Do We Teach Them How to Think?*

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Abstract

In today's marketplace there is an urgent need for innovative “out-of-the-box” thinkers with teaming, communication, and interpersonal skills. Many college courses focus on knowledge acquisition and less on thinking. Some students are losing basic skills for defining, understanding and solving problems while some others struggle with logical and critical thinking. Teaming and communication skills are being addressed in a relatively small number of college courses. In order to get students who can solve real problems, we must address the need for development and implementation of course modules in innovation and inventiveness in different disciplines, especially engineering and technology. Such modules can and should be designed to enhance teaming, communication and interpersonal skills.

This paper discusses some of the problems in teaching innovative problem solving and suggests some possible solutions based on experience in an undergraduate course at Florida Atlantic University titled: “Introduction to Inventive Problem Solving in Engineering”. Its goal is to enhance innovative and inventive thinking abilities of undergraduate students resulting in skills that can be used in science, math, engineering and technology. In this paper we detail projects and homework assignments, teaming and communication activities, and hands-on and fun interactive class actions. One of the core ideas of the class is the Eight-dimensional methodology for inventive and innovative problem solving: a systematic approach that stimulates innovation by effectively using *both* sides of the brain. The methodology is a unified approach that builds on comprehensive problem solving knowledge from industry, business, marketing, math, science, engineering, technology, and daily life. It allows the generation of unique and high quality, out-of-the-box multiple solutions in a short period of time. The methodology can be easily taught, learned, and used, and may be practiced by individuals as well as teams.

The new course uses hands-on problem-based learning and emphasizes expanding creativity and thinking skills of students. The activities include 3-D mechanical puzzles, games, mind teasers, LEGO® Mindstorms competitions, and design projects. These activities allow for self-paced, semi-guided exploration. They lead to out-of-the-box inventive thinking, imagination, intuition, common sense, and teamwork. The course and the use of the Eight-dimensional methodology have been recently evaluated with encouraging results.

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*This work has been supported in part by the National Collegiate Inventors and Innovators Alliance (NCIIA), and was supported in part by a grant from the National Science Foundation, Division of Information, Robotics and Intelligent Systems, Grant # IIS-9615688,.

1. Introduction

In today's marketplace there is an urgent need for innovative "out-of-the-box" thinkers and approaches. In many courses students are not being encouraged to think out-of-the-box and are losing some basic skills for defining, understanding and solving problems. Many have a difficult time to think logically and critically towards obtaining desired solutions. In fact the problem is broader in that there is a need for thinkers with interaction skills such as teaming, communication, and interpersonal. Part of the problem is related to what and how instructors teach. The following table summarizes what the author believes is the case in many courses.

We teach to	We *should* teach to
Follow instructions, "Stay within the lines", "Do not break the crayon", "Don't try something new".	Think out of the box, Take risks, Be creative, Be imaginative.
Expect only one solution. Find the "right" answer.	Expect more than one solution. Prepare for "no-answer" or "unknown answer".
Do it yourself. Don't share. *Compete* with others.	Work in Teams. *Share* knowledge.
Move forward as fast as you can. Don't look back. Just do it.	Learn, understand. Pause, look back, and use common sense.
Don't talk to others.	Communicate.
Work as hard as you can.	Work smart. Have fun.
Do it faster.	Work at your own pace.
Memorize, follow "cookbook", accept the given.	Inquire, understand, solve problems, challenge the obvious.
Acquire knowledge.	Think.
Behave "uniformly".	Be different. Don't be indifferent.
Be judgmental ("you vs. us").	Coach ("let's work together").
Please the teacher.	Please yourself.

Thinking is a skill that can be developed, and the earlier the better. In order to get students who can solve problems, we must address the need for development and implementation of courses in innovation and inventiveness in different disciplines, especially engineering and technology.

