

## **Hands-on Inventive Solutions in Engineering Design\***

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### **Abstract**

This paper describes an Eight-dimensional methodology for teaching inventive and innovative problem solving. It has been developed and taught as part of an on-going course at Florida Atlantic University titled: “Introduction to Inventive Problem Solving in Engineering”, and has been sponsored in part by the National Science Foundation (NSF) and the National Collegiate Inventors and Innovators Alliance (NCIIA).

The Eight-dimensional problem solving methodology is 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 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. The methodology works extremely well in brainstorming sessions. It is easy to teach, learn and use.

This new methodology has been taught using hands-on activities that include more than 250 different 3-D mechanical puzzles, many games, brain-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 Eight-dimensional methodology has been recently evaluated with encouraging results.

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## 1. Introduction

A new Eight-dimensional methodology for generating inventive and innovative ideas is presented. The work is based on an NSF-supported research project previously conducted by the author, and an on-going E-team project supported by the National Collegiate Inventors and Innovators Alliance (NCIIA). It is a systematic approach that stimulates innovation by effectively using *both* sides of the brain, and allows to quickly generate unique and high-quality multiple solutions in a short period of time. The Eight-dimensional methodology works extremely well in brainstorming sessions. It is easy to teach, learn and use. The methodology has been implemented in different team and individual settings as part of a class titled “Introduction to Inventive Problem Solving in Engineering” at Florida Atlantic University. The related teaching material may be extended or shrunk, thus allowing flexibility for incorporating it in different classes such as design, introduction to engineering, and problem solving.

The material includes: a) course material for specific eight problem solving strategies, and b) hands-on activities that include more than 250 different 3-D mechanical puzzles, many games, mind teasers, LEGO® Mindstorms competitions, and design projects, each of which illustrates principles and strategies in inventive problem solving. In addition, students use patent-related software packages and websites. These activities allow for self-paced, semi-guided exploration that improves self-esteem and encourages questioning and daring.

This new eight-dimensional methodology has been taught to engineering and computer science students in upper undergraduate and introductory graduate levels. 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 taught to faculty and students at other universities.

The nature of the methodology makes it inter-departmental, inter-disciplinary, regionally unconstrained, and thus nationally applicable with the promising potential to be adopted by engineering and science colleges nationwide. An important outcome is offering an opportunity for students to work in interdisciplinary teams. Based on feedback from students the module has changed the way they think and added to the intellectual capital that the students develop.

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

## 2. Rationale

In today's global marketplace, the pace of competition, the increasing demands of customers, and the explosion of knowledge and technology, cause a need for innovative “out-of-the-box” thinkers with interaction skills such as teaming, communication, and interpersonal. In many courses nationwide students are being taught to expect only one solution, follow “cookbook”

instructions, and accept the given. They are not being encouraged to think out-of-the-box, and are losing basic skills for defining, understanding, and solving problems.

Problem solving books detail steps to solve problems from understanding to implementation. 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. Strategies are being used in everyday life but not well documented.

There is a need to consolidate, unify and document many problem solving strategies. To come up with an answer to this need, we asked very basic questions: How have people solved problems? What strategies have they used? The answers came from many related books, papers, patents, products, and services from industry, business, marketing, math, science, engineering, technology, and daily life. We realized that the methods could be unified and categorized under an eight-dimensional methodology.

### **3. Related work**

The literature on creativity and problem solving is quite rich. Some books focus on creativity in general<sup>1-10</sup>; some on general methods for problem solving such as brainstorming, brainwriting and lateral thinking<sup>11-17</sup>; and others deal with identifying creativity styles<sup>10,18-20</sup>. There are books that focus on mental blocks and how to overcome them<sup>21-23</sup>. The literature is engineering- and technology-oriented<sup>24-32</sup> with focus on inventions<sup>33</sup>, business- and industry-related<sup>34-36</sup>, or math specific<sup>37</sup>. Many books are intended for younger students<sup>38,39</sup>. Puzzles and games for developing creative minds<sup>41-46</sup> 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<sup>29</sup>) describe general methods, but mention only a few specific strategies, indicating a real void.

