CHARACTERIZING THE EFFECTS OF NOISE AND DOMAIN DISTANCE IN ANALOGOUS DESIGN

A Thesis

by

RICARDO LOPEZ

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Mechanical Engineering

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Approved by:

Chair of Committee,	Julie S. Linsey
Committee Members,	Richard M. Malak
	Steven M. Smith
Head of Department,	Dennis O'Neal

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ABSTRACT

Characterizing the Effects of Noise and Domain Distance in Analogous Design.

(May 2011)

Ricardo Lopez, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Julie S. Linsey

Idea generation is one of the major initial steps of the design process. Designers frequently use analogies to explain concepts, predict potential problems, and generate ideas. Analogous design can stimulate idea generation and lead to novelty and creativity. At present, there is little research that explores analogous design under the presence of irrelevant information, 'noise', or the effects of using analogies from semantically distant domains.

An "Analogies and Noise" experiment extends previous findings which indicate that the use of two analogues instead of one can enhance analogous transfer. It tests whether this holds true for increased numbers of analogies. This study hypothesizes that analogue transfer improves with increasing number of example analogues and deteriorates under the presence of noise. The experiment evaluated this hypothesis by presenting designers with a design problem and a set of analogues and noise. Improvement was primarily measured by the rate of participants identifying the relevant high level principle (HLP). The results indicate that: (1) recognition of HLPs deteriorates

under noise (2) increasing numbers of analogues under noise initially improves HLP recognition; however, once many items are present, designers are overwhelmed and the HLP recognition rate decreases (3) using two analogues is optimal for design and (4) noise cannot be defined as all those items without a functional feature relevant to the problem.

A “Distant Domains” pilot experiment explores the use of distant-domain analogies. This study hypothesizes that distant domain analogies lead to more abstraction resulting in more creative designs. The experiment presented participants with a predetermined set of analogues then asked them to solve a problem. The set contained analogies from the problem domain and from a domain of varying distance. The following patterns were observed: (1) the number of emergent features peaked with near-domain analogies and decreased thereafter (2) the mean total number of ideas increased with increasing domain (3) designers deemed analogies from distant domains as ‘less useful’ and solutions generated using distant domains as ‘less effective’ and ‘less practical’. These trends warrant future experimentation with an increased sample size.

DEDICATION

I dedicate this work to my parents, Ricardo Lopez Botello and Raquel Rocha Perales. Without their constant support and encouragement throughout my entire life I would not be where I am today.

ACKNOWLEDGEMENTS

I would like to express my greatest sense of gratitude to my committee chair, Dr. Linsey for her guidance, encouragement and patience throughout the course of this research. I would also like to thank the members of my committee, Dr. Steven Smith and Dr. Richard Malak for their support, and my lab mates for their support and encouragement.

TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

Page

Page

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Continued innovation is essential for economic prosperity. In a knowledge-based economy, profits are becoming increasingly influenced by innovation capabilities (DeVol & Wong, 2010). Innovation can be efficiently increased by enhancing designers' efforts with refined design methods. One such method is analogous design. Novel solutions and designs have can be formed through analogous problem solving. Analogous problem solving has been formally studied for nearly thirty years but there still many questions to be answered. This thesis explores two aspects of analogous design: noise and semantic distance.

Studies have shown that designers frequently use analogies not only to generate ideas, but also to explain them and at times to predict potential problems (Casakin & Goldshmidt, 1999; Christensen & Schunn, 2007). Idea generation through design-by-analogy can enhance the prospect of producing innovative and novel ideas (Mak & Shu, 2004). Design-by-analogy consists of transferring information from a base analogue to a target analogue. A common example of analogous design is Velcro (Figure 1). It was invented by George de Mestral when he noticed the small hooks present in burrs (base analogue) and their tendency to grab onto his pet's fur. Maestral transferred this miniscule hook feature to textiles (target analogue) and created Velcro.

This thesis follows the style of *Journal of Engineering Design*.

