AC 2009-2369: TECHNIQUES TO ENHANCE CONCEPT GENERATION AND DEVELOP CREATIVITY

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Techniques to Enhance Concept Generation and Develop Creativity

Abstract

The concept generation (CG) step in the design process presents tremendous and unique opportunities for enhancing creativity in students. Other researchers have developed a variety of techniques specifically to aid in the CG or ideation process. Based on their work, as well as original work we have done in this area, we have developed a suite of CG techniques for use by students in design classes. The techniques include a modified 6-3-5 technique, functional decomposition combined with morphological analysis, TIPS/TRIZ, a method to produce products with the ability to transform, a search for cross-domain or far-field analogies, implementation of creativity principles from historical innovators and a design by analogy technique using a WordNet-based search procedure. Various sets of these CG techniques have been implemented at both the University of Texas and the US Air Force Academy. In addition, in an effort to assess the ability of these techniques to enhance creativity in our students, we implemented a survey that attempts to measure creativity before and after the students learned to use the CG techniques. Our results show that the implementation of the suite of CG techniques produces a increased quantity and innovation in the concepts. Also, the assessment indicates that exposure to these CG techniques increases creativity when compared to a control group that were not exposed to the suite of CG techniques.

1. Introduction

Innovation and creativity are central to the engineering design process. Numerous versions of the "design process" have been proposed[1-4]. Two examples are captured below in Figures 1 and 2. Figure 1 shows the process as depicted by Ullman[1] and Figure 2 provides a similar description from Ulrich[2]. In both these cases, and in the majority of other portrayals of the design process, one of the steps in the overall process is identified as "concept generation" (CG). As shown in Figure 3 from Otto & Wood[3], the CG step itself can be separated into a set of sub-processes. Note the dual paths depicted in the figure, which divide the process into two categories, basic and more advanced. Similarly, Shah[5] also uses two categories that he refers to as intuitive and directed. The upper path in the Figure 3 corresponds to the directed type CG methods and the lower path to the intuitive methods. The goal of the intuitive methods is to create an environment that enhances creativity for the designer allowing for maximum opportunity to produce innovative solutions. Classic examples in the intuitive category include brainstorming and morphological analysis. The goal of the directed methods is to follow more of a step-by-step or systematic process to develop a solution. Technical information combined with fundamental physical laws play a key role in this directed method set of CG techniques.

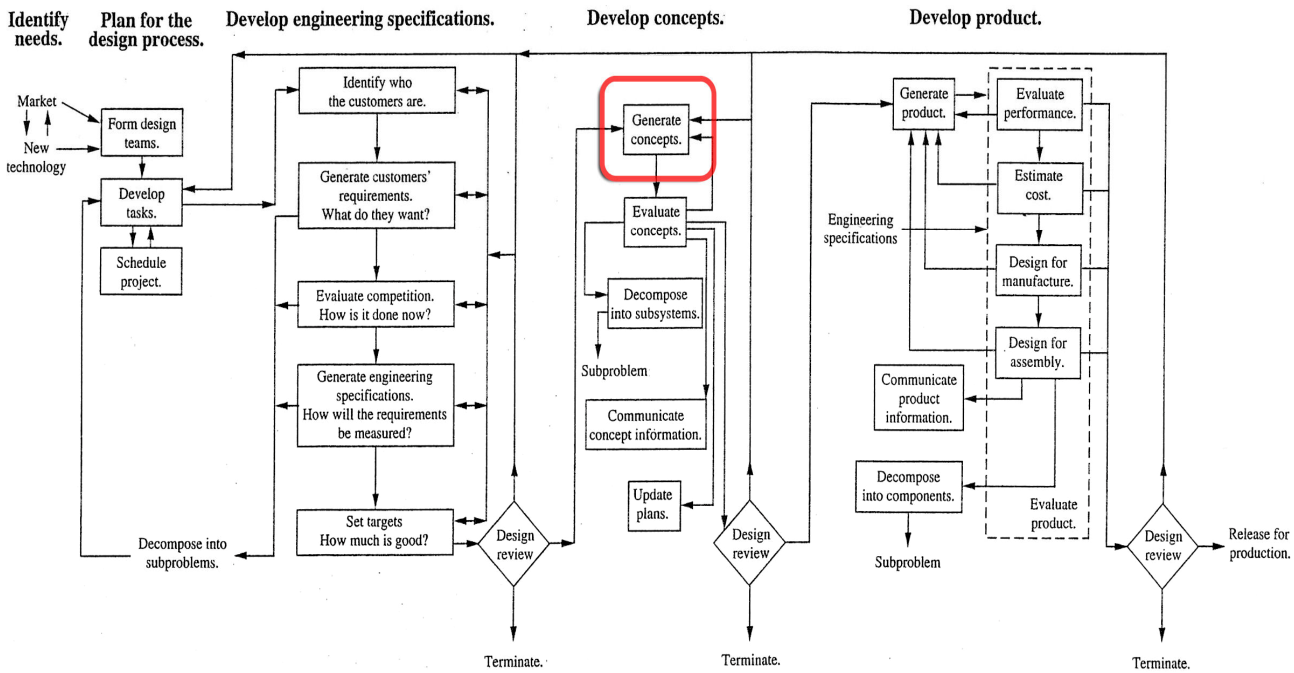


Figure 1 – Ullman's Depiction of the Design Process[1]

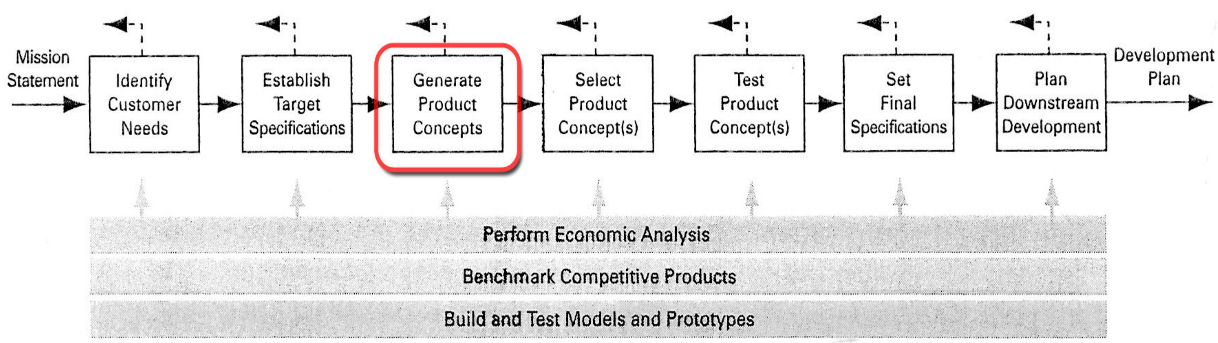


Figure 2 – Ulrich & Eppinger's Depiction of the Design Process [2]