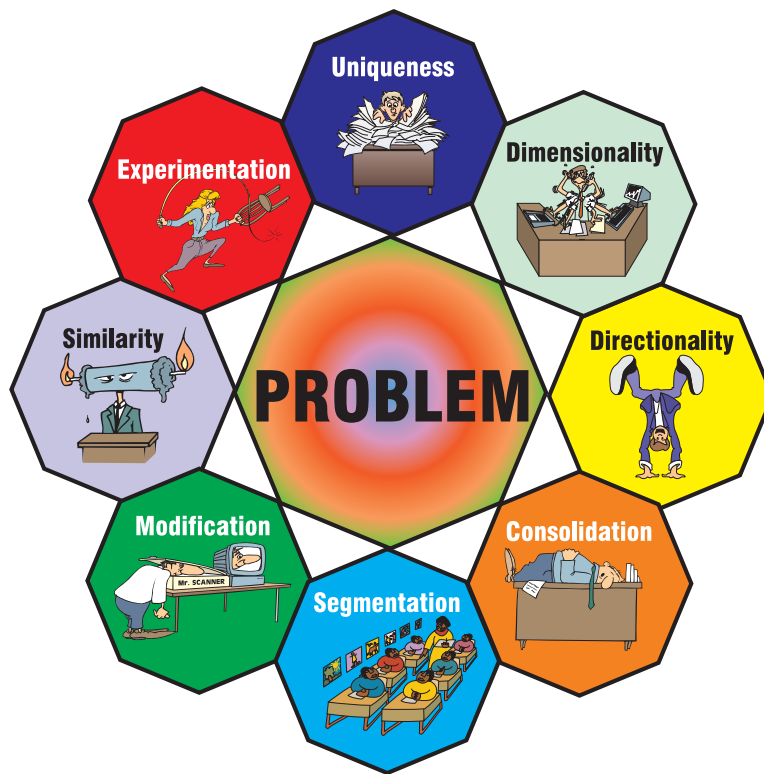
The strategies described in this paper contain several levels of sub-strategies that can be used to solve problems. The following are examples of two resources used in our related research.

Systematic methods using the TRIZ methodology. TRIZ is a Russian Acronym for the theory of inventive problem solving. Genrikh Altshuller<sup>24-26</sup> 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 28.

Non-systematic strategies used by industry, in particular, Du Pont successful program on innovation and creativity. It has been shown <sup>36</sup> how the company recognized and successfully implemented the six dimensions of creativity.

#### 4. The strategies

The following is detailed information on the eight-dimensional methodology for inventive and innovative problem solving. The strategies are: 1) Uniqueness, 2) Dimensionality, 3) Directionality, 4) Consolidation, 5) Segmentation, 6) Modification, 7) Similarity, and 8) Experimentation. As pictorially illustrated 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.