The goal of the "Introduction to Inventive Problem Solving in Engineering" course reported in this paper is to enhance inventive thinking abilities of undergraduate students. In this course there is no "right or wrong", and no "unique solution". Trying, inquiring, and questioning is what counts. It emphasizes "out-of-the-box" inventive thinking, imagination, intuition, common sense, and elements of teamwork. The course is based on: a) well established systematic and non-systematic approaches to inventive problem solving, b) results from NSF support to FAU on a

unified framework for inventive problem solving strategies, c) proven successful methods that have been used in high-tech innovative industries, and d) on going E-teams projects sponsored by the National Collegiate Inventors and Innovators Alliance (NCIIA).
The new course uses hands-on problem-based learning for introducing undergraduate engineering students to concepts and principles of inventive problem solving. The hands-on activities include more than 250 different 3-D mechanical puzzles, games, mind teasers, LEGO® Mindstorms competitions, and design projects, each of which illustrates principles and strategies in inventive problem solving. These activities allow for self-paced, semi-guided exploration that improves self-esteem and encourages questioning and daring.

The course uses a new Eight-dimensional methodology for solving problems which has been implemented in different team and individual settings. The nature of the methodology makes it inter-departmental, inter-disciplinary, and regionally unconstrained. Based on feedback from students the module has changed the way they think, and added to the intellectual capital that the students develop. An evaluation of the course showed a significant increase in thinking skills.

2. Overview of the Eight-dimensional methodology

A significant portion of the class (Appendix A) is dedicated to section (IV) "Creativity in Problem Solving". In this section we spend more time on the sub-section "Unified Approach to Strategies", also called the Eight-dimensional methodology for problem solving.

Problem solving books detail phases to creatively solve problems from understanding to implementation. For example in[1] the steps are: a) Preparation, b) Concentration, c) Incubation, d) Inspiration, and e) Verification. In many "idea generation" chapters, general methods such as "lateral thinking," "brainstorming" and "mind mapping" are usually well covered, but specific strategies are only partially mentioned, if at all. There are many problem-solving strategies and it is sometimes confusing to decide which one to use. Strategies are being used in everyday life but not well documented.

There is a need to collect, consolidate, unify and document many problem-solving approaches. To satisfy this need, we first searched for methods that people use to solve problems. This was done using different resources such as related books, papers, patents, products, and services, as well as knowledge from industry, business, marketing, math, science, engineering, technology, and daily life. Later we realized that the methods could be consolidated under one unified scheme.

The Eight-dimensional problem solving methodology is a systematic approach that stimulates innovation by effectively using both sides of the brain. It allows the user to quickly generate unique, and high-quality multiple solutions in a short period of time. Problems are not constrained to a particular profession or subject, and may be used by individuals and teams.

It works extremely well in brainstorming sessions. It is easy to teach, learn and use. Hands-on activities are used to experience the eight strategies. The methodology includes the following strategies: *Uniqueness, Dimensionality, Directionality, Consolidation, Segmentation, Modification, Similarity, and Experimentation.*

This new eight-dimensional methodology has been taught to engineering and computer science students at Florida Atlantic University. Recently, students from other colleges such as Social Sciences, Arts and Humanities, Business and Marketing joined classes and workshops where this new methodology has been taught. In addition, workshops have been conducted to faculty and students at other universities.

The new methodology has been recently evaluated with encouraging results. They show a great increase in the number of ideas generated by students who were exposed to the new strategies.

3. Innovative Problem Solving: Related work

The literature on creativity and problem solving is quite rich. Some books focus on creativity in general [2-11]; some on general methods for problem solving such as brainstorming, brainwriting and lateral thinking [12-18]; and others deal with identifying creativity styles [11,19-21]. There are books that focus on mental blocks and how to overcome them [22-24]. The literature is business- and industry-related [25-27], engineering- and technology-oriented [28-37] with focus on inventions [38], or math specific [39]. Many books are intended for younger students [40,41]. Puzzles and games for developing creative minds [42-48] are the subjects of many books.

Most of related literature can be used in place of reference books but is not suitable nor meant to be used as textbooks. To teach these topics the instructor has to extract bits and pieces from many sources. When it comes to strategies, even the best available problem solving books in engineering and computer science (for example [33]) describe general methods, but mention only a few specific strategies, indicating a real void in the literature.