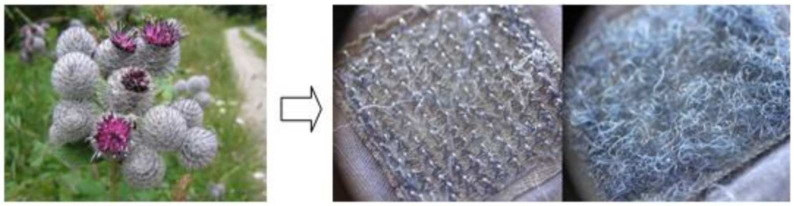


Figure 1 - Velcro (right) was devised through analogous design using burr (L) as a base analogue (Epukas, 2008) (Salguero, 2006).

Previous research shows that using two base analogues improves analogue transfer over a single base (Gick & Holyoak, 1983; Markman & Gentner, 1993; Namy & Gentner, 2002) and that when presented with two analogues people easily make connections (Gick & Holyoak, 1980), (Keane, 1988), (Gentner, 1983). This is likely due to a decrease in the number of similarities shared in common between a larger set of analogues, making it easier to identify the linking high level principles. Increasing the number of analogues is generally agreed to be beneficial to analogue transfer, however, very few studies have explored the effect of using multiple analogues along with irrelevant information, or 'noise'.

Higher levels of abstraction are required to make connections between increasingly semantically-dissimilar problems. Semantic domains classify problems based on their concrete details, or surface features (Reeves & Weisberg, 1994). For example, wood, bark, and saw can be classified under the carpentry semantic domain. Previous studies in semantic distance have focused on interpretations of simple combinations. In these, subjects were given novel noun-noun phrases and asked to generate solutions based on them (Costello & Keane, 2000; Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010). For example, subjects were asked to generate concepts based on the phrase 'leg screw', which could have different meanings such as "screws used to affix table legs", "screws with a leg shape", or perhaps a pivoting joint. Others have carried out observational studies to determine if engineers prefer analogies from within the domain or from an outside domain. They concluded that engineers prefer to use within-domain analogies for both explaining and solving problems (Christensen & Schunn, 2007). At present, no research was found which studied problem solving using analogous design with analogues from controlled semantic distances.

This thesis explores the effects of noise and semantic distance in analogous design through two experiments. The first, "Analogies and Noise", seeks to determine if analogue transfer deteriorates under presence of noise. Additionally, it will assess whether the previous findings that two analogues are better than one can be extended to a larger number of analogues. To this end, the experiment presents engineering students with a design problem and a varying number of analogous and noise products. The second, "Distant Domains" Experiment, will test the effects of semantic distance of base analogues on the on the results from analogous design. Specifically, it will measure the total number of ideas, number of analogous and non-analogous ideas, and the number of new features that emerge in the designs that are not part of the base analogues. The experiment will present engineering students with a design problem and a predetermined set of base analogues from domains of varying semantic distance. The following chapters describe the foundations, designs, and results from the two experiments.

CHAPTER II

BACKGROUND

Cognitive science provides a rigorous basis to study analogous design in various analogous reasoning theories. This section introduces the structure-mapping theory, and discusses some cognitive science fundamentals relevant to analogous design: abstraction, functional and surface features, and embedded vs. abstract principle learning methods. Finally, it discusses the implications of previous studies in the identification of high level principles, and explorations of semantic distances.

Cognitive Science Models for Analogical Reasoning

Various Analogical Reasoning models have been proposed with the majority agreeing on a four step process (Figure 2) (Reeves & Weisberg, 1994):

1. Encoding:
    a. Identifying abstract principles which characterize the base and target analogues to determine potential similarity
2. Selection:
    a. Selecting the base analogue which is relevant for the given target
3. Mapping:
    a. Transferring information from the base to the target
4. Guideline Induction:

a. Developing abstract rules or solution principles (schema) for application to future problems, without the need of a base analogue