## **1. Uniqueness**

### **1.1 Discover what does not change**

1.1.1 Discover and use invariants

### **1.2 Compare characteristics/features**

1.2.1 Look for and use unique

/distinguishing features

1.2.2 Magnify the difference

## **2. Dimensionality**

### **2.1 Start with less**

2.1.1 Solve a special case or several special cases

2.1.2 Simplify / reduce the problem

2.1.3 Solve an easier related problem

2.1.4 Identify and solve sub-problems/ cases

### **2.2 Start with more**

2.2.1 Look at the global picture

2.2.2 Generalize & solve a more general/global case

### **2.3 Manipulate time/space/cost dimensions and structure/topology/state**

2.3.1 Take it to the extreme

2.3.2 Change Spatial dimensions

2.3.3 Change temporal dimension

2.3.4 Observe upper and lower limits

2.3.5 Move it

2.3.6 Move back in time; reverse

2.3.7 Move forward in time

Extrapolate/ predict/ anticipate

2.3.8 Combine operations in time (in parallel)

2.3.9 Add dimension

2.3.10 Eliminate dimension

2.3.11 Trade/exchange dimensions

2.3.12 Separate dimensions

2.3.13 Share dimensions

2.3.14 Compare dimensions

### **2.4 Reduce details:**

Look from Far Away

### **2.5 Duplicate it/ Repeat it**

2.5.1 Copy and duplicate

2.5.2 Continue useful actions

## **3. Directionality**

### **3.1 The other way around**

3.1.1 Solve it indirectly

3.1.2 Use indirect measurement

3.1.3 Solve a complementary problem

3.1.4 Inverse it implement the opposite action

3.1.5 Turn it upside down

### **3.2 All Directions**

3.2.1 Start backwards

3.2.2 Start forward

3.2.3 Start both ways

3.2.4 Start somewhere

3.2.5 Reverse roll

3.2.6 Find a better path

## **4. Consolidation**

### **4.1 Combine**

4.1.1 Combine and put together

4.1.2 Use many

### **4.2 Multi purpose**

## **5. Segmentation**

### **5.1 Learn to share and Manage resources**

### **5.2 Segment/cut**

5.2.1 Divide an object into independent parts

5.2.2 Make an object sectional

5.2.3 Increase the degree of segmentation

### **5.3 Separate**

## **6. Modification**

### **6.1 Rearrange**

### **6.2 Extract/pull**

6.2.1 Extract unnecessary elements

6.2.2 Extract disturbing parts

6.2.3 Extract only the necessary part/property; use what's needed.

## **6.3 Substitute/exchange**

6.3.1 Substitute

6.3.2 Reject and regenerate parts

6.3.3 Replace linear motion with rotational motion; utilize centrifugal force

6.3.4 Replace mechanical system with another system

## **6.4 Add/ Subtract**

6.4.1 Add

6.4.2 Subtract

## **6.5 Change**

6.5.1 Change the color

6.5.2 Transform physical or chemical states of an object

6.5.3 Add saturation/ hysteresis

## **6.6 Self Modification**

6.6.1 Convert harm into benefit

6.6.2 Use self service

6.6.3 Feedback

## **6.7 Add something in between**

## **6.8 Localize**

6.8.1 Focus on local quality

6.8.2 Use different parts to carry different functions

6.8.3 Place parts in most favorable conditions

## **6.9 Take partial or overdone action**

## **6.10 Automate It**

Add automation

## **6.11 Purify / mix**

## **7. Similarity**

### **7.1 Look for Pattern/Rule**

7.1.1 Follow the pattern

7.1.2 Generalize the pattern

### **7.2 Look and use analogy**

7.2.1 Recall same or similar problem/goal

7.2.2 Recall a path of thought. Adapt it

7.2.3 Recall and combine two or more other relevant ideas

7.2.4 Adapt an old/new principle to an old/new problem

7.2.5 Use metaphors

## **7.3 Make it similar**

7.3.1 Use counterweight

7.3.2 Make it equal potential

## **8. Experimentation**

### **8.1 Work it out**

8.1.1 Simulate and experiment

8.1.2 Estimate and check

8.1.3 Try it out

8.1.4 Guess and test

## 5. Examples

### 5a) Course material

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

#### a1) Example for the **Uniqueness** strategy

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) Example for the **Dimensionality** strategy

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.

#### a3) Example for the **Directionality** strategy

A frequently used sub-strategy in this category is “starting backwards”, i.e., starting from the desired state and working towards the initial state. A well known example is: An eight-gallon jug is full, and both a three-gallon jug and a five-gallon jugs are empty. Without using any other containers, divide the water into two equal amounts.

Working backwards leads to: 0-4-4, 3-4-1, 2-5-1, 2-0-6, 0-2-6, 3-2-3, 0-5-3, 0-0-8.

#### a4) Example for the **Consolidation** strategy

How would you measure the diameter of a thin wire with a regular ruler?

A solution: wind the wire around a cylinder to form a coil. Measure the length obtained by many diameters (say, 100) and then divide the result by the number of rotations (100). For example, if this length is 8 mm (+/- 0.5mm), after dividing by 100 we get 0.08 (+/-0.005) mm.