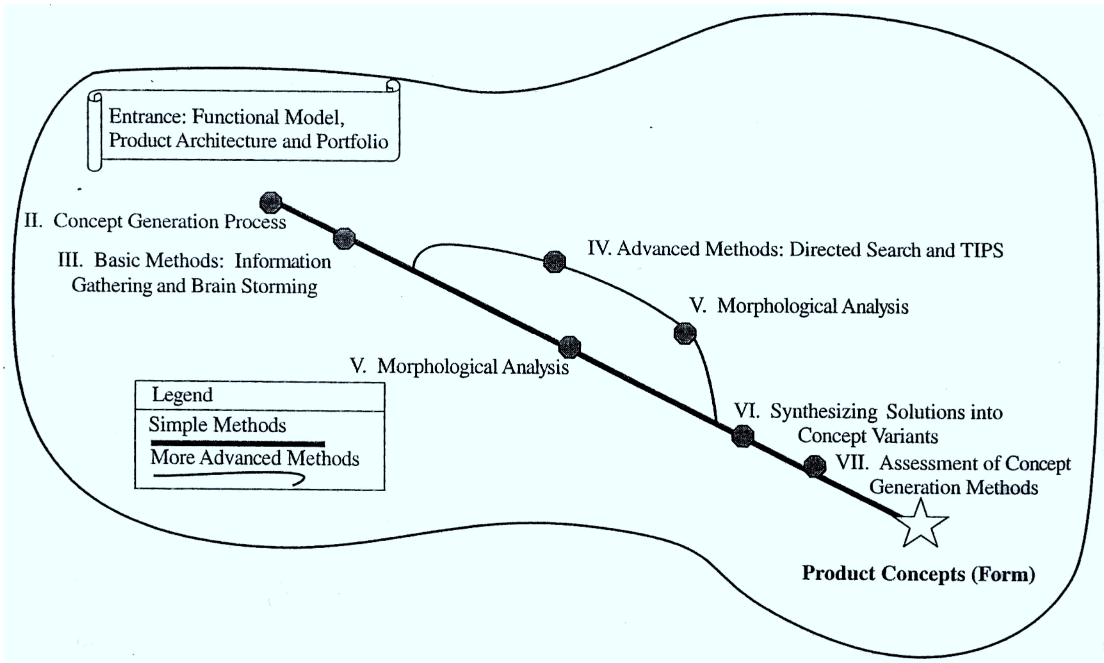


Figure 3 – Otto & Wood's Depiction of the Concept Generation Process[3]

This paper reports on the implementation and assessment of a suite of intuitive CG techniques designed to increase creativity in students' design teams. Specifically, six techniques were examined: (1) Morphological analysis combined with 6-3-5 directed brainstorming, (2) Transformational design using mind-mapping, (3) WordNet-based design by analogy, (4) Far-field analogies, (5) Principles from historical innovators and (6) The Theory of Inventive Problem Solving (TIPS). Two of these CG methods (TIPS and Morphological analysis combined with 6-3-5 directed brainstorming) are relatively well established[3]. Two of the methods are new (Transformational design using mind-mapping[6-7] and WordNet-based design by analogy[8]), but have been described recently in the literature. The remaining two methods (Far-field analogies and Principles from historical innovators) were developed by the authors and have not previously been reported in the literature. Each of these six methods is described in detail below.

Over the course of the last two years, a number of design teams at the US Air Force Academy and the University of Texas have worked to implement and assess these techniques. The goal of the assessment process has been to provide insight into the effectiveness of the six different CG methods. The suite of CG methods was evaluated in two ways. First, the number of concepts generated and their innovativeness (as judged by the students) is quantified for each CG method. Second, the students' self-evaluation of their level of creativity is measured both before and after use of the CG suite. This provides insight into the level to which these methods actually increase the users' creativity. Specifically, a creativity measurement instrument (described in section 4.2) has been used on both "control" design teams (who did not use the six CG techniques) and "experimental" teams (who used the complete suite of CG techniques). The creativity measurement instrument was used both at the beginning and at the end of the CG process so that an increase in creativity could be quantified. Results of both of these assessment procedures for teams at the US Air Force Academy are discussed in detail in section 4.

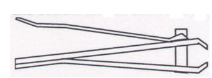
2. Concept Generation Techniques

As mentioned previously, CG techniques can be separated into directed and intuitive categories. The directed techniques rely heavily on the application of physical laws or other technical insights to the resolution of design conflicts. The intuitive techniques rely more on a divergent thought process to produce new ideas for the solution to a problem. Although the intuitive processes are, in many cases, less structured than the directed processes, they are certainly not without a certain level of order. In fact, the challenge in development of innovative solutions to design problems is, at least in part, in structuring a learning environment that will be conducive to this divergent, creative idea generation. It is with this goal in mind that we are implementing these six intuitive CG techniques.

2.1 Morphological Analysis Combined with 6-3-5 Directed Brainstorming

Functional decomposition is a method that helps designers describe *what* a product will be required to do (functions), *not* *how* it will accomplish these tasks (embodiment). There are a number of different ways to accomplish this functional decomposition with common methods including function trees and function structures[3]. Functional decomposition combines with morphological analysis to provide a method for organizing potential embodiments for each function. Figure 4 shows a very simple morphological matrix for a set of finger nail clippers. The design problem is first broken down into its functions. The functions of the device are then listed in the first column. Solutions (embodiments) that were generated during the CG process are then organized by their function in the rest of the columns.

Morph Matrix:
Finger Nail Clipper



Function	Solution 1	Solution 2	Solution 3
Apply finger force	shaped top, bent bottom	shaped top and bottom	
Convert to large force	pivot	linkage	
Move file into place	pivot out file	file on arm	slide arm out
Stop motion	teeth hit	mechanical stop	
Release force	spring of bent body		

Figure 4 – Morph Matrix Containing Functional Solutions For a Set of Finger Nail Clippers[3]

In the classic method of "brainstorming," a small group of people openly discuss possible new solutions to an existing problem or conceptual solutions for new design problems. While this method may be effective in some forums, it has been shown in some design situations to lack the synergistic effect that is desired. Specifically, it has been determined in some situations that the group will not produce more quantity or quality of solutions in this "brainstorming" environment then a group of individuals working alone[9]. This finding has led many in the design community to the use of a modified brainstorming technique called 6-3-5, which is described graphically in Figure 5. In this technique, a small design team (approximately 6 members) each takes the initial 5-15 minutes of the exercise to develop a small number of concepts intended to solve a design problem[3]. These ideas are captured through a combination of sketches and words. Optimally, large sheets of paper and different colored markers are provided for each participant. After this initial 5-15 minutes, participants pass their paper to the adjacent team member. An additional 5-10 minutes are now provided for the members to add to/comment on the ideas of their colleague, or create an entirely new idea as inspired by the sketches passed to them. This rotational process continues until each member has taken the opportunity to add to the concepts from all other members. No verbal communication is allowed during this entire process until all team members obtain their original concept sheet.

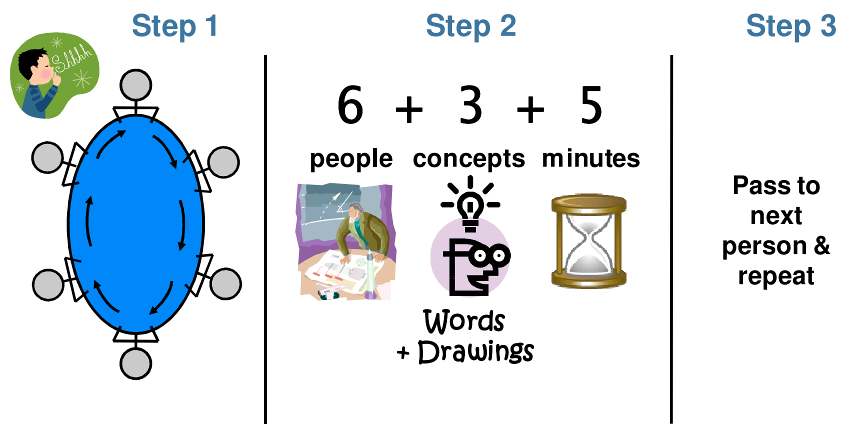


Figure 5 – 6-3-5 Concept Generation Process[3]

In our particular case, we have combined the 6-3-5 technique with Morphological Analysis and implemented the method following a function structure type functional decomposition[10] of the problem. The ideas developed from 6-3-5 were arranged in a morphological matrix based on how they met certain functions.

Figure 6 shows a sample result from the first and second round of a 6-3-5 session. In the first time period, one of the team members drew three different solutions to the problem of a device to shell peanuts. During the second time period, a second team member combined and added to the original set of ideas.