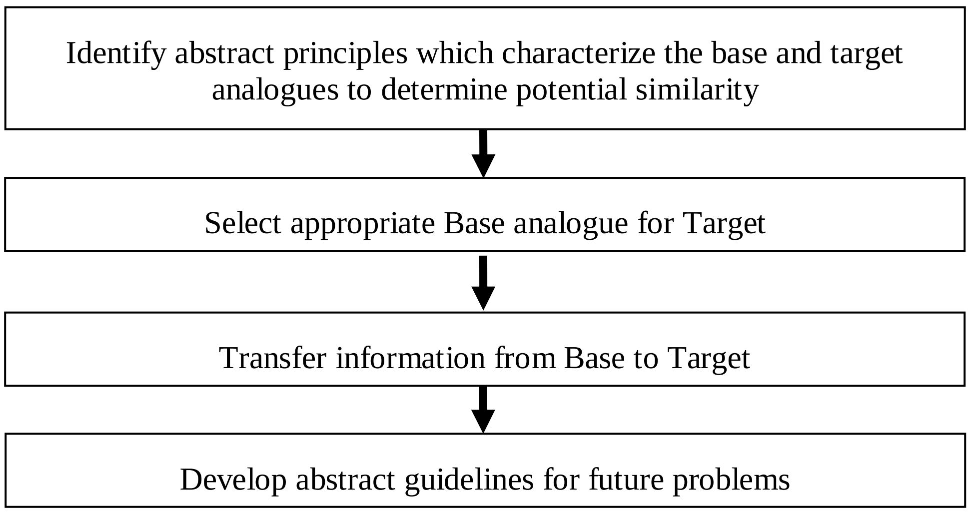


Figure 2 - Diagram of the analogical reasoning process, adapted from (Reeves & Weisberg, 1994).

The various models tend to disagree on the importance given to the surface features or *semantic* content versus the deep structure or *schematic* information during the analogue reasoning process. Semantic-leaning theories (Ross, 1987) posit that analogues are stored as complete units. In this model, the mapping stage is driven by the details of the base analogue and abstract principles are not generated. The experiment hypotheses were formed using the schematic-leaning models. They assume the participants will perform better when ignoring surface features. The following section describes structure-mapping, a schematic-leaning theory.

Structure Mapping

Structure-mapping (Gentner, 1983) theory considers structural information to be the major factor in the mapping stage, with surface features being used primarily for analogue selection. Surface features are defined to be entities (stand alone individuals or objects) or attributes (generally adjectives or descriptions). Structural elements consist of (a) *first-order predicates*, which form a relationship between two entities and (b) *higher order relations*. Higher order relations form connections between entities, attributes, or even first order predicates. For example, in the higher order relation “The bicycle moves because crank-a turns wheel-b”, “crank-a turns wheel-b” is a first order predicate; bicycle, crank-a, and wheel-b are entities and surface features, The transfer of the information in structural elements is what leads to successful analogue transfer. Abstraction of structural elements is vital to initiate mapping from base to target analogue (Reeves & Weisberg, 1994).

Abstraction

Cognitive science theories argue that abstraction is key to successful analogous transfer(Reeves & Weisberg, 1994). Design and research agrees. Studies in biomimcry found that biomimetic designs are fully realized only when the designers can abstract a strategy from an appropriate biological analogue (Mak & Shu, 2004). Linsey’s study in representation found that participants who were given more abstract descriptions of analogues were more likely to use those analogues for design (Linsey, 2007). Abstraction allows designers to ignore the incidental and focus on the essential, allowing designers to better define the overall functional requirements and constraints (Otto & Wood, 2001).

Functional Features vs. Surface Features

True analogues are those problems that share a similar deep structure, or functional feature, but not necessarily specific semantic content (Reeves & Weisberg, 1994) However, studies have shown that individuals tend to focus on surface features (ex. the size or color of athletic shoes) and overlook functional features (ex. Improved traction through friction in athletic shoes) (Reeves & Weisberg, 1994), (Lopez de Mantaras et al., 2005). This is an obstacle for analogous design since it is the mapping of functional features, or high level principles (HLPs), which leads to effective solutions. Despite surface features having greater influential in analogue retrieval, when individuals are presented with two analogues they can easily overcome the appeal of surface similarities recognize the connecting principle (Gick & Holyoak, 1980), (Keane, 1988), (Gentner, 1983). Further, increasing the number of analogue items improves analogue transfer (Markman & Gentner, 1993), (Namy & Gentner, 2002).