**a5) Examples for the Segmentation strategy**

Venetian blinds are made of many parts. Railroad train and cars are many independent parts put together. Garden hoses can be joined together to form a longer hose. Personal computers are modular to allow flexibility in personalizing and changing them, as well as for easy maintenance.

**a6) Example for the Modification strategy**

A well known sub-strategy in this case is “using feedback”. Feedback can be added to a system or may be an integral part of it. Examples: Cruise control system of a car uses velocity feedback to maintain a constant speed. Some eyeglasses adjust to the ambient light by changing the color of the lenses.

**a7) Example for the Similarity strategy**

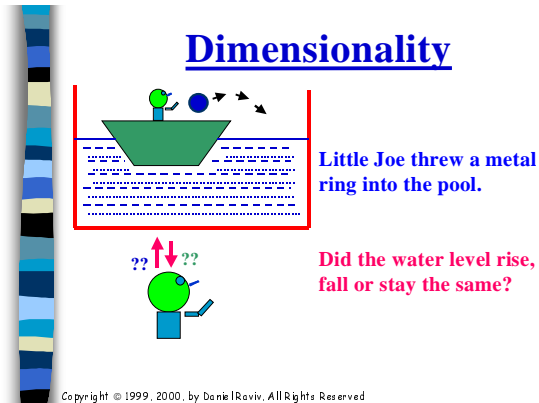
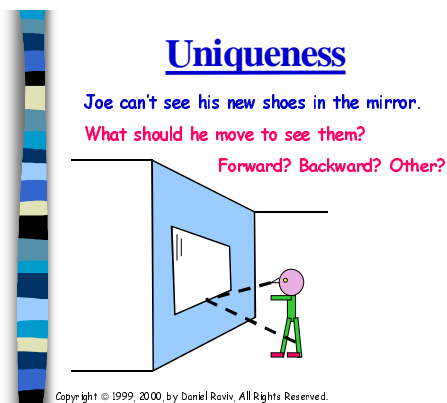
How can sunflower seeds be separated from their shell? How can parts wrapped in protective paper be unpacked?

An inventive (patent-based) solution to both problems is: place some quantity of the product into a hermetic chamber. Slowly increase the pressure inside the chamber. Then abruptly let the pressure drop. This will result in an explosion that will split the product.

**a8) Example for the Experimentation strategy**

This strategy refers to estimating, guessing, simulating, and using the trial and error approach. Example: Estimate the number of barbers in New York City.


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






### Directionality & Uniqueness

**Looking at things differently**

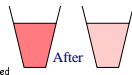




Before

Joe poured 20cc from the “wine cup” to the “water cup”, and then 20cc from the “water cup” to the “wine cup”.

Is there more water in the “wine cup” **OR** more wine in the “water cup”?



After

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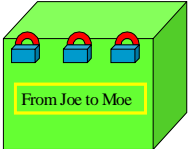
### Consolidation

Joe wants to mail a package to his friend Moe. If the package is not secured by at least one lock, the post office will empty the package and keep its content.

**How was the package sent?**

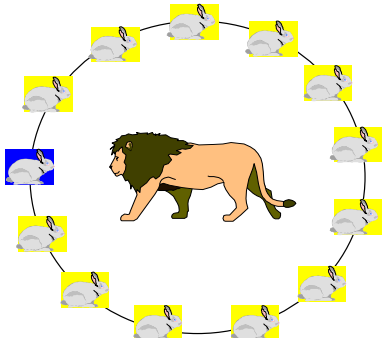
*Note:* Joe and Moe communicate by mailing packages only.

No letters, fax, phone, e-mail, etc., are available.



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



**In his dream the lion is offered a deal:**

Eat all 13 bunnies ... **But:** after eating the first bunny, he has to count 13 bunnies clockwise, eat the 13<sup>th</sup> one, count 13 bunnies again, eat the 13<sup>th</sup> one, and so on.

The last bunny to be eaten must be the blue one...

Otherwise... there is no deal... Where should he start?

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 by the eight strategies:


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.