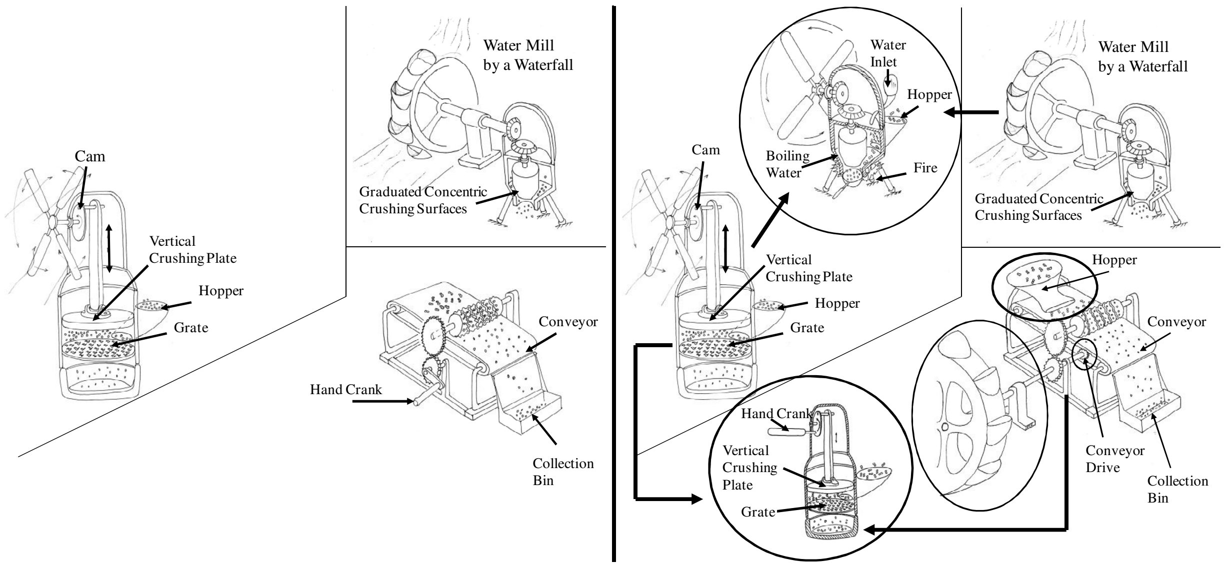


Figure 6 – Example Results from a First and Second Round of 6-3-5[8]

2.2 Transformational Design using Mind-Mapping

We define transformation as changing state in order to provide new functionality; for example, a Swiss army knife. Although products with the ability to transform are not new, until recently there has not been a theory of transformation, nor have there been CG methods specifically devoted to the development of transformational products. Over the course of the last three years, both a transformational theory and a supporting set of CG techniques has been developed[6,7]. The transformational theory describes a set of three transformational principles and 20 transformational facilitators. The transformational principles describe how the transformation takes place while the transformational facilitators describe key components of the transformation. These 3 principles and 20 facilitators shown in Table 1 have been validated through the study of over 200 electro-mechanical devices that have the ability to transform.

Table 1 – Transformational Principles & Facilitators

PRINCIPLES		
Expand / Collapse	Expose / Cover	Fuse / Divide
FACILTATORS		
Conform w/ Structural	Interchange Working Organ	Share Power Transmission
Enclose	Modularize	Shell
Fan	Nest	Telescope
Flip	Roll/Wrap/Coil	Utilize Composite
Fold	Segment	Utilize Flexible Material
Furcate	Share Core Structure	Utilize Generic Connections
Inflate	Share Functions	

The principles and facilitators are used in conjunction with a semantic network technique called Mind Mapping[3]. The technique places key words toward the center of a piece of paper and then organizes related information accordingly. Figure 7 shows a mind map created based on using transformational principles as secondary nodes to generate concepts for a product that transforms from a motorcycle to an ATV.

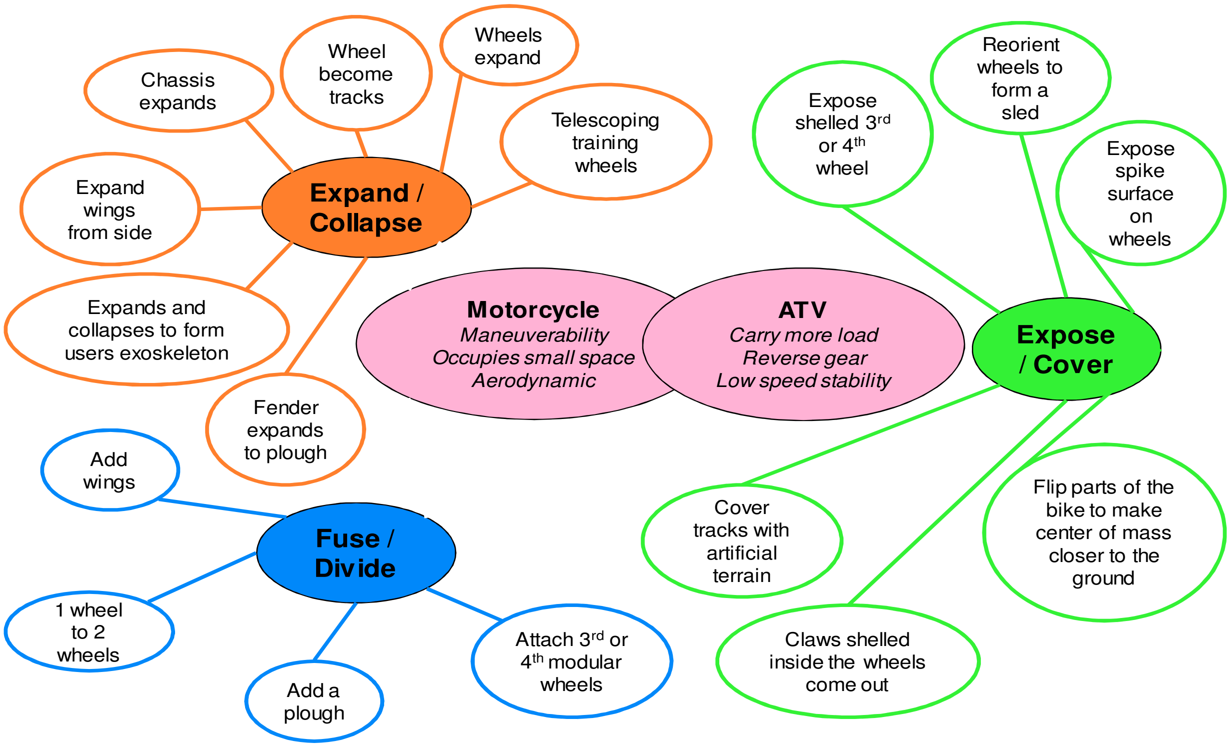


Figure 7 – Mind Map using Transformational Principles for a Motorcycle / AVT Product[7]

2.3 WordTree Based Design by Analogy

Using analogy is a powerful method for developing concepts. However, identification of analogies that will prove most helpful can be difficult. Recently, a technique for systematically seeking analogies based on the semantic representation of the functions being solved has been developed[11]. Multiple linguistic representations are created through intuitive brainstorming and using a tool created at Princeton called WordNet[12, 13]. WordNet is similar to a thesaurus, but with far more functionality. The tool takes an input word (which in the case of a design problem could be a key function or key customer need, stated as an active verb) and outputs troponyms and hypernyms. Troponyms are more specific synonyms and hypernyms are more general synonyms of the input word. By producing troponyms and hypernyms of key functions and customer needs, WordNet provides input to the design by analogy method. Appendix 1 has more detail including a step-by-step method for using the WordNet tool.

In order to organize the information provided by WordNet, an instrument called a WordTree was developed[8]. The word tree organizes the information by simply arranging chosen hypernyms above the input word and the troponyms below it. Additional words found through other intuitive methods can also be added. An example of a word tree using the input word "Track" is given below in Figure 8.