Embedded Principle vs. Abstract Principle Method

Problem solving methods can be explained through the use of examples (*embedded principle*) or the explanation of a set of guidelines (*abstract principle*). For instance, students learning math by solving several examples are trying to learn by embedded principle. If, instead, the students are given asset of rules and the asked to solve a problem, they are then learning through abstract principles. Studies attempted to determine which is more successful have found conflicting results (Bernardo, 2001; Ross, 1987).

Identifying High Level Principles

A key step in successful analogous design is the identifying the relevant high level principle for a given problem. Research shows that people have inherent difficulties with this task. For one, surface features tend to have a greater influence in base analogue selection than do deep similarities (Reeves & Weisberg, 1994), (Lopez de Mantaras, et al., 2005). The primary problem with base analogue selection through surface features is that it is often the mapping of deep similarities, or high level principles, which lead to effective solutions.

Despite surface features having greater influential in analogue retrieval, when presented with two analogues people easily make connections (Gick & Holyoak, 1980), (Keane, 1988). Studies by Markman and Gentner, have found that by using two analogues instead of just one participants were able to focus more on the high level relational attributes than on surface features (Markman & Gentner, 1993). Namy and Gentner’s studied of children in comparative learning. They concluded that by using two examples from a given category, children were more likely to form categorization rules that were more abstract than when given only one example (Namy & Gentner, 2002). In practice, designers have massive selection of potential analogues from which to select an appropriate base analogue. More analogues increase the likelihood of accurate analogue transfer; but the effects of irrelevant information in remains to be investigated.

This leads to the first research questions: Is an increasing number of analogues always beneficial for analogue transfer? Is analogue transfer affected by the presence of noise?

Semantic Distance and Creativity

Semantic distance is the apparent relation between two different domains. More distant domains will require a higher level of abstraction in order to recognize an underling similarity. The semantic distance between the base and target influence the results of analogical transfer (Reeves & Weisberg, 1994). One of the earliest studies in analogous problem solving proved that distant domain analogies can be effective to solve problems (Gick & Holyoak, 1980). More recently, research suggests that a larger semantic distance between analogues results in a better grasp of the underlying principle that connects the two domains and stimulates innovation (Holyoak & Thagard, 1995), (Costello & Keane, 2000), (Dahl & Moreau, 2002), (Green, et al., 2010).

Previous studies in semantic distance have focused on how individuals interpret simple combinations. In these, subjects were given novel noun-noun phrases and asked to generate solutions based on them (Costello & Keane, 2000), (Green, et al., 2010). For example, subjects were asked to generate concepts based on the phrase ‘leg screw’, which could have different meanings such as “screws used to affix table legs”, “screws with a leg shape”, or perhaps a pivoting joint. Their findings were used to create a model, the C^3 model, to predict the possible interpretations of these noun-noun terms based on three constraints: diagnosticity (requiring that the final interpretation contains elements from both components), plausibility (requiring that the final interpretation is somewhat understandable to the participant), and informativeness (requiring that the final interpretation can stand on its own to convey its information). Others have carried out observational studies to determine if engineers prefer analogies from within the domain or from an outside domain. They concluded that engineers prefer to use within-domain analogies for both explaining and solving problems (Christensen & Schunn, 2007).

Increasing the distance between analogue domains stimulates abstraction of the connecting principle. This thesis hypothesizes that accurate assessment of the connecting principle between analogues gives the designer a more abstract understanding of what is required to solve a problem. Higher levels of abstraction will lead to an increased solution space and a greater number of emergent features (features which emerge during the design process and are not present in the base analogues). At present, no research was found which studied the effects of domain distance in analogous design for design problems that could be encountered in the real world. Thus, the second question of this thesis is: Does increasing distance between analogue domains increase the solution space (total number of designs) and yield designs with a greater number of emergent features?

