AC 2007-72: FOSTERING CREATIVITY IN THE CAPSTONE ENGINEERING DESIGN EXPERIENCE

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Fostering Creativity in the Capstone Engineering Design Experience

Abstract

Can creativity be fostered during the capstone engineering design experience? What promotes the creativity of undergraduate seniors in mechanical engineering? The ideal venue to answer these questions is Youngstown State University's mandatory capstone design course sequence of two semesters, the goal of which is to prepare senior engineering students to become project leaders in industry. The capstone sequence includes a combination of lectures, case studies, visiting speakers, and team projects. Oral presentations and written reports promote the required communication skills for project leadership. Expectantly, improving creativity skills in project leaders will impact future engineering designs.

This capstone design class consisted of nine student design teams that synthesized, analyzed, manufactured, tested, and evaluated various projects for industry and other clients. Aspects of TRIZ, a Russian acronym for the Theory of Inventive Problem Solving, were incorporated into the existing capstone design instruction. The emphasis was on encouraging the students to think creatively using convergent methodology. Many real-world problems encompass multiple fields of engineering science involving open-ended problems and various possible solutions. The capstone design experience utilizes team projects to solve real-world problems through the application of TRIZ. Fostering creativity helps students to think in broader terms and enables them to become more innovative in finding solutions.

This research has two objectives: 1) to study the teaching of creativity in the capstone design experience and 2) to assess the effectiveness of the creativity instruction with pre-tests and post-tests using the Torrance[12,13] Tests of Creative Thinking (TTCT) for adults. The results of the first year of this three year, outcome-oriented, process study are presented and discussed in this work.

Nomenclature

ABET = Accreditation Board for Engineering and Technology
AP = Academic Performance
Nat'l %ile = National Percentile
SD = Standard Deviation of data points
TRIZ = Teoriya Resheniya Izobreatatelskikh Zadatch
TTCT = Torrance Tests of Creative Thinking

Introduction

Barak[2] states "The challenge in education is to find an optimal combination and balance between fostering activity based on openness and 'disorder', on the one hand, and imparting systematic methods for innovative thinking and problem-solving, on the other." He presents a case study for the design and manufacture of hand tools. In this study, plant workers were trained in Systematic Innovative Thinking (SIT) and he credits this training with the development of new products. In addition to this case study, Moehrle[9] documents 45 significant applications of TRIZ in industry.

According to Clark[3], the Professional Component of ABET (Accreditation Board for Engineering and Technology) Criterion 4 implicitly specifies creativity as follows: "The engineering sciences have their roots in mathematics and basic sciences but carry knowledge further toward creative application. These studies provide a bridge between mathematics and basic sciences on the one hand and engineering practice on the other." Once more explicit standards for creativity are developed by ABET, Smith[11] proposes that senior engineering students could be taught TRIZ during the capstone project stage of their education. However, ideally the capstone course should only be a demonstration of previous learning. So, it may be more desirable to teach creativity prior to the capstone and perhaps even in several different courses to reinforce the concepts.

Fleith et al[5] summarized the research on creativity training programs and decided on a program developed by Renzulli[10]. Both the Verbal and Figural TTCT were administered to 217 children between the ages of 8 and 12 years old. Form A was used as the pre-test and Form B was used as the post-test. Their conclusion was that the creativity training may improve the creativity of students. Kim and Michael[8] studied the creativity of 193 junior high school students using the TTCT. The students with right brain dominance were found to have higher creativity scores than those classified otherwise.

The effect of creative problem solving training on adults was investigated by Wang and Horng[17] and Wang et al[18]. The studies for both papers involved the same 106 workers with graduate degrees over a one year time period. Of this number, only 71 participated in creativity training. And of that number, only 61 were tested before and after 18 total hours of training using a modified brainstorming method. This final number of participants was not arrived at randomly. The results of the TTCT (abbreviated figural form) showed that the fluency and flexibility scores were higher after the creativity training.

Problem Statement

The goal of this study is to foster more creativity in the students to improve results in their capstone engineering design projects. The creativity of the students is measured before and after creativity training. If the students become more creative, it is logical that it would affect the quality and outcome of their projects. This increase in creativity would most likely result in more innovative solutions in their designs.