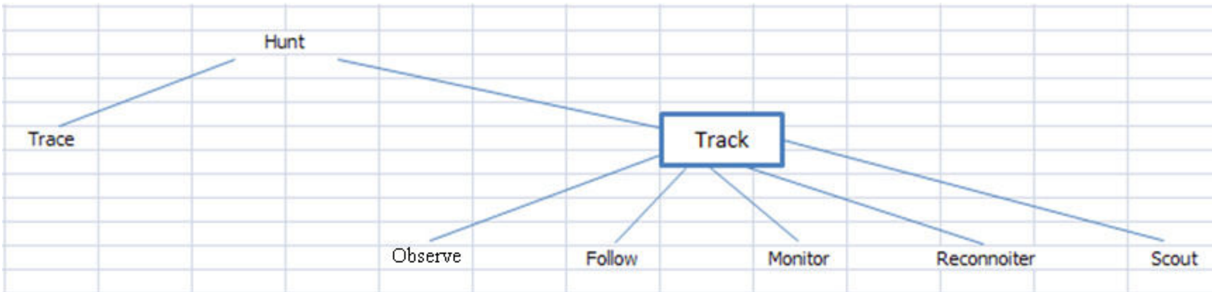


Figure 8 – Example of a Word Tree Generated using Information from WordNet

As can be seen in Figure 9, the text from the word tree can be combined with pictures to enhance the utility of the method. In this case, the design team was redesigning an automatic cat litter box. The team was searching for ways to clean the litter box. Unexpected analogies generated included dredging, panning for gold and a dump truck tailgate[8].

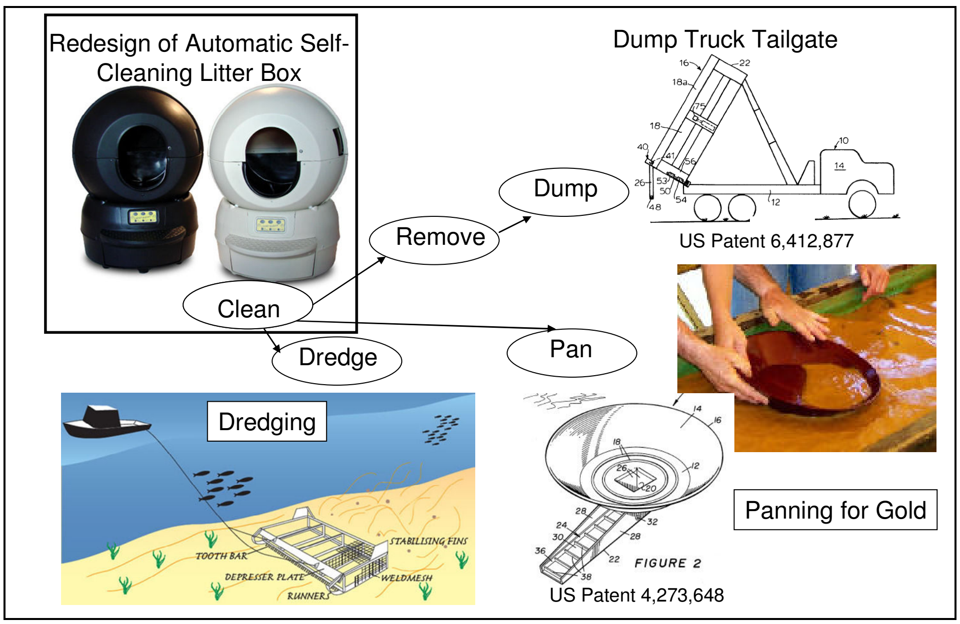


Figure 9 – WordTree for Cleaning Cat Litter Box

2.4 Far-Field Analogies

Much of design by analogy is successfully accomplished using biological analogies. If we wish to develop a product with the ability to hop, we consider how a rabbit or a grasshopper accomplishes this function. If our goal is to develop a product with new visualization capabilities, we might consider how the rods and cones of the human eye function. While biology appears to provide a very fertile set of analogies, it is not clear that this is always the most productive realm in which to search for analogies. Perhaps searching in different realms might provide analogies with some different distinctive features.

In light of this, we have developed a relatively unstructured method for encouraging students to look for analogies in other realms. The method is called Far-Field Analogies. The technique proposed three distinctly different fields where students might attempt to discover helpful analogies. These fields, along with an example question students can use to lead the discovery of analogies, are shown in Figure 10. Although we do not propose that these three fields (Physics, Art, and Societal Mechanics) are an optimal set for use in the Far-Field Method, we have used a wide variety of different fields and these appear to be our most optimal set to date. Perhaps this is because these three fields are quite diverse. Note that we have had students use this technique with different fields of their own choice with some success as well.

POTENTIAL REALMS FOR FAR FIELD ANALOGIES

Physics: State Changes, Quantum Mechanics, Relativity, Classical Mechanics (fluids, structures, orbital)

Art: Painting, Sculpture, Music, Poetry, Literature, etc.)

Societal Mechanics: Governments, Interpersonal relationships, Family dynamics, Organizational systems (corporate, military, family, recreational…)

Far Field Question:

How does ________ (insert a specific realm here)
do ________ (insert a specific Customer Need or Function here).

Figure 10 – Overview of Far-Field Analogy Concept Generation Technique

As an example of this method, we are attempting to design products that have the ability to "hide in plain sight". This would be a distinct advantage for surveillance systems. Using the Far-Field Analogy method, we implement the Far Field Question (Figure 10) and ask how does music hide in plain sight. We hypothesize that one way this occurs is that the music (see Figure 10 / Art Category) blends in with surrounding noise. This instigates that next step of inquiring how we can have our surveillance system blend in to its background. In accordance with this we are developing a technique that mounts LCD screens on the edges of the surveillance system, takes a picture of the background behind the system and projects that picture on the screen, causing the edges of the system to blend into their background.

2.5 Principles from Historical Innovators

Although significant questions remain on what precise traits give a person the ability to be creative, there is general agreement that history has numerous examples of individuals who have exhibited tremendous creative accomplishments. The concept generation technique of "Historical Innovators" attempts to capture some of the principles that these extraordinary individuals used to accomplish their innovative feats and then apply these principles to the concept generation process. There are, of course, literally thousands of possible historical innovators that could be used in this endeavor. We provide the students with four initial cases and then allow them to select others of their choosing. The four currently used have been chosen because the principles their work exemplifies appear to be quite broad and fairly applicable to the CG process. The four individuals we currently use are Nicolai Copernicus, Christopher Columbus, Plato and Albert Einstein. For each of these four innovators, we provide some background information, a set of “innovation principles” and a proposed application of the principles. Figures 11 and 12 show some of the information provided for the Historical Innovators CG process. Although sources for historical innovators are ubiquitous, helpful starting points include contributions from Christensen and Gelb[14, 15].