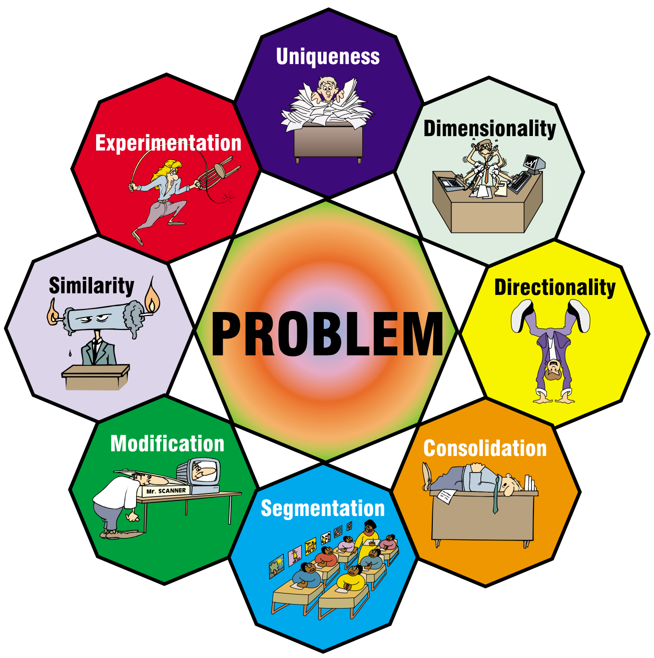
The strategies described in this paper contain several levels of sub-strategies that can be used to solve problems. The following are examples of two resources used in our related research.

<u>Systematic methods</u> One example is the TRIZ methodology. TRIZ is a Russian Acronym for the theory of inventive problem solving. Genrikh Altshuller [28-30] and his colleagues studied over two million patents and identified the main principles and knowledge that define the process for solving inventive problems. TRIZ makes use of the global patent collection and the known effects of science (physics, chemistry and geometry) as a database to support the needs of problem solvers. TRIZ is currently being used internationally leading to a substantial increase in the number of patents by many corporations including Motorola, Proctor and Gamble, Xerox, Kodak, McDonnell Douglas, Hughes, AT&T, General Motors, General Electric, and Ford [32].

Non-systematic strategies Several are being used by industry; in particular, DuPont had a very successful program on innovation and creativity. It has been shown [27] how the company recognized and successfully implemented the six dimensions of creativity.

4. The Eight-strategies

The strategies for inventive and innovative problem solving are pictorially illustrated next. They can be used in any order to solve problems. They provide directions for thinking, thus allowing the use the left and right modes of the brain. The related sub-strategies are listed next.



1. Uniqueness

1.1 Discover what does not change
1.2 Compare characteristics/features

2. Dimensionality

2.1 Start with less
2.2 Start with more
2.3 Manipulate time/space/cost dimensions and structure/topology/state
2.4 Reduce details:
2.5 Duplicate it/ Repeat it

3. Directionality

3.1 The other way around
3.2 All Directions

4. Consolidation

4.1 Combine
4.2 Multi purpose

5. Segmentation

5.1 Learn to share and Manage resources
5.2 Segment/cut
5.3 Separate

6. Modification

6.1 Rearrange
6.2 Extract/pull
6.3 Substitute/exchange
6.4 Add/ Subtract
6.5 Change
6.6 Self Modification
6.7 Add something in between
6.8 Localize
6.9 Take partial or overdone action
6.10 Automate It
6.11 Purify / mix

7. Similarity

7.1 Look for Pattern/Rule
7.2 Look and use analogy
7.3 Make it similar

8. Experimentation

8.1 Work it out

5. Examples for course and laboratory material, projects, teaming and communication activities

5a) Course material

The following are some example-based explanations for the different strategies:

a1) <u>Example for the **Uniqueness** strategy</u>

There is a need to separate juicy and non-juicy oranges at a high rate. How can this be done?

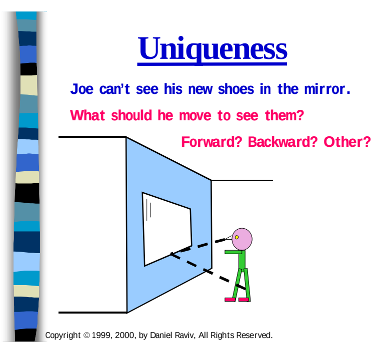
A solution: look for a feature or property of an orange that highly correlates with juiciness. Obviously it is not color, size, weight, or texture. The main property that distinguishes the oranges is *specific density*. To measure the specific density it is not necessary to measure the weight and volume of each orange separately and then find the ratio of the two. It can be done directly by observing the time it takes for an orange to surface from under the water after being thrown from a certain height. The longer time the juicier the orange. This simple "uniqueness" strategy was used to separate oranges at a high rate, by letting them slide into a canal with moving water that had some longitudinal dividers. When an orange surfaces, it appears between two dividers, signifying a certain level of juiciness.