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

**UNIQUENESS** - Compare Characteristics and Features  
*Magnify the difference*


In 1876, Galileo Galilei saw that Mercury changed slightly and constantly with Temperature. He put a small amount into a thin container and created the first Thermometer.



Presence "Encyclopedia of Inventions" p.85

**DIMENSIONALITY** - Start with More  
**Generalize & Solve a more general/global case**

Edward Jenner is renowned as the "father of smallpox vaccination". He concluded that people who had earlier caught the mild disease of cowpox did not catch the normally fatal disease of smallpox.




The word vaccination derives directly from this connection with cowpox. Vacca is the Latin for cow.

<http://home.sprynet.com/~btomp/smallpox.htm>

**DIRECTIONALITY** - The Other Way Around  
*Use indirect Measurement*

A conventional sphygmomanometer provides a pressure sensor for determining the blood pressure and developing an oscillation frequency. Piezo-electric elements of the pressure sensor was utilized for converting an amount of the blood pressure into the oscillation frequency.



US Patent No. 4,262,675

**CONSOLIDATION** - Combine  
*Combine and put together*

In 1891 Charles Elsener, the son of a Swiss hat maker, was trying to find a way to stay in his motherland. Many people were migrating to the Americas and resources in Switzerland were becoming scarce.




He took a blade, an awl, a can opener, and a screwdriver – connecting them together to create the soldier's knife, the first multipurpose tool

**SEGMENTATION** - Segment / Cut  
*Divide an object into independent parts*

Rubber had been widely spread when in 1820, Englishman Thomas Hancock cut a rubber bottle into these strips. He used these strips as garters and waistbands. Oddly, he never took out a patent on his invention.

It was Stephen Perry in 1845 who made the patent for Rubber bands when he discovered their wide variety of uses.



Wulfsson "The Invention of Ordinary Things" p.66


**MODIFICATION** - Take Partial or Overdone Action  
**Take Partial or Overdone Action**

During the 1880s English manufacture Walter James Alcock found a way to make Outhouse visits more convenient by inventing perforated Toilet Paper



**SIMILARITY** - Look for Analogy  
*Recall a path of thought - Adapt it*

In 1964, Bill Bowerman, a track coach from the University of Oregon, and one of his runners, Phil Knight, created a company to produce better running shoes. In 1972, Bowerman invented waffle soles by shaping rubber in the waffle iron in his kitchen. His soles gave running shoes optimal traction.




They named the company NIKE, after the Greek goddess of Victory.

<http://web.mit.edu/invent/www/inventorsA-H/bowermanknight.html>

**EXPERIMENTATION** - Work it Out  
*Try it out*

Jacques and Joseph Montgolfier realized smoke always rises, and in 1783 captured the smoke to lift objects. Thus, they created the first hot-air balloon.



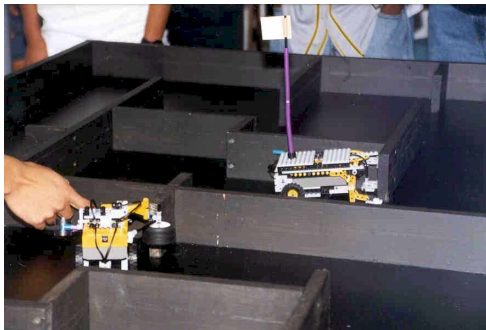
Presence "Encyclopedia of Inventions" p.54

## 5b) Laboratory material

Laboratory activities have been developed for hands-on experience by individuals and teams. We view team building and team work 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, semi-guided exploration that improves self-esteem and encourages questioning and daring. The material and activities are specific with clear identification of the relevance of the different hands-on activities to the teaching of the different concepts.

**b1) Accomplishing a strategy-oriented robotic task** using off-the-shelf programmable autonomous (sensor-equipped) wheeled mini-robots. The programming is done at a high-level language. Software packages for the robots are available from the robot manufacturers. In the last few semesters we used the LEGO® MindStorms™ in three different team-based autonomous competition: 1) speed, 2) getting out of a maze, and 3) down-hill obstacle-avoidance. All competitions were 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 modifications* improvements 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.