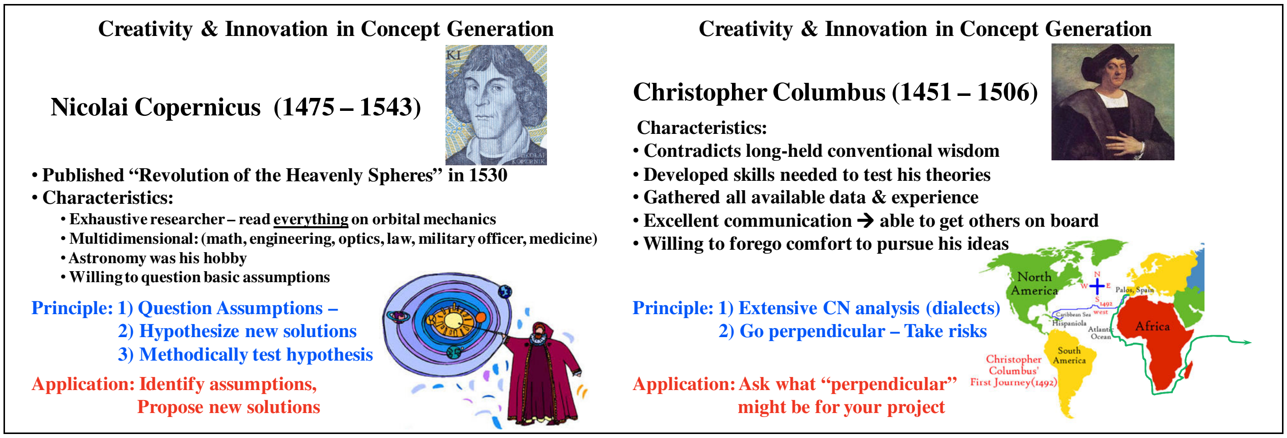


Figure 11 – Historical Innovators Copernicus & Columbus

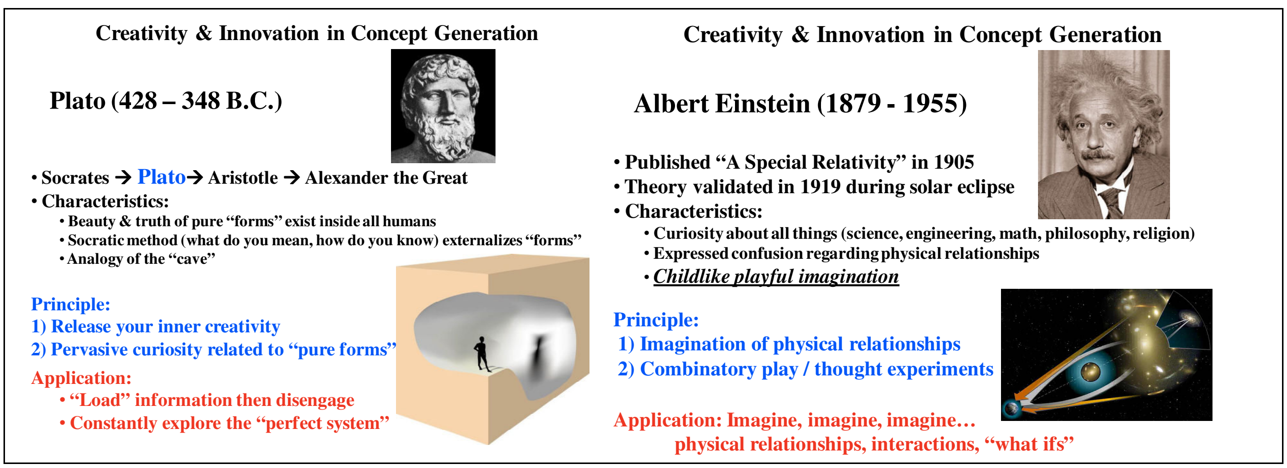


Figure 12 – Historical Innovators Plato & Einstein

As an example of how this method can be applied, one of our design teams worked with small remote controlled aircraft equipped with small cameras. The systems are used for surveillance missions for the military, fire fighters and natural disaster relief. Unfortunately, these systems are very limited by short battery life. One idea for dealing with this limitation is to give the aircraft the ability to perch. However, the control system to guide, flare wings, stall and grab that is used by most birds is quite difficult to implement in a man-made, mechanical system. While possible, the implementation of this system is likely years away from completion. A principle from the historic innovator Columbus, “go perpendicular - take a risk to shorten the time for completion of your mission,” provided the inspiration for an alternative design where the small aircraft simply hits a vertical perch location (like a wall) head on at low speeds, then sticks to the location by means of a “sticky pad” on the aircraft’s nose. This risky solution was implemented successfully in a very short period of time[16].

2.6 The Theory of Inventive Problem Solving (TIPS)

TIPS is a well documented method for solving conflicts in designs[3, 17]. Based on a study of thousands of patents[18], TIPS puts forth a set of 40 principles that can be used to inspire creative solutions to conflicts in a design. The designer examines the problem and identifies inherent contradictions in the design requirements. As an example, a designer may want to increase the acceleration of a vehicle. An engine capable of higher acceleration may be used, but this will likely have implications for other system parameters: cost may go up, the system may be larger and heavier, maintenance needs and durability may be affected. These contradictions may be summed up with general engineering parameters, such as power vs. volume, weight vs. cost.

A conventional approach may simply try to compromise in these tradeoffs, finding an optimal design that is “good enough” with respect to all the conflicting parameters. TIPS, however, guides the designer toward specific design principles that can resolve or eliminate these conflicts. This is done through a matrix that tabulates all combinations of contradicting engineering parameters and lists the principles used to creatively resolve them. To continue the previous example, identifying the contradiction between power and volume would lead to, among others, the principle of “*universality: make a part or object perform multiple functions; eliminate the need for other parts*.” This may lead to an attempt to increase function sharing and decrease the number of components in the engine and surrounding system, minimizing the additional volume resulting from the increase in power. While this method is normally included in the CG stage of design, to some extent it requires embodiment solutions to already be conceptualized. A design conflict must be identified (which is more readily apparent in fleshed-out embodiments) before the TIPS method can suggest a path to a resolution. Therefore, we have tended to use this method at the end of the CG process. Otto and Wood[3], as well as other sources, provide all the details needed to implement this CG method.

3. Background on Measurement of Creativity

The measurement of creativity is elusive at best. Although the research in this area is quite substantial, even the definition of creativity remains in question among the various researchers. Kerr and Gagliardi[19] provide a wonderful overview of the research in this area. Often the measurement techniques are used to identify people (usually children) that have high potential to be creative. However, the correlation between those who “score” high on these creativity measures and then later manifest this creativity is not always very high[20]. There are a variety of hypothesized reasons for this lack of correlation and researchers are working diligently to investigate this phenomenon. One such effort is the work by Csikszentmilhalyi[21] where the correlation between creativity and the mastery of a specific domain’s knowledge was investigated. Others have investigated psychological variables that can block creativity[22], environmental variables that enhance creativity[23, 24], and task motivation that drives creativity[25].

Two of the most common methods for measuring creativity are divergent thinking testing and creativity trait testing. Divergent thinking is a process that allows for various, sometimes seemingly unrelated, streams of thoughts that produces innovative solutions to a problem.

Runco[26] explains, "Because some of the resulting ideas are original, divergent thinking represents the potential for creative thinking and problem solving" (pg 577). Divergent testing is thus testing that attempts to measure the ability of an individual to think in this divergent manner. Torrance[27] produced a set of divergent thinking tests that are probably the most widely used and also are supported by a wide range of validity assessment data[28]. However, the use of testing like Torrance's requires fairly extensive time and also the support of experts who have been trained to evaluate the tests' results[29]. This makes these sorts of testing procedures less functional in an academic environment.

Creativity trait testing is based on the hypothesis that people who are creative share a common set of personality traits[30-32]. For example, a specific characterization from the Myers Briggs personality tests[33] has been correlated positively with creativity. There are a variety of instruments used to provide the Myers Briggs type data. A web version commonly used in academic settings has been developed by Kersey[34]. The test provides 4 personality descriptors. A person is either "extroverted" or "introverted", they are either "sensing" or "intuitive", they are either "thinking or "feeling" and they are either "judging" or "perceiving". The strength of one's preferences is also delivered by the test. Across a variety of fields including managers[35] and teachers[36] those individuals who are "introverted", "intuitive", "thinking" and "perceiving" tend to be more creative than those with other Myers Briggs designations. This Myers Briggs data appears to be a useful way to measure creativity in an academic setting and in this light has been used to develop a team formation and team coaching strategy[37].