Creativity Training

The first objective was to incorporate the teaching of creativity into the capstone design experience. The class textbook, Dieter[4], described the various creativity methods of brainstorming, synectics, force-fitting, mind-mapping, and TRIZ (pronounced treez). The TRIZ method was created by Altshuller[1]. He established five levels of inventiveness based on his observations of thousands of international patents from 1965 to 1969. The levels are measures of patent quality rather than steps in the design process. Level 1 included typical design concepts and accounted for 32% of patents. Level 2 consisted of non-significant revisions to current designs and made-up the largest share of patents at 45%. Level 3 was composed of primary enhancements to current designs and comprised 19% of patents. Level 4 involved improvements based on new scientific principles and accounted for approximately 4% of patents. Finally, Level 5 contained revolutionary discoveries and represented less than 1% of patents. TRIZ has the potential to improve design concepts at levels 3 and 4 whereas lower level methods such as brainstorming typically produce solutions at levels 1 and 2. Therefore, TRIZ was chosen for this creativity training program study.

TRIZ is an acronym for the Russian phrase Teoriya Resheniya Izobreatatelskikh Zadatch (pronounced Tee-OR-ee-a ree-SHAY-nee-a eez-owe-bree-TIE-till-skech zuh-DUTCH). Translated into English it is the Theory of Inventive Problem Solving (TIPS). TRIZ has spawned modified TRIZ approaches of Systematic Innovative Thinking (SIT), Advanced Systematic Innovative Thinking (ASIT), and Unified Structured Inventive Thinking (USIT). Altshuller[1] summarized his patent work into a TRIZ contradiction matrix. He discovered the same problems had been solved in different technical areas using only 39 engineering characteristics such as energy and weight, 1250 fundamental technical contradictions such as energy versus weight, and 40 basic inventive principles. For example, principle #28 is the replacement of a mechanical system. Each of the 40 principles has recommendations associated with it. Altshuller[1] defined invention as the removal of at least one fundamental technical contradiction, that is, the improvement of one characteristic of an engineering system degrades another important characteristic and the incongruity must be resolved for an invention to be created.

A case in point could be the fact that the use of gasoline to fuel automobiles pollutes the environment. Therefore, the main goal is to increase the efficiency of an engine for automobiles and thereby reduce the use of pollution-producing gasoline. If the characteristic to be improved is ‘loss of energy,” then a conflicting characteristic is “weight of a mobile object”. So the technical contradiction would be “loss of energy” versus “weight of a mobile object”. Consulting the TRIZ contradiction matrix gives four principles for consideration: universality, dynamicity, periodic action, and replacement of a mechanical system. Ignoring the first two principles for now, one of the recommendations of the principle of periodic action is “replacing a continuous action with a periodic one or impulse.” One of the recommendations of the principle of replacement of a mechanical system is “using an electric, magnetic, or electromagnetic field to interact with an object”. To the author, these recommendations suggested the invention of a motor powered by permanent magnets. In this case, a permanent magnet motor does not use fossil fuels and therefore is emission free. Of course, it is also possible that a totally different solution could result from the same recommendations.

Students were instructed in the TRIZ method via lectures, handouts, and homework assignments. Applications of TRIZ were included in their capstone design projects. In addition to the problem solving training in class, the students were instructed in using library resources properly and in the principles of teamwork. The students chose their team members and projects. In general, they either worked with local industries on actual problems or with faculty members on student competitions. They learned about budget concerns, manufacturing processes, current needs in the field, working with management and faculty advisors, and communication skills. As a team, the students made presentations to learn computer skills, speaking skills, organizational skills, and presentation skills. They also wrote a technical paper about their project to learn research and technical writing skills.

Creativity Tests

The second objective was to measure the effectiveness of the creativity instruction with pre-tests and post-tests using the Torrance[12,13] TTCT, Verbal Forms A and B. Form A was used for pre-testing at the beginning of the academic year and Form B was used for post-testing at the end of the academic year. These tests measured fluency, flexibility, and originality. Fluency refers to the ability to offer a large number of solutions to an exercise. Flexibility is the ability to develop a wide range of different solutions to an exercise. Originality is the ability to create original solutions to an exercise. Specifically, these exercises involved asking questions, improving products, and fantasizing outcomes. The tests were scored locally using the documents written by Torrance[14,15,16]. For each student, standard scores and national percentiles were determined for each of the three areas and a battery average was computed for each student worksheet.