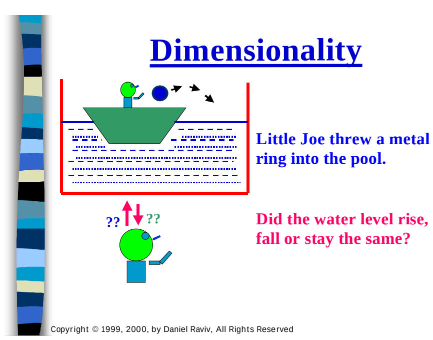
a2) <u>Example for the **Dimensionality** strategy</u>

One of the major problems in picking an object from a pile (known as the "bin-picking" problem) using a robotic arm, a camera, and a computer, is to identify which object is on top.

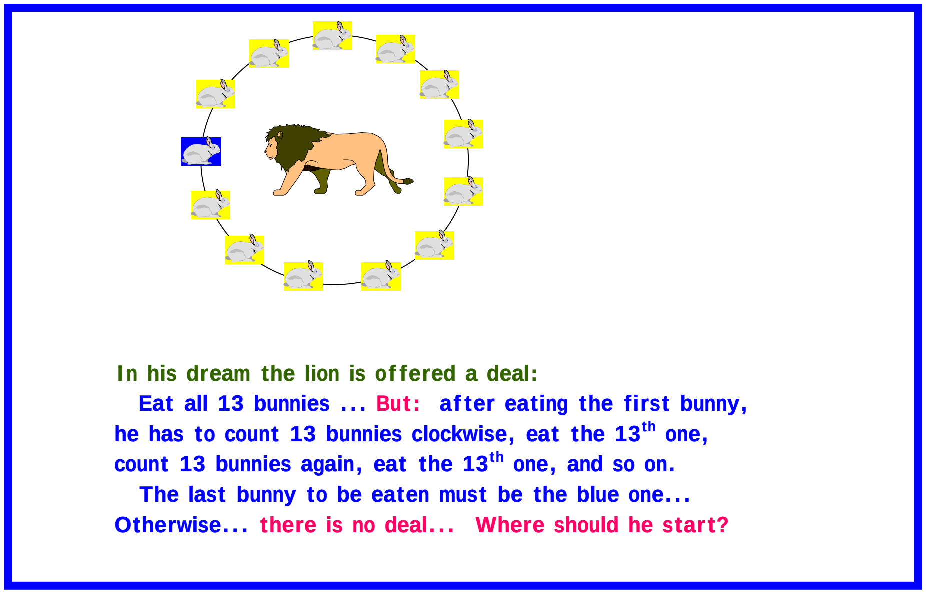
A solution is to move a light source around the bin. The portions in the image of the bin that get no shadow from all illuminated directions belong to surfaces of objects on top. Here a time dimension was added to solve the problem.

The following are a few **brain-teasers** examples used to introduce some of the strategies:





The following **brainteaser** is one of many that has been used to introduce the use of several strategies:



There are several possible solutions to this problem. Clearly “trial-and-error” will eventually lead to a solution (**Experimentation**). However, more efficient solutions can be utilized using the eight-dimensional methodology:

1. **Dimensionality**: Start at a bunny (your choice) and find which bunny is the last one to be eaten. Count the number of bunnies needed to align the last one with the desired blue bunny. Use this number to shift your starting point. For example, if you ended up three bunnies short of the blue one, shift your first chosen bunny by three. This is the desired solution.
2. **Directionality**: Start backwards from the blue bunny counter-clockwise to find the first bunny.

