TRIZ increases the Novelty and Variety of ideas generated when compared against the control group. The use of TRIZ also reduces the Quantity of ideas generated when compared against the control group. These results indicate that TRIZ helps designers generate ideas with higher levels of Novelty and Variety while reducing the number of ideas generated.

7 Conclusions

Our experimental results indicate that TRIZ improves some of the metrics while worsening others. This implies that some ideation methods are better for some tasks, depending on the outcome sought. Although some of the results are not statistically significant at the standard p=0.05 level, they indicate a trend that is worth considering. In general, the ideation method is a complex process, even under experimentally controlled settings; this indicates that the ideation method outcome is dependent on the involved variables: subject, design task, design method, and other environmental variables. It then would make sense to qualify our results with these variables; further, the recommendation of a particular idea generation method should be based on the information provided on these variables.

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Bibliography

1. Klukken, P.G., Parsons, J.R. and Columbus, P.J. (1997). "The Creative Experience in Engineering Practice:Implications for Engineering Education", Journal of Engineering Education, 1997,86(2), 133-138.
2. León-Rovira, N., Heredia-Escorza, Y., Río, L. (2008), "Systematic Creativity, Challenge-Based Instruction and Active Learning: A Study of its Impact on Freshman Engineering Students" International Journal of Engineering Education, Volume 24, Number 6, December 2008 , pp. 1051-1061.
3. Burkett, S.L., Lusth, J.C, Kotru, S. (2011). Creativity in an Introductory Engineering Course, Proceedings of the 2011 American Society for Engineering Education Annual Conference and Exposition, Vancouver, Canada.
4. Veltman, T., Rosehart, W., Eggermont, M., Onen, D. (2011). Evaluation and Analysis of Freshman Design Courses in Engineering, Proceedings of the 2011 American Society for Engineering Education Annual Conference and Exposition, Vancouver, Canada.
5. Dieter, G.E, Schmidt, L.C. (2009). Engineering Design, 4th edition, McGraw-Hill, New York.
6. Vargas Hernandez, N., Kremer, G., Linsey, J., Schmidt, L. (2010). Systematic Ideation Curriculum Effectiveness Investigation & Deployment to Enhance Design Learning, Proceedings 2010 ASEE Conference, Louisville, KY.
7. Altshuller, G., Shulyak, L. (2002). 40 Principles: TRIZ keys to Technical Innovation, Technical Innovation Center, Inc., Worcester, MA.
8. Chan, J., Fu, K., Schunn, C., Cagan, J., Wood, K., and Kotovsky, K. (2011). "On the Benefits and Pitfalls of Analogies for Innovative Design: Ideation Performance Based on Analogical Distance, Commonness, and Modality of Examples," Journal of Mechanical Design, August 2011, Vol. 133.
9. Chiu, I, Shu, L.H., (2008). "Effects of Dichotomous Lexical Stimuli in Concept Generation," DETC2008-49372, Proceedings of the ASME 2008 International Design Engineering Technical Conferences & Computers in Engineering Conference, August 3-6, 2008, Brooklyn, New York, USA, 2008.
10. Ahmed, S. and Christensen, B. T. (2009)."An In Situ Study of Analogical Reasoning in Novice and Experienced Design Engineers," Journal of Mechanical Design, November 2009, Vol.131.
11. Raskin, A. (2003). "A Higher Plane of Problem-Solving," Business 2.0, June 2003 (www.business2.com/b2/web/articles/0,17863,515713,00.html).
12. Okudan, G.E., Ogot, M. and Shirwaiker, R. (2006). "An Investigation on the Effectiveness Design Ideation Using TRIZ," Proceedings of IDETC/CIE 2006 Design Education Conference, September 10-13, 2006, Philadelphia, PA.
13. Howard, T., Culley, S. and Dekoninck, E. (2008). "Creative Stimulations in Conceptual Design: An Analysis of Industrial Case Studies," DETC2008-49672, Proceedings of the ASME 2008 International Design Engineering Technical Conferences & Computers in Engineering Conference, August 3-6, 2008, Brooklyn, New York, USA, 2008.
14. Shah, J., Vargas-Hernandez, N., and Smith, S. (2003). "Metrics for Measuring Ideation Effectiveness." Design Studies, 24(2), 111-134.