Additional testing was done to determine the students' preferred hemisphere of the cerebral cortex. At the beginning of the academic school year, the students took Hopper's[7] online hemispheric dominance inventory of 19 questions for right, left, or middle brain preference that required 'yes' or 'no' answers. The preferred hemisphere for each student contains more neural connections and learning occurs at a faster rate. The right hemisphere of the brain is the center of spatial ability and processes information in an intuitive, random manner. The left hemisphere of the brain is the center of verbal ability and processes information in a logical, sequential manner. The corpus callosum is a band of nerve fibers that connects the hemispheres. Therefore, students may be right-brain dominant or left-brain dominant. However, another possibility is middle-brain dominant, which indicates no preference. While at first this may seem to be a more flexible condition, it may result in a propensity for hesitancy and incomprehension.

This testing protocol and collection of data was approved by the Human Subjects Research Committee at Youngstown State University. The participating students completed an informed consent form, which is kept on file.

Results

Table 1 tabulates the capstone design projects, which consisted of 30 students divided into nine design teams that synthesized, analyzed, manufactured, tested, and evaluated various projects for industry and other clients. The team member numbers refer to the student protocol test numbers in Table 2. The team averages for academic performance and creativity scores are given as well as the disposition of the projects.

Table 2 summarizes the academic performance and creativity data for 30 students. The academic performance values are based on their college grades. The hemispheric dominance designation of right-brain, left-brain, or middle-brain was determined from an online hemispheric dominance inventory by Hopper[7]. The students were given the Torrance[12,13] pre-test and post-test. The results are stated as national percentiles, which indicate, for example, that a student with a percentile score of 30 has scored higher than 30% of all test takers.

Table 1. Disposition of Capstone Design Projects

Project Name for 2005-2006	Source of Project	No. of Students on Team	Team Member Numbers	Team Average of AP (%)	Team Average TTCT Form B Nat'l Percentile	Disposition of Project
Permanent Magnet Motor	Freelance Inventor	2	108 & 118	71	50	Constructed and tested.
Extrusion Design	Industrial Company	4	102, 116, 121 & 124	71	20	Project failed.
Process Design	Industrial Company	4	104, 109, 117 & 119	90	46	Developed and tested.
Hydraulic Dynamometer	Faculty Member	2	101 & 115	77	17	Project failed.
Racing Go-Kart	Faculty Member	4	111, 114, 122 & 123	72	26	Constructed and tested.
Human Powered Vehicle	Collegiate Competition	4	105, 110, 112 & 113	86	23	Constructed and competed.
Super-Mileage Vehicle	Collegiate Competition	4	103, 106, 129 & 130	79	33	Constructed only.
Mini-Gas Turbine	Faculty Member	2	120 & 125	79	22	Constructed and tested.
Moon-Buggy	Collegiate Competition	4	107, 126, 127 & 128	78	29	Constructed and competed.

Conclusions

The following parameters were investigated in this study: academic performance of students, hemispheric dominance of students, and creativity of students as measured by the TTCT. The academic performance does not correlate with creativity scores and this agrees with Ghosh[6]. However, academic performance was a factor in the disposition of the projects. Table 1 shows both projects that failed had low academic performance and low creativity scores in comparison with the mean values of all 30 students.

A statistical analysis of all 30 students in Table 2 gives the mean academic performance as 78.6% with a standard deviation of 12.6%. The mean of the battery average for TTCT Form A (pre-test) is a 27.9 national percentile and for TTCT Form B (post-test) is a 29.2 national percentile, with standard deviations of 20.2 and 20.0, respectively. This indicates an average increase of 4.5% in creativity. The actual breakdown for the three areas was an increase of 2.0% in fluency, an increase of 15.6% in flexibility, and a decrease of 4.7% in originality. The problem solving training in class increased fluency (quantity of ideas) and flexibility (range of ideas) but had an adverse effect on originality except for the right-brain dominated group as discussed in the following paragraph.