In the present work, we wanted to be able to measure fluctuations in an individual's creative ability. This desire is obviously based on a belief that, while some creative ability is likely intrinsic to the person's personality and mental capabilities, it is possible to ***develop*** creative capabilities as well. In order to measure changes in an individual's creativity, we have chosen to use an established set of "creativity descriptors". Gough's[38] list of 18 descriptors has been evaluated across multiple fields using over 1700 subjects. These 18 adjectives have been shown to positively correlate to creativity (as measured by experts in the different fields). The list of descriptors is shown below in Table 2. Our assessment strategy entails asking the students to self-evaluate in these 18 areas both before and after they are exposed to the set of CG techniques described previously. We propose that the difference between their before and after assessment in these 18 areas is a measure of their increase or decrease in creative ability. Both a control group and experimental group are used as described in detail in the assessment sections below.

Table 2 – Gough's List of Creativity Descriptors

Capable	Egotistical	Informal	Interests wide	Reflective	Sexy
Clever	Humorous	Insightful	Inventive	Resourceful	Snobbish
Confident	Individualistic	Intelligent	Original	Self-confident	Unconventional

4. Assessment of the CG Suite

As stated previously, this paper assesses the effectiveness of the six CG methods using data from a number of design teams taking their senior capstone design course at the US Air Force Academy in the academic years 2007-2008 and 2008-2009. The teams worked on a variety of projects ranging from the Society of Automotive Engineers Formula Car Intercollegiate Competition to various smaller projects sponsored by the Air Force Research Laboratories. Team sizes ranged from 12 (for the formula team) to 6 (for the smallest AFRL team). Half of these groups served as a "control" group, only using 6-3-5 for concept generation. These three teams included the SAE formula car, a project to design a "quiet" Baja-type vehicle, and a project to design an exercise machine for rehabilitating the walking gate of those with neuro-muscular diseases. The other three teams utilized the complete suite of six CG methods detailed in section 2. Two of these teams worked on different aspects of a project to enable UAVs to tag and track targets, while a third worked on the previously mentioned project to enable UAVs to perch.

The assessment of the suite of CG techniques contains two components. These two components correspond directly with the two objectives for using the CG methods as shown in Table 3.

Table 3 – Objectives for the CG Methods

1- Provide a suite of CG methods that will enable students to develop a large quantity of diverse concepts to solve a design problem
2- Provide a suite of CG methods that will, through the use of the methods, enhance the creativity of the students

The first assessment component addresses Objective 1 and, as such, involves collecting data on the number of concepts generated by the different teams using the different methods. The second assessment component addresses Objective 2 by measuring the creativity of the control and experimental groups before and after their use of CG techniques. Both of these assessment components are described in detail below.

4.1 Assessing the Ability to Develop Multiple Concepts

Three different student teams in the Fall 2008 semester used the full suite of CG methods described in Section 2. Table 4 shows the number of concepts generated by the different teams broken down by the different CG methods. For each method, the teams had approximately 30 minutes of training (lecture) on the use of the method followed by approximately 90 minutes of time to implement the method. Therefore, the use of the 6 methods represents about 9 hours of total time. Each of these teams had 6 members and each team worked on the methods separately.

Note from Table 4 that the average number of concepts generated by each "experimental" group through the use of the six CG methods was 89. As teams were instructed to only "count" concepts that were distinctly different from their other concepts, we believe this to be a positive result. The three "control" teams, using only the 6-3-5 method, generated an average of about 7 concepts. Of course, this result is not directly comparable to the 89 concepts generated by the experimental group, as the control groups spent only a fraction of the time spent by the experimental teams on concept generation. However, a quantitative measurement can be made noting that the experimental groups developed an average of 14.8 ([average of 89 concepts] / [6 CG methods]) new concepts per CG method while the control group developed only 7. This result is even more persuasive when one considers that fact that the experimental teams might tend to experience some "burn-out" of their creativity as they proceed through the suite of CG techniques. Note also from the table that the number of concepts generated generally decreases as one moves down a team's column in the table. This, we hypothesize, is due to the fact that, in general, the teams used the techniques in chronological sequence from the top row to the bottom row. Considering the TIPS row of the table, it is helpful to know that team 2 interpreted the instructions such that each possible solution to a design conflict produced by TIPS was counted as a new concept. Teams 1 and 3 did not count these as new concepts since they were solutions to existing design conflicts inherent in concepts that had already been developed using the previous CG methods. Finally, note that the "top" producing CG methods (red numbers in the table) were different for each team. This might indicate that the team dynamics for each team or the type of design problem presented created different levels of productivity for each CG method. If this were correct, then the use of multiple methods as was done here would have the advantage of being able to access the unique strengths of the different teams/projects.

Table 4 – Number of Concepts and Innovation Ranking for the Different Teams and CG Methods

	Number of Concepts Generated				**Innovation Rating**			
CG Technique	Team 1	Team 2	Team 3	Avg.	Team 1	Team 2	Team 3	Avg.
6-3-5 + Morphological Analysis	16	3	**43**	21	8	6	**10**	8
Transformational Design +Mind Maps	23	1	10	11	5	5	4	5
Design by Analogy + Word Trees	**51**	10	17	26	**10**	8	7	8
Far Field Analogies	6	**25**	27	19	6	9	9	8
Historical Innovators	0	5	3	3	4	7	6	6
TIPS	0	27	0	9	4	**10**	6	7
TOTAL # CONCEPTS	**96**	**71**	**100**	**89**				

Note from the table that the students were also asked to rate the "innovativeness" of each of the CG techniques. While this is quite subjective, it is interesting to note that each team chose a different CG method as most innovative (red 10's in the table). There are some observable trends in the innovation data. The 6-3-5/Morphological Analysis, Design by Analogy/Word Trees and Far-Field Analogies ranked high while Transformational Design/Mind maps ranked lower. However, the relative dissimilarity of the ranking between teams suggests that, as with the number of concepts generated, the variety of CG methods may be important in capturing innovation across a variety of teams.

4.2 Assessing the Ability to Enhance Students' Creativity

In the academic years 2007-2008 and 2008-2009, both control (used only the 6-3-5 CG method) and experimental (used a suite of CG Methods) groups were surveyed using the instrument shown in Figure 13. The students rated themselves for each of the 18 descriptors given, using the scale provided (1 through 6). This assessment was conducted before the CG process and again after completion of all concept generation.

INSTRUCTIONS

For each of the 18 adjectives listed below,
rate yourself (fill in blue cells) using the (1-6) scale shown (green cells)

#	I am …	Rating		
1	Capable		SCALE	
2	Clever		1	Strongly Disagree
3	Confident		2	Disagree
4	Egotistical		3	Slightly Disagree
5	Humorous		4	Slightly Agree
6	Individualistic		5	Agree
7	Informal		6	Strongly Agree
8	Insightful			
9	Intelligent			
10	Interests Wide			
11	Inventive			
12	Original			
13	Reflective			
14	Resourceful			
15	Self-confident			
16	Sexy			
17	Snobbish			
18	Unconventional			

Figure 13 – Creativity Measurement Instrument

Forty-two student surveys were recorded representing over 700 data points (recall each survey used has 18 questions). Table 5 shows the results of the assessment. Note that the control group experienced an 8.2% increase while the experimental group experienced a 13.6% increase as they progressed through the CG process. Therefore, the experimental group had a 67% better increase in their rating compared to the control group. Using Gaussian statistical analysis a confidence interval is developed. The confidence interval provides a statistical answer to the question "how confident are we that the increase in creativity ratings for the control and experimental groups (8.2% vs. 13.6%) are really different". This question is relevant because these numbers (8.2% and 13.6%) are actually averages, with corresponding standard deviations, across a large student base. In this case, we are 90% confident that the 8.2% and the 13.6% are in fact statistically different. Thus, using the suite not only resulted in a large number of useful and innovative concepts, but actually improved the students' self-perception of their own creativity, which could possibly lead to lasting impact on their effectiveness as designers and engineers.