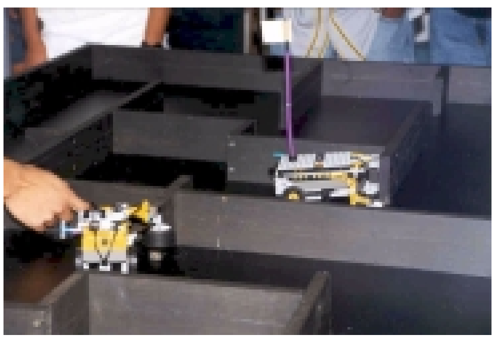
The following is a sample of some examples used to introduce some of the eight strategies:

5b. Laboratory material

The eight strategies are experienced by individuals and teams. We view team building and teamwork as extremely important, since communication skills, trust, sharing ideas, etc. are crucial in the workplace. In addition to demonstrating the strategies, the laboratory material is intended to add a fun component to the learning experience, allow for self-paced exploration that improves self-esteem.

b1) A strategy-oriented robotic task using off-the-shelf programmable autonomous (sensor-equipped) wheeled mini-robots. The programming is done at high-level languages. Software packages for the robots are available from the robot manufacturers. Three different tasks were developed. In the last few semesters we used the LEGO® MindStorms™ in three different team-based autonomous competitions: 1) speed, 2) getting out of a maze, and 3) down-hill obstacle-avoidance, all developed, designed and implemented by the author. The following two pictures were taken during the "speed" and "maze" competitions.

Example: In a fenced floor area that contains five different size stationary objects, use a robot to find an object and stop next to it. This introductory example involves many of the strategies that were previously discussed. The robot needs to: 1) be programmed to discover the *unique features* of the desired object based on actual measurements; 2) move in two *dimensions* along well thought-out directions that may change on line due to new sensory information; 3) *segment* a task into several sub-tasks; 4) *cooperate* with other robots, etc. *Experimentation* and *modification*s are expected until the robot "behaves well".



b2) Short term design projects for individuals and teams from different disciplines in particular, Electrical Engineering, Mechanical Engineering, and Computer Science.

b2.1) Mechanical Engineering example

A team consisting of three students is given a mirror, an 8 ½"x11" sheet of paper, a pencil, and a ruler. The task is to find a method to determine the height of an unreachable ceiling. This project involves teamwork and the use of limited resources (*uniqueness*), using proportion (*dimensionality*), specific spatial alignment of the mirror (*directionality*), teaming up with other groups (*consolidation*), *similarity* (similar triangles approach), and *experimentation*. Another important feature of this project is the better understanding of the "no right or wrong" and "no unique solution" concepts.

b2.2) Electrical Engineering example
A team of students gets light-emitting diodes (LED's) and integrated logic circuits. Using a power source, a breadboard and wires they need to solve the following problem:

An ENGINE in a new car can be turned ON if:
(The KEY is ON) AND (BATTERY is ON) AND (The A/C is OFF OR The LIGHTS are OFF)
Use smallest number of NAND and NOT Gates to implement the "ENGINE ON" function.
This example relates to *dimensionality, modification, similarity,* and *experimentation* strategies.

b2.3) Computer Science example

Find the general solution to the "Tower of Hanoi" problem. Write a program that will produce the solution for N disks (N< 10). In this example students experiment with a small-scale hands-on solution (*segmentation* and *experimentation* strategies), then generalize it (*dimensionality* strategy).

b3) Long-term multidiscipline industry-oriented design projects for individuals and teams. Each of the design projects includes the task, materials, assumptions, constraints, rules, criteria for winning, etc.
Example: Use two mousetraps and a $30 budget to build a mobile platform that can overcome one speed bump and one large obstacle, move 8 meters and stop.
This team project may incorporates *all strategies* depending on the particular design.

b4) Learning to use patent related software to speed-up generation of ideas.

There are several US companies that have developed software for speeding up the inventing process. They use databases of about two million patents clustered according to inventive principles. Given a problem the software directs the user to several clusters of patents that solve similar or related problems. Recently we purchased and used the basic versions of TRIZ software from Ideation International Inc. and Invention Machine Inc.

b5) Learning to use several different patent databases for searching for patents and ideas via the internet.

The US Patent and Trademark Office (www.uspto.gov), and IBM (www.ibm.com/patents) provide databases for "smart" patent searches.

b6) Practicing the eight dimensional strategies using 3-D mechanical puzzles.

Example: Three cups containing two marbles each are labeled as follows: Red-Blue, Blue-Blue and Red-Red. All three cups are labeled incorrectly. There are two blue marbles in one cup, two red marbles in a second cup, and a red and blue marbles in a third cup. By pulling out *one* marble, and not looking at the other cups' contents, determine the color of the marbles in each cup. The solution involves the strategies of *uniqueness* and *experimentation*.