CHAPTER III

RESEARCH QUESTIONS AND HYPOTHESES

Based the literature, the following research questions are posed:

- Is an increasing number of analogues always beneficial for analogue transfer?
- Is analogue transfer affected by the presence of noise?
- Does increasing distance between analogue domains increase the solution space (total number of designs) and yield designs with a greater number of emergent features?

The background research suggests the following hypotheses:

Multiple Analogues Hypothesis: Increasing the number of analogues will increase the likelihood of identifying the appropriate high level principle.

This is based on the various studies (Gick & Holyoak, 1980; Keane, 1988; Markman & Gentner, 1993; Namy & Gentner, 2002) which concluded that the use of two analogues was better than one. This thesis aims to expand these findings to determine if they apply to larger numbers of analogies.

Noise Hypothesis: *The identification of a high level principle decreases under the presence of noise.*

This is based on the fact that individuals tend to focus on surface features and overlook deep similarities (Reeves & Weisberg, 1994), (Lopez de Mantaras, et al., 2005), yet it is often the mapping of deep similarities, or high level principles, which lead to effective solutions.

Domain Distance Hypothesis: Base analogies from semantically distant domains lead to higher levels of abstraction, resulting in more ideas, more non-analogous ideas and more emergent features.

Increasing the distance between analogue domains requires higher levels of abstraction to find a connecting principle. Higher levels of abstraction will lead to an increased solution space and a greater number of emergent features (features which emerge during the design process and are not present in the base analogues).

Close Domain Preference Hypothesis: Designers will focus on surface features to assess the similarity of a distant domain to a design problem. As a result, they will deem near-domain analogies as more useful.

Christensen and Shunn found that engineers prefer to use within-domain (close) analogies for both explaining and solving problems (Christensen & Schunn, 2007). Further, individuals tend to focus on surface features and overlook deep similarities (Reeves & Weisberg, 1994), (Lopez de Mantaras, et al., 2005). Although distant domain analogies could be just as affective, both of these facts suggest that participants will deem close domain analogies as more useful.

CHAPTER IV

EXPERIMENT 1 – ANALOGIES and NOISE

Overview

The literature suggests that analogue transfer will improve with an increasing number of analogues and deteriorate in the presence of noise. These hypotheses were evaluated with a between-subjects 4X2 factorial experiment. The first factor in the experiment was the number analogues presented (1,2,3,5) and the second factor was the amount of noise (none or 3 noise products per analogue). The number of analogues was selected based on prior literature. Research shows that two analogues are better than one (Gick & Holyoak, 1983; Markman & Gentner, 1993; Namy & Gentner, 2002), and the author wanted to explore if this effect extended past two analogues. To this end, a maximum of five analogues were tested, and the 3-analogue condition was chosen arbitrarily to be between the 2- and 5-analogue conditions.

The noise level was chosen as triple the analogues. Since the participants were given physical copies of each analogue. By using three noise items per analogue the participants example products contained a majority of noise (75%), but the number of physical items given to the participants was still manageable. For example, in the five-analogue with noise condition, the participants received a total of 20 products which were placed on their desks. One condition of all noise products was also run to serve as a basis for analyzing the results of the analogues under noise conditions. The all noise condition served as an additional control.

The experiment presented participants with a design problem and a varying number of analogous or noise products. Nine conditions were tested in three groups:

1. Analogues only – participants received 1, 2, 3, or 5 analogues
2. Analogues under noise – participants received 1, 2, 3, or 5 analogues and an additional 3 noise products per every analogue
3. Noise only – participants received the 15 noise products

Analogues were defined to be items which contained a functional feature relevant to the design problem. For the problem used, the functional feature was energy storage and release through elastic deformation. A principle had to be chosen where a large variety of applicable products could be identified that did not share surface features. As per the structure mapping model, products without elasticity as a functional feature were considered noise. Once the design problem and items were described the participants began with an idea generation period followed by a series of questionnaires to characterize their ideas and obtain demographic information.

