Learning Systematic Problem Solving: Case Studies*

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Abstract

This paper describes several case studies where students generated innovative solutions using a systematic problem solving methodology. The approach is based on The Eight-Dimensional Methodology for Innovative Thinking that stimulates innovation by effectively using *both* sides of the brain. It is a unified approach that builds on comprehensive problem solving knowledge from industry, business, marketing, math, science, engineering, technology, and daily life. The different dimensions, namely *Uniqueness, Dimensionality, Directionality, Consolidation, Segmentation, Modification, Similarity, and Experimentation* provide leaders, managers, and other problem solvers with new insights and thinking strategies to solve everyday problems they face in the workplace. Problems are not constrained to a particular profession or subject, and may be used by individuals and teams. It is easy to teach, learn and use the methodology.

1. Introduction

This paper details case studies where students generated innovative solutions using a systematic problem solving methodology. The methodology has been taught as part of a course titled: "Introduction to Inventive Problem Solving in Engineering" (please see syllabus at: http://www.ee.fau.edu/faculty/raviv/EGN4040_SP2003_Syllabus.htm). The main goal of the course is to enhance inventive and innovative thinking abilities of undergraduate students. In this course there is no "right or wrong", and the emphasis is on "out-of-the-box" inventive thinking, imagination, intuition, common sense and elements of communication/teamwork. The course uses hands-on problem-based learning for introducing undergraduate engineering students to concepts and principles of inventive/innovative 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/innovative problem solving. (Please see some of the puzzles at: http://www.ee.fau.edu/faculty/raviv/teach.htm). These activities allow for self-paced, semi-guided exploration that improves self-esteem and encourages questioning and daring.

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

The systematic problem solving approach is based on The Eight-Dimensional Methodology for Innovative Thinking that stimulates innovation by effectively using *both* sides of the brain. It builds on comprehensive problem solving knowledge from industry, business, marketing, math, science, engineering, technology, and daily life. The different dimensions, namely *Uniqueness, Dimensionality, Directionality, Consolidation, Segmentation, Modification, Similarity, and Experimentation* provide leaders, managers, and other problem solvers with new insights and thinking strategies to solve everyday problems they face in the workplace. The methodology looks at problems systematically and helps to generate many unique "out-of-the-box" and unexpected multiple solutions.

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. 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. 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 problem solving skills.

2. Innovative Thinking and Problem Solving: Related work

The literature on problem solving is quite rich. Some books focus on creativity in general [1-5, 24], others on general methods for problem solving such as brainstorming, brainwriting and lateral thinking [6-9]. The literature is business- and industry-related [10-15], engineering- and technology-oriented [16-22] with focus on inventions [22], or math specific [23].

There are too many different methods, a fact that sometimes makes the idea generation of the problem solving process confusing. After all, how would one know which one to use or which one is better for a specific problem? Some methods are systematic others are more heuristic, some leave lots of space for creative thinking, others are more "linear". Several methods are time consuming or must be used in team settings. In many, past problem solving experience is not documented so each time there is a need to start "from scratch" to find new ideas and rely on creative or experienced people. Some methods are limited in scope and can be applied only to particular sub-sets of problems. For example, many current settings of "Brain Storming" sessions, one of the most popular idea generation methods, take significant team "best" time. Its approaches are often not systematic leading to missed ideas. The brainstorming method uses little documentation of past problem-solving knowledge and solutions, and there is always the problem of "psychological inertia" and the attempts to please others (especially if the boss is there and has specific expectations).

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Systematic methods: One example is the TRIZ methodology. TRIZ is a Russian Acronym for the theory of inventive problem solving. Genrikh Altshuller [16,17] 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 global patent collections 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[19]. Recent methods include Structured Inventive Thinking (SIT/ASIT)[25] and marketing oriented approaches[26]. Recent papers by the author[27,28] detail some aspects of the Eight-Dimensional Methodology and the course at FAU.

There has been a need for a **unified** and **systematic** approach to generate ideas that **overcomes disadvantages** of existing methods and **uses past experiences** from many disciplines: an approach that allows one to exercise different levels of creativity. In an attempt to find the new approach, we asked a very basic and simple question: "How do people generate ideas to solve problems?" This led to a search not only of methods but also to problem/solution scenarios in different disciplines. It turned out that existing methods that were invented by problem solvers could be unified under an "eight-dimensional" umbrella.