Table 2. Data for Academic Performance and Creativity

Student Protocol Test Number	Academic Performance (%)	Hemispheric Dominance	TTCT Form A (Nat'l. Percentile)	TTCT Form B (Nat'l. Percentile)
101	61	right-brain	13	6
102	90	right-brain	21	23
103	75	right-brain	16	35
104	98	right-brain	25	28
105	88	right-brain	28	33
106	92	right-brain	36	25
107	77	right-brain	38	64
108	70	right-brain	83	72
109	95	right-brain	79	87
110	89	left-brain	4	10
111	69	left-brain	10	6
112	73	left-brain	4	19
113	94	left-brain	9	28
114	69	left-brain	16	30
115	93	left-brain	20	27
116	67	left-brain	32	16
117	88	left-brain	20	28
118	72	left-brain	32	27
119	79	left-brain	41	39
120	81	left-brain	52	37
121	68	left-brain	58	33
122	92	left-brain	41	60
123	58	middle-brain	7	7
124	59	middle-brain	10	6
125	77	middle-brain	17	6
126	83	middle-brain	7	17
127	98	middle-brain	21	11
128	55	middle-brain	23	23
129	78	middle-brain	41	32
130	71	middle-brain	34	41

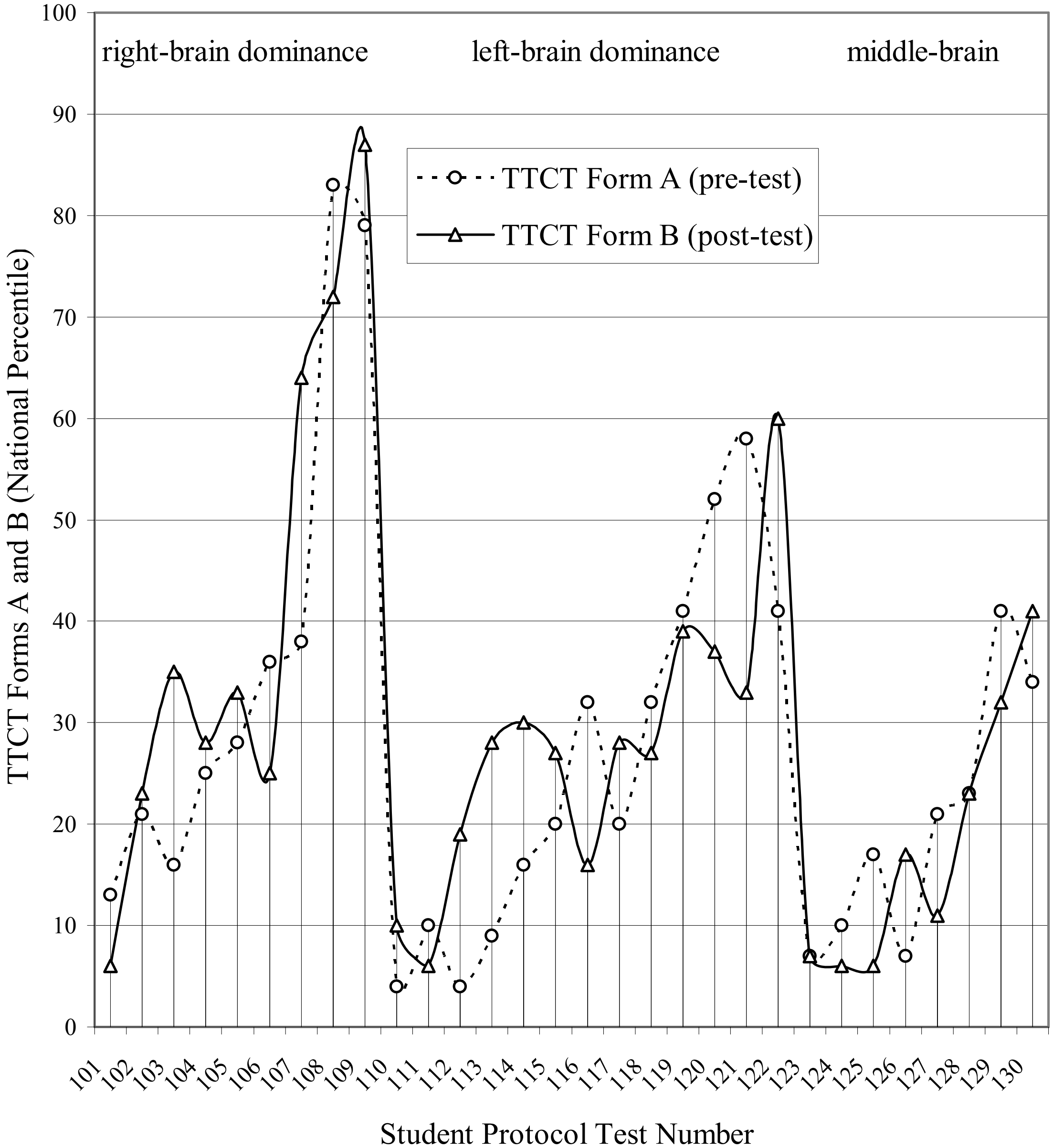

Figure 1. Change in TTCT Scores (Pre-Test and Post-Test) for Hemispheric Dominance Groups

Further elucidation of the data requires establishing three groups based on hemispheric dominance. These groups are plotted on Figure 1 and summarized in Table 3. The right-brain dominated group had a mean increase of 10.0% (plus 13.0% fluency, plus 11.3% flexibility, plus 5.1% originality) in their battery average scores and the left-brain dominated group had an average increase of 6.2% (minus 6.7% fluency, plus 32.0% flexibility, minus 3.9% originality) in their battery average scores. Conversely, the middle-brain group actually had a 10.6% decrease (minus 1.2% fluency, minus 6.2% flexibility, minus 24.8% originality) in their battery average scores. The middle-brain group also had academic performance scores that were on the average 10.5% lower than the combined right-brain and left-brain groups.

Table 3. Statistics for Hemispheric Dominance Groups

Hemi-spheric Domin-ance	Number of Students in Group	Group Mean AP (%)	SD for AP (%)	Battery Avg TTCT Form A (Nat'l. %ile)	SD for TTCT Form A	Battery Avg TTCT Form B (Nat'l. %ile)	SD for TTCT Form B
right-brain	9	82.9	12.6	37.7	25.9	41.4	26.6
left-brain	13	79.5	10.5	26.1	18.0	27.7	13.8