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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 logic gates integrated 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. These design projects include 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 incorporate *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**

The US Patent and Trademark Office ([www.uspto.gov](http://www.uspto.gov)), and IBM ([www.ibm.com/patents](http://www.ibm.com/patents)) provide databases for “smart” patent searches. They are being used to search for specific patents and ideas via the internet.

**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. 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. Task examples:

- 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

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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<sup>47</sup>: 1) Qualities of the person<sup>47</sup>, 2) Aspects of the process<sup>48</sup>, 3) Characteristics of products<sup>49</sup>, and 4) Nature of the environment<sup>50</sup>. 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<sup>7</sup>. It also deals with examining the effect of process training<sup>48</sup>.

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.

### 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 at 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 two 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”.

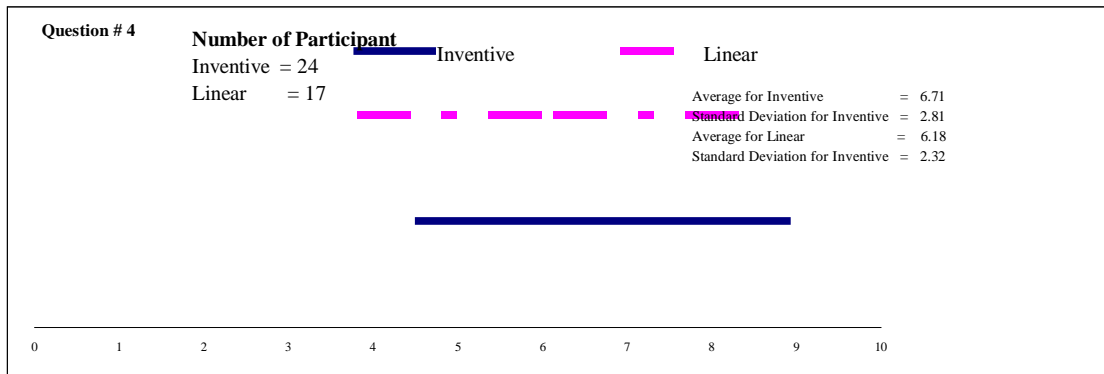
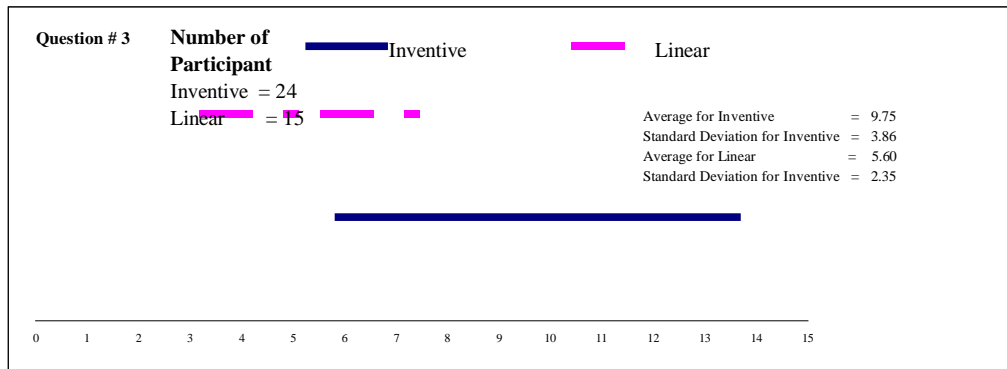
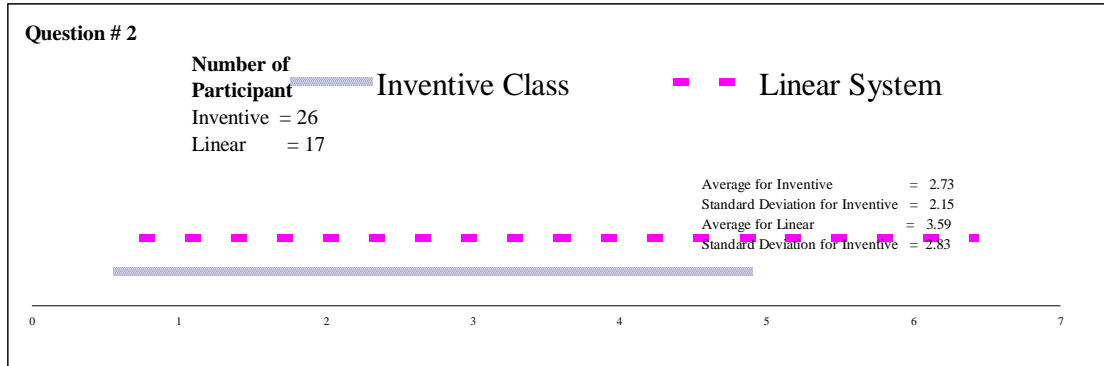
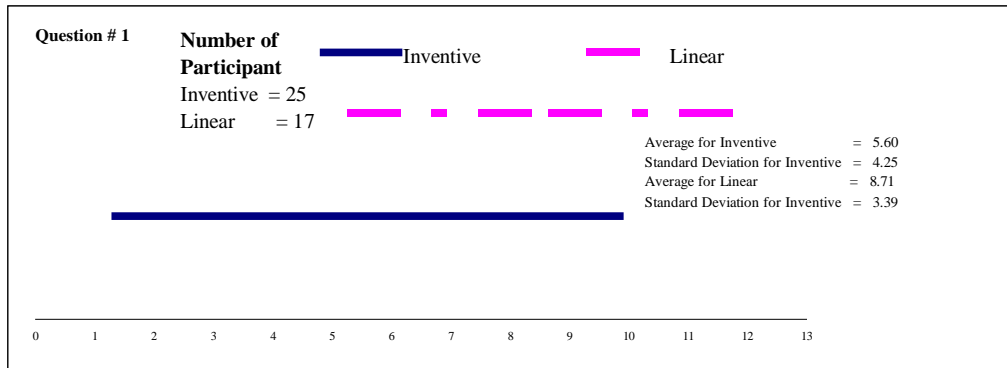
During the **“end” visits** (one per class) the “inventive” class students performed better than the students in the “linear” class: in question 3 the average number of solutions in the **“linear”** class was **5.60** with standard deviation of 2.35, where in the **“inventive”** class the average was **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.