Table 5 – Results of Creativity Assessment Process

Group	Increase in Creativity Rating (%) (from before to after the CG process)
Control (did not use CG Suite)	8.2
Experimental (did use CG Suite)	13.6
Percent Increase for "Experimental" over "Control" = 67%	
Confidence Interval for Experimental/Control Difference = 90%	

5. Conclusions

A suite of 6 concept generation (CG) methods was used by multiple teams of engineering design students. One purpose of this suite is to facilitate creation of a large number of innovative solutions to various design problems. In addition, the CG methods are intended to increase the creativity of the students who use them. These CG methods include two methods that are well known (6-3-5 and TIPS), two methods that have recently been reported in the literature (WordNet based Design by Analogy and Transformational Design Methodology) and two methods that have not yet been reported (Historical Innovators and Far-Field Analogies). Assessment consisted of quantifying the number of concepts generated using the six CG methods and also evaluating the increase in creativity of the students using these methods compared to those who did not use the suite of CG methods. The number of concepts per team, generated from the suite of CG methods, averaged 89 from all 6 methods. This equates to 14.8 concepts per CG method. The control group used only the 6-3-5 method and generated approximately 7 concepts per team. Additionally, the increase in creativity for the group using the suite of CG methods was 67% greater than for the group that did not use the CG methods, advancing from an 8.2% increase to a 13.6% increase. There is a 90% confidence interval in the difference between the 8.2% and 13.6%.

6. Acknowledgements

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Appendix 1 – Details on the Use of WordNet

WordNet and Creating a WordTree to find Analogies

WordNet is like a sophisticated thesaurus. It gives a series of words that mean similar things but WordNet provides eve more information. Verbs within the English language have a hierarchical structure to them. We have very general verbs that have very little domain information such as “locomotion” and there are very specific types of locomotion that contain lots of domain information. For example, “jog” contains domain information such as a person is involved and their speed is neither a very fast locomotion (“running”) nor a slow, leisurely locomotion (“strolling”).

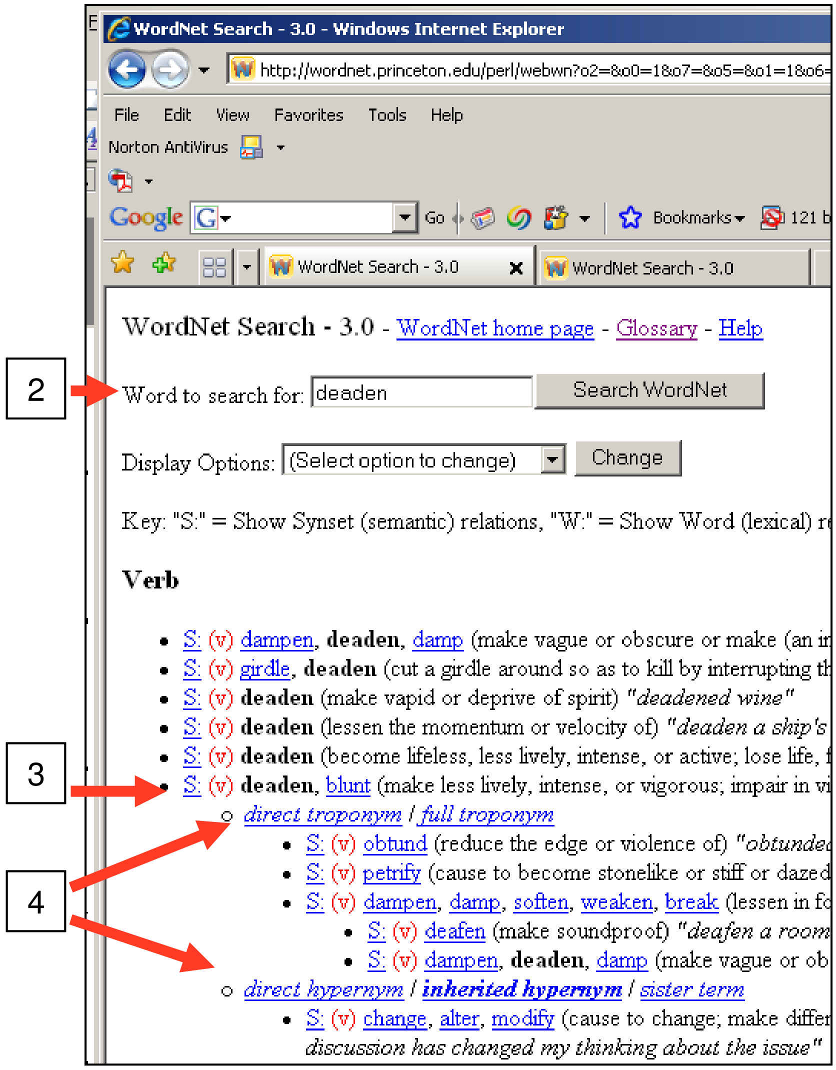

Figure A1: Screen Shot of WordNet and Procedure References.

WordNet is also an effective tool for identifying possible analogies and analogous domains. Functions of a device use verbs and other ways of phrasing them can be found through WordNet. WordNet will provide assistance finding analogies, analogous domains and also rephrasing your design problem in new ways. By re-phrasing your design problem you may think of other analogies and solutions.

Searching for terms in WordNet

1. Go to http://wordnet.princeton.edu/perl/webwn
2. Enter the word you want to search for in the “Word to search for:” box and click “Search WordNet”. Reference Figure A1.
3. Select the correct sense or senses of the word. Remember, functions are verbs so you need to select the verb sense of the word. Sometimes only one sense is application to your problem, other times there may be more than one. For example, the word wash has multiple senses. It can be in the sense of “to wash clothes” or “the ocean washed over the shore” or “a thin coat of paint was washed over the table to make it look antique”. Click the blue “S” next to the correct sense or senses of the word.
4. Expand the WordNet Results: Click “full troponym” and “inherited hypernym. Troponyms are more specific words and hypernyms are more general terms with less domain information.

Creating the WordTree

5. Create a WordTree by first placing the word you are searching for in the middle of the page.
6. Now place the hypernyms directly above your original word. Each tab in on the WordNet display corresponds to one level higher on the tree. See the green arrow in Figure A2.
7. Next place the troponyms directly below your original word. Each tab in on the WordNet display corresponds to one level lower on the tree. See Figure A2.

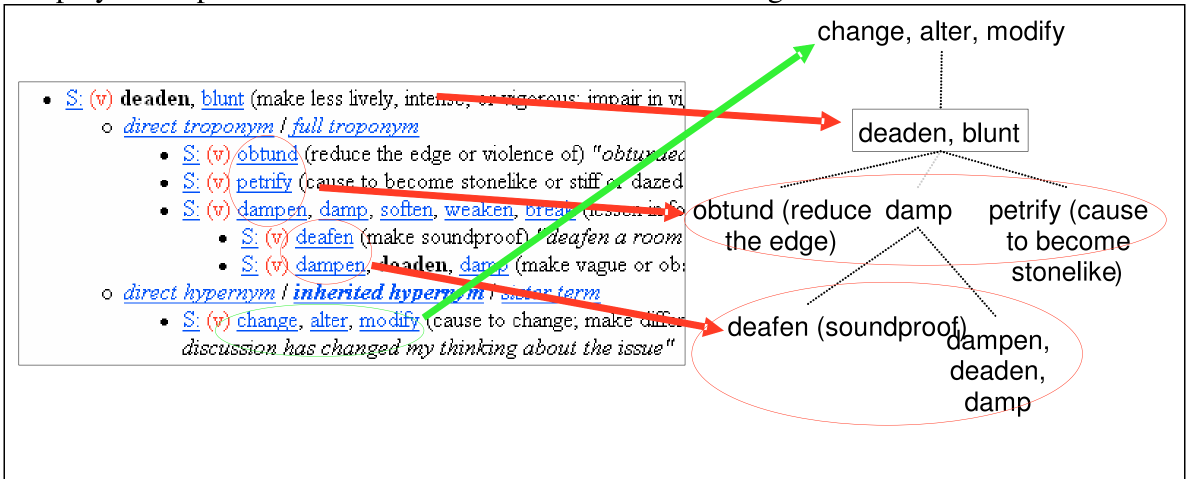

Figure A2: Example of part of a WordTree built using WordNet

8. Now add additional branches to your tree to find analogous domains and more analogies. Search for each hypernym of your original word and add the results to your tree (Repeat steps 1-7 for each hypernym). See a more complete tree in Figure A3.