middle-brain	8	72.4	14.7	20.0	12.5	17.9	13.1

Since these are initial results (Table 2) of the first year of a three year study, the conclusions must be viewed with that in mind. At this stage of the study, all 30 students have a battery average for TTCT Form A (pre-test) of 27.9 national percentile and a mean academic performance of 78.6%. There is a slight improvement in the battery average TTCT Form B (post-test) of 29.2 national percentile. The students scored better than only 29.8% of all test takers. This indicates a great need to improve the creativity of students.

The project disposition in Table 1 is adversely affected by low team creativity scores and low team academic performance. The combination of the two seems to predict a failure of the project. Teams that excelled in both scores seemed to perform better than teams that only did well in one of the two areas. Therefore, one of the lessons learned from this study is that enhanced creativity along with a certain level of academic performance leads to improved design quality and innovation.

The results on Figure 1 for the three hemispheric dominance groups are based on small numbers of students and will be reassessed when more data is available. One interesting result was that the right-brain group had a 10.0% increase in creativity and improved in all three areas (fluency, flexibility, and originality) while the middle-brain group had a 10.6% decrease in their creativity scores and declined in all the creativity areas. The mediocre performance of the middle-brain group was also demonstrated by mean academic performance scores that were 10.5% lower than the combined right-brain and left-brain groups (Table 3).

Additional work needed to enhance the understanding of creativity in the capstone engineering design experience includes:

1) Gather more data in order to further validate conclusions using statistical analysis,

2) Investigate the effect of team dynamics (preferred hemisphere and personality types) on creativity in student teams, and

3) Measure the creativity of final design products to give further evidence of student improvement.

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