The following pictures show the students in action. Currently we use more than 250 different 3D puzzles. For more information please see**: http://www.ee.fau.edu/faculty/raviv/teach.htm.**

b7) E-teams projects

Several E-teams were formed to solve specific problems in intelligent vehicles. Each E-team was assigned a task. The team members used the eight-dimensional methodology to generate solutions, chose the best solution, completed comprehensive patent and marketability searches, and designed prototypes. If the results deem patentable and marketable, the ideas would be patented.

The theme for the E-team projects is related to the author research area, i.e., intelligent vehicles. In particular, the projects are related to collision avoidance. Examples for E-team tasks:

- Sensor fusion system for detecting obstacles
- Smart bumpers to minimize collision effects
- Advanced collision-warning system
- Radar-based system for controlling traffic lights
- Alternatives to speed bumps

These tasks involved students from different disciplines. They were meant to change the way student teams approach and solve problems with commercial potential in the short and long runs. In these activities individuals and teams experienced the eight strategies. In addition to demonstrating the strategies, the projects were intended to add an industry-related component to the learning experience, allowed for self-paced, semi-guided exploration that improved self-esteem and encouraged questioning and daring.

6. Evaluation

When dealing with assessment of creativity, there are four different facets to consider [49]: 1) Qualities of the person [49], 2) Aspects of the process [50], 3) Characteristics of products [51], and 4) Nature of the environment [52]. This project deals mainly with the process facet of creativity. It focuses on the various stages of thinking or problem solving people engage in while producing something new and useful, including practical strategies for creative thinking [8]. It also deals with examining the effect of process training [50].

Little has been said and done regarding measurement of this creativity dimension, perhaps due to its "application" focus. The surprising little research work in this area leaves us with a particularly challenging task of evaluating the success of the project's goals.

In addition to peer evaluation **we chose to measure student achievements by**:

1. Measuring the difference within the same control group (pre-tests and post-tests).
2. Measuring the relative incremental change between two different groups of students: one that participates in the class and the other that does not.

The following are results obtained from two different classes: "Linear Systems", usually taken by students in their fourth or fifth semester, and "Inventive Problem Solving" usually taken by senior level students.

Each class was visited twice. At the beginning and towards the end of the Fall 2000 semester. At each visit students were given two different problems and asked to generate as many solutions as possible. The problems in the "beginning visits" were different from the problems of the "end visits". The problems given to students were identical in both classes. Questions #1 and #2 were given in the "beginning visits", and questions #3 and #4 at the "end visits".

Number of participants in the study

Question #1: "linear" class: 17, "Inventive " class: 25.
Question #2: "linear" class: 17, "Inventive " class: 26.
Question #3: "linear" class: 15, "Inventive " class: 24.
Question #4: "linear" class: 17, "Inventive " class: 24.
The missing student from the "beginning" visit of the "inventive" class was late and missed the first question. The missing students from the "end" visit of the "linear" class were late and missed the third question.

Results

During the **"beginning" visits** (one per class) the "linear" class students performed better than the students in the "inventive" class: in question 1, the average number of solutions in the **"linear"** class was **8.71** with standard deviation of 3.39, where in the **"inventive"** class the average was **5.60** with standard deviation of 3.39. In question 2, the average number of solutions in the **"linear"** class was **3.59** with standard deviation of 2.83, where in the **"inventive"** class the average was **2.73** with standard deviation of 2.15. These finding surprised us since we did not expect to notice meaningful differences. They may be due to the fact that students in their early stages of their college studies are more "open minded".

During the **"end" visits** (one per class) the "inventive" class students performed better than the students in the "linear" class: in question 3 the average number of solutions in the **"linear"** class was **5.60** with standard deviation of 2.35, where in the **"inventive"** class the average was **9.75** with standard deviation of 3.86. In question 4 the average number of solutions in the **"linear"** class was **6.18** with standard deviation of 2.32, where in the **"inventive"** class the average was **6.71** with standard deviation of 2.81

7. On-going and future work

In this paper we reported on a class that attempts to enhance inventive thinking skills of undergraduate students. It is based both scientific and educational merits that expose students to hands-on inventive problem solving. The class uses: a) well established systematic and non-systematic approaches to inventive problem solving, b) results from NSF support to FAU on unified frame for inventive problem solving strategies, c) proven successful methods that are currently being used in high-tech innovative industries, and d) on going E-teams projects sponsored by the National Collegiate Inventors and Innovators Alliance (NCIIA).