The **relative improvement** in the number of average ideas (per student) generated by the students in the “inventive” class compared to the students in the “linear” class varies from **42%** (worst case:  $[(6.71/6.18)/(2.73/3.59)-1] \times 100\%$ ) to **170%** (best case:  $[(9.75/5.60)/(5.60/8.71)-1] \times 100\%$ ).

We view this improvement as a highly encouraging indicator for the methodology. However, it is too early to draw conclusions since it was only a one-semester experiment and the number of participants was limited.

The following charts are pictorial representation of the results mentioned above. The horizontal lines stands for the standard deviations. Solid lines are for the “inventive” class and broken lines are for the “linear” class. All the data was compiled by the TA for this class, Mr. Allapon.





**Chart 1:** Evaluation results for the two classes. Questions #1 and #2 were given at the beginning of the classes, and questions #3 and #4 at the end of the classes.

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## 7. On-going and future work

We are currently working on further development of the eight dimensional methodology at FAU. 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 will be incorporated as part of the new “Design 1” course. The “Inventive Problem Solving” course is currently being considered to become a core course in Engineering. Recently it was officially approved for Social Science, Arts and Humanities majors. We believe that other colleges will approve it as well. We are working with the College of Business to build a “Minor in Entrepreneurship and Creativity” program for engineering students, where the Eight-dimensional methodologies will be part of it. 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 the on-going hands-on material of this course.

We are highly interested in sharing and working with other colleges and institutions nationwide. Some work already started with UF, NCSU. North Carolina State University. Please see [www.productivethinking.com](http://www.productivethinking.com).

## 8. Acknowledgement

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