Participants

A total of 71 senior undergraduate Mechanical Engineering students from Texas A&M University participated voluntarily and were recruited through in-class announcements. Sixty-eight were compensated with extra credit in their design class and the remaining three received $20. Participants who wished to earn extra credit but not participate in the assignment were offered an alternate assignment. Fifty-six males and fifteen females enrolled with an average 22.3 years of age and 4.8 months of full time engineering work experience.

The participants were randomly distributed across the nine conditions as shown in Table 1. The experiment was run in various sessions with one to four participants at a time. Only one condition was tested per session and care was taken to avoid participants from interacting with each other. At the conclusion of each session, the participants were asked not to discuss any aspect of the experiment with their peers to prevent bias.

Table 1 - Number of participants in each condition.

	No. Analogues				
	1	**2**	**3**	**5**	**All Noise**
Analogues Only	7	13	7	7	7
Analogues under Noise	9	7	7	7	

The experiments were run in sessions with up to four participants at a time, and only one condition was run per session. As a result, one condition received 9 participants. The experiment proctor made a mistake in the experiment schedule and as a result the condition with two analogues was ran more times than intended, receiving a total of 13 participants.

Design Problem

The design problem was introduced after the example products were described. The problem asked participants to devise methods or devices to automatically lock a broken door on a Mars habitat. Participants were given a hard copy of the problem statement (Figure 3) and a drawing showing the current locking mechanism (Figure 4) to further clarify the problem. The goal of their designs was to have the pin return to the locked position without the use of electricity or coil springs. This problem was selected because it is easily understood, it is unlikely the participants have any significant prior experience with the task, and there is a large set of potential solutions. In addition, solutions for the problem can be found through analogous design by mapping energy storage through elasticity. This is convenient since there are many commonly available products with elasticity as a functional feature. Before the idea generation period, participants were reminded that the example products might or might not be useful and that their designs should not be limited by them.

NASA astronauts are on a mission to Mars and the locking mechanism of a latch has broken down.

Your task is to provide a fix to this problem satisfying the following condition.

- **The door locking pin must automatically return to the locked position even when there is no electricity.**

NASA will send supplies to the space station with the astronauts but has not determined what materials and tools will be needed for this problem. It costs them millions of dollars per pound, so they want to send as little material as possible. Since the parts are still being designed, you can add or remove features to the parts.

Constraints:

- **You cannot use a metal coil spring. NASA is aware of this solution and needs others.**

Figure 3 - Problem statement given to participants. The goal of their designs was to automatically lock a door without electricity or coil springs.

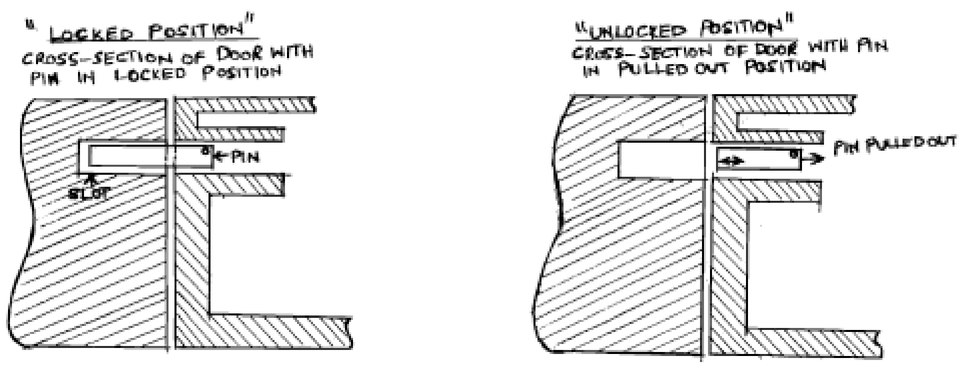


Figure 4 – Drawing of the locking mechanism. This was given to the participants to describe the design problem, but they were allowed to modify it in their designs.

The Example Products

The example products were commonly available items from several different