3. Overview of the Eight-Dimensional Methodology for Innovative Thinking

Here is how it works: The user explores solutions in eight different thinking directions, one at a time. In each direction ("dimension") he/she are guided through multiple questions or suggestions that stimulate his/her mind in sub-spaces in which solutions may be found. These thinking dimensions are: Uniqueness, Dimensionality, Directionality, Consolidation, Segmentation, Modification, Similarity, and Experimentation. The user may choose to use them at a high level by asking only eight different questions, or at deeper, more detailed levels of specific sub-strategies. The following are the dimensions and the related questions:

Uniqueness
What is unique about the "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, or solutions"? Could these observations be used to find solutions?
Sub strategies include: discover what does not change; compare characteristics/features; look for ideal solutions.

Dimensionality
What could be done with space, time, cost, color, temperature, or any other dimension?
Sub strategies include: start with less; start with more; manipulate time/space/cost dimensions and structure/topology/state; reduce details; duplicate it/ repeat it.

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Directionality
Could things be done from different directions or points of view? If so, how?
Sub strategies include: look the other way around; look in all directions.

Consolidation
Would it be helpful to consolidate "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, or solutions"? If so, in what way?
Sub strategies include: combine; use for several purposes.

Segmentation
How could segmentation of "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, or solutions" help?
Sub strategies include: learn to share and manage resources; segment/cut; separate.

Modification
What if modifications to the existing "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, solutions" are introduced?
Sub strategies include: rearrange; extract/pull; substitute/exchange; add/subtract; change; allow for self modification; add something in between; localize; take partial or overdone action; automate It; purify / mix.

Similarity
Why not look at similar "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, or solutions"?
Sub strategies include: look for pattern/rule; look and use analogy; make it similar.

Experimentation
Could estimating, guessing, simulating, or experimenting help? If so, how?
Sub strategies include: work it out; simulate; estimate.

Advantages of The Eight-Dimensional Methodology for Innovative Thinking

The Methodology:

- unifies existing problem solving knowledge, techniques and solutions from different disciplines Engineering and technology, Inventions, Business and Marketing, Industry, Math and Science, Art, and Daily life. Well known methods such as Analogy, TRIZ, SCAMPER, Lateral Thinking are embedded in it.
- is discipline independent. The nature of its construction implies that it can be used to generate ideas for problems from Engineering to Business to daily life.
  is comprehensive and systematic thus allows anyone to be creative in the idea generation process, a key step in innovation.
- stimulates thinking by focusing on eight different problem solving strategies, one at a time.

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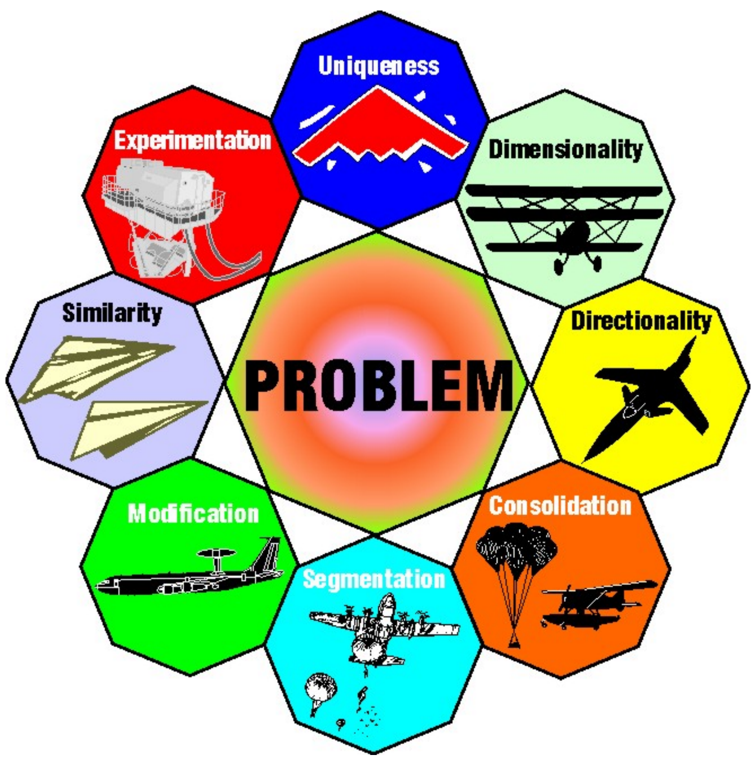
- generates many out-of-the-box and high-quality ideas in a short period of time.
- may be used by individuals/teams anytime. It is in particular useful in increasing efficiency in both quality and quantity of brainstorming and similar team setting methods. In addition, it allows individuals to generate ideas even when their minds are "too tired to think".
- reduces and even eliminates psychological inertia. It reduces the well known scenario of dominant "bully" individuals that control brain storming sessions and shut off any creative idea attempted by other participants. Unexpected and "crazy" ideas may be awarded or blamed on the method instead of individual. In other words it eliminates finger-pointing.
- is easy to learn and to use. After all who wants to learn or use a complicated method?