Currently, we are focusing on expansion of the course and in particular the Eight dimensions, to include more hands-on and design activities, and on formative as well as summative evaluations.

Ideas from the course are being used in the "Fundamentals of Engineering" course offered to all engineering at the freshmen level, and starting Spring 2001 semester they have been incorporated as part of the new "Design 1 and 2" course sequence. The course is currently being considered for becoming a core course in Engineering. It was officially approved for Social Science, Arts and Humanities majors, and we believe that other colleges will approve it as well. In addition, we are exploring the creation of a "Minor in Entrepreneurship and Creativity" program for engineering students, in which this course will be incorporated. Select pieces of the material have been taught to high school students as part of the "Engineering Scholar Program" intended for top high school seniors. The National Inventors Hall of Fame is considering the development of programs to high school students based on this class.

We are interested in sharing and working with other colleges and institutions nationwide. Some work already started with the University of Florida, and North Carolina State University. A new company has been formed to offer portion of the course to industry. See www.productivethinking.com

8. Acknowledgement

The author would like to thank NSF and NCIIA for supporting research and implementation of the project. Special thanks to Mr. Allapon, the Teaching Assistant of the class for his dedicated work, and Mr. Richard Viens who put some of the industry-related examples together in a nice and clear format. Tal Raviv suggested very constructive comments to the paper.

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Appendix A

“Introduction to Inventive Problem Solving in Engineering”: Topics

I. Introduction
Making a case for creativity
Creative thinking as a skill
The multi-dimensional approach to creative thinking
Creativity and inventiveness
II. Valuing diversity in thinking
Thinking preferences
Creativity styles
Behavior patterns
III. Setting the stage for success
Basic philosophy
Having a vision
Setting the right attitude
Recognizing and avoiding mental blocks

Avoiding mindsets
Risk taking
Paradigm shift and paradigm paralysis
Individual and teamwork

IV. Creativity in problem solving

A. Problem Definition

Type of problems
Understanding
Representing
Current state, desired state
Defining the real problem

B. Pattern Breaking

Out of the box
Thinking differently
Changing your point of view
Watching for paradigm shift
Dreaming and day-dream
Challenging conventional wisdom
Lateral thinking and random words
Morphology
Mind stimulation: games, brain-twisters and puzzles
Always listen to your mind and body

C. General Strategies

Idea-collection processes

- Brainstorming and Brainwriting
- The SCAMPER methods
- Metaphoric thinking
- Outrageous thinking
- Mapping thoughts
- Talking and listening
- Other (new approaches)

D. Using Math and Science

Systematic logical thinking
Using math concepts
Geometry
Science

E. Unified Approach to Strategies

1 Uniqueness
2 Dimensionality
3 Directionality
4 Consolidation
5 Segmentation
6 Modification
7 Similarity
8 Experimentation

F. Systematic Inventive Thinking

Systematic inventive thinking
- The TRIZ methodology
- The problem/function
- Levels of inventions
- Evolution of technical systems
- Ideality and the ideal final result (IFR)
- Stating contradictions and the contradiction table
- 39 standards features and 40 inventive principles
- Separation in time and space

Use physical effects
Use geometrical effects
Use chemical effects
Use fields
Substance-field method
ARIZ

V. Decision and Evaluation

Focused thinking framework
- Listing and checking solutions
- Six thinking hats
- PMI
- Matrix
- Synectics

Other criteria
Ethical considerations
Generalizing solutions
Identifying potential problems

VI. Implementation

Planning
Carrying through
Following up

VII. Ideas to market

VIII. Intellectual Property

Introduction to intellectual property: Patents, Copyrights ©, Trademarks ®, Trade Secret, Unfair Competition.

* Patents
  What is a patent? Types of patents, Patentability
  Patent application; patent claims
  Disclosure Document Program (DDP)
  Provisional Patent Application (PPA)
* Copyrights ©
* Trademarks ®
* Trade Secrets
* Unfair competition
* Relationships between Trademarks, Trade secrets, Copyrights and Patents

IX. Creativity and the organization

Organizational support
Setting an inventive environment
Supporting inventive individuals