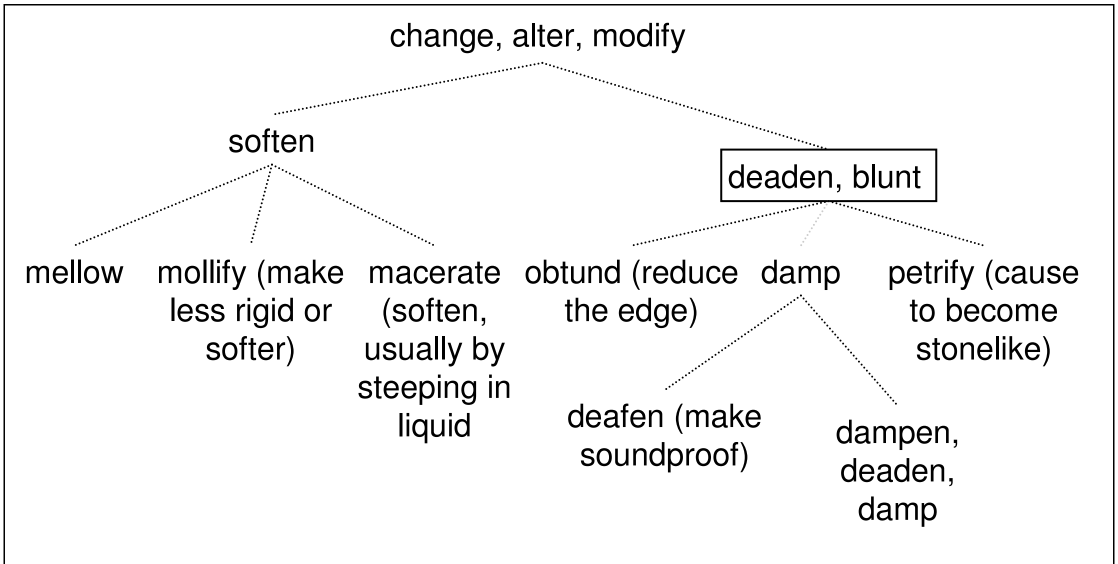

Figure A3: Example of a Partial WordTree for "deaden".

Notes

- For certain words, WordNet produces an excessive number of results and the user must select which words to add to the WordTree.
- If any sort of error message appears at the top of the page, close the web browser and restart WordNet.
- Occasionally WordNet will produce too many results to display. In this case you should click on "direct troponym"/"direct hypernym" instead of "full troponym"/inherited hypernym". The "direct troponym" and the "direct hypernym" option will only produce words one level down or one level up respectively. You will then need to use WordNet to search for the "troponym/hypernym" to determine the other levels.

Finding Analogous Domains and Analogies: Example Design Problem "Device to Fold Laundry"

Once a complete WordTree has been created, possible direct analogies and analogous domains can be found. Shown in Figure A4 is part of a WordTree for the design problem of creating a device to fold laundry (the complete WordTree does not fit on a 8 ½" by 11"). Analogous domains occur frequently in branches on the tree that are separate from the initial word's branch, circled in red on Figure A4. For this design problem, sailing appears to be an analogous domain along with milling in the sense of rolling metal. Possible direct analogies are frequently found on the leaves of the tree (at the ends of the branches). These words are most often both verbs and nouns (for example "reef: roll up a portion of a sail"). They are also very domain specific terms.

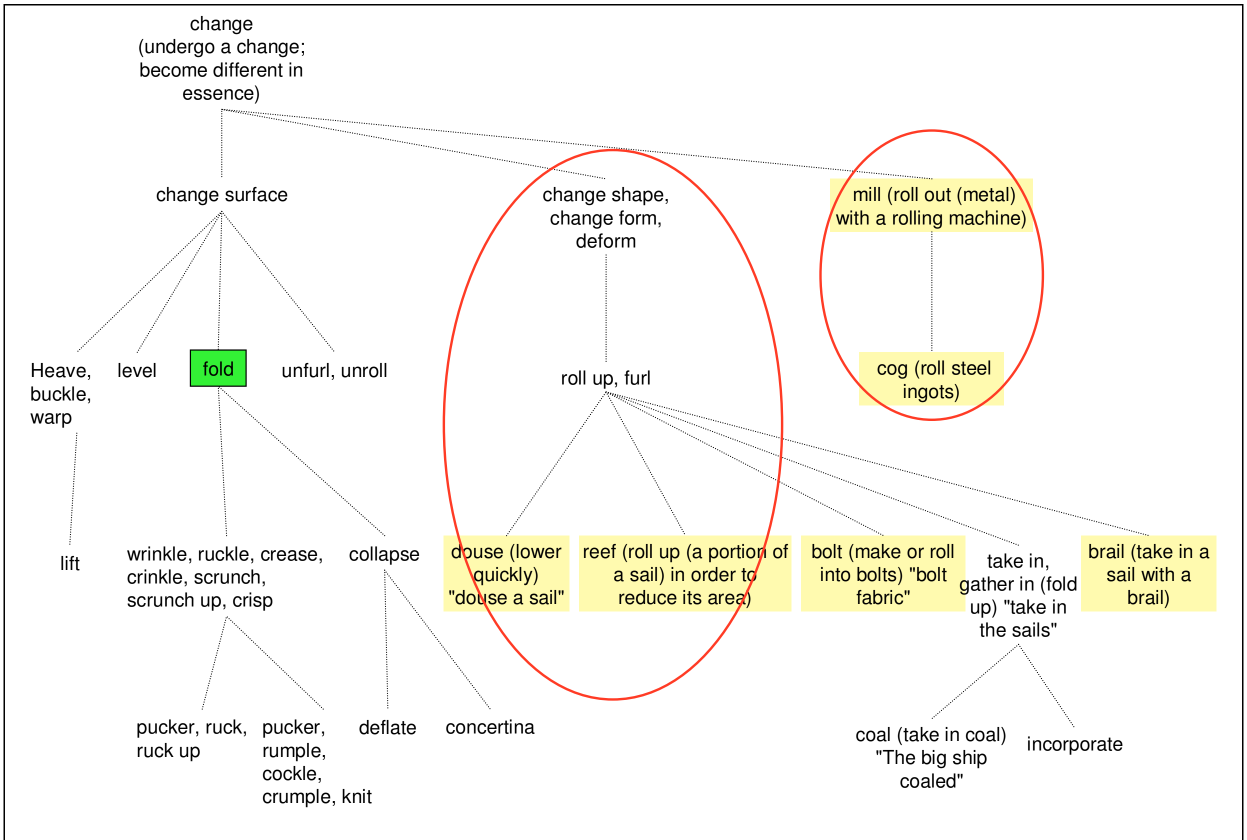

Figure A4: A partial WordTree for "fold". Possible direct analogies are highlighted in yellow and branches with analogous domains are circle in red. This WordTree shows two analogous domains for the laundry folder, sailing and metal cogging or milling (in the sense of rolling). Cogging is an analogous domain since part of the folding process involves smoothing the wrinkles prior to folding.