It should be emphasized again that the methodology focuses ONLY on the process of idea generation step of the problem solving process.

In addition, it is important to clarify that it is **not** a problem-solving cookbook.

4. Introducing The Eight-Dimensional Methodology to Students

The strategies for inventive and innovative thinking are pictorially illustrated next. They can be used in any order to solve problems.



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The following problem was presented in class to illustrate the high level use (i.e., without using sub-strategies) of the Eight-Dimensional Methodology. It is intentionally simple and non-technical.

The coffee cup problem

Dr. Coff was drinking coffee in a restaurant when he saw a bug floating in his cup. "Waiter" he yelled, "there is a bug in my coffee. Would you please replace it with another cup?" "Certainly!" replied the waiter. Moments later after Dr. Coff got the coffee, he exclaimed: "Waiter, what's going on? This is the same cup of coffee !!!"

Q: How did he know?

Now let's list ideas that come to mind from each dimension even if the same idea pops up in two different dimensions.

Uniqueness
Q: What is unique about the "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, or solutions"? Could these observations be used to find solutions?

One of a kind cup
Chip in cup
Cream/sugar in coffee
Lipstick on cup
Customer fingerprints on cup
Customer marked the cup
Unique bug features left in cup
Customer mixed milk with coffee

Dimensionality
Q: What could be done with space, time, cost, color, temperature, or any other dimension?

Less coffee in cup
Waiter returned too quickly
Restaurant repeats the same strategy
There was no coffee in the coffee machine
Bug escaped from cup and flew in front of customer

Directionality
Q: Could things be done from different directions or points of view? If so, how?
Waiter did not go to kitchen

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Consolidation
Q: Would it be helpful to consolidate "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, or solutions"? If so, in what way?

Cream or sugar were still there
Remaining bug pieces were visible

Segmentation
Q: How could segmentation of "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, solutions" help?

Customer analyzed a sample of it
Elements of bug surrounded the cup

Modification
Q: What if modifications to the existing "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, solutions" are introduced?

Coffee was too cold
Coffee had strange color/temperature

Similarity
Q: Why not look at similar "processes, objects, dimensions, situations, resources, concepts, principles, features, patterns, problems, or solutions"?

Happened in the past at the same restaurant
Knew the waiter was too lazy to bring a new cup
Customer decided to see the waiter's reaction to a question and compared it to previous reactions

Experimentation
Q: Could estimating, guessing, simulating, or experimenting help? If so, how?

Coffee tasted strange
In response to a question, the waiter admitted
Saw the waiter removing the bug
Heard the waiter telling others about the cup
Heard other people talking about what they saw
Customer figured it out by conducting a scientific experiment

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The following comics problem is another non-technical introductory problem to the "Eight Dimensions". Students were asked to write down solutions, first without the methodology and later with it. In the beginning the average number of ideas was about five per student. However, when students were asked to use the methodology and its sub strategies to find solutions, the number of ideas generated by each student varied from 15 to 35. These include ideas that are "unacceptable, non-feasible, expensive, too imaginative, unmarketable, useless, etc."

The comics problem

Every morning T and G sit on the opposite sides of the table trying to read the same comics section of the newspaper at the same time.

Q: How can they both read it without fighting?

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:

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.

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.

The following is a **brain-teaser** example used to introduce the dimensionality strategy. Little Joe is sitting in a boat that floats in a pool. He throws a metal ring from the boat into the pool. Will the water level rise, fall, or stay the same? (The answer is “fall”. It can be easily obtained by imagining the effect of a very small, and at the same time very heavy, ring.)

The following is a sample of some examples used to introduce some of the Eight Dimensions.

-- Directionality: Blood pressure is being measured indirectly. A conventional sphygmomanometer provides a pressure sensor for determining the blood pressure and developing an oscillation frequency. Piezo-electric elements of the pressure sensor were utilized for converting the amount of the blood pressure into the oscillation frequency.

-- Consolidation: The Swiss army knife is a multipurpose tool.

5b. Laboratory material

Individuals and teams experience the eight strategies. 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.

Example 1:
In a fenced floor area that contains five different size stationary objects, use a LEGO MindStorms 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”.

Example 2:
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*), similar triangles approach *(similarity)*, and *experimentation*. Another important feature of this project is the better understanding of the “no right or wrong” and “no unique solution” concepts.

Example 3:
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-

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on solution (*segmentation* and *experimentation* strategies), then generalize it (*dimensionality* strategy).

Example 4:
This example has to do with using the Eight Dimensional Methodology using 3-D mechanical puzzles: 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*.

6. Evaluation

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

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
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".

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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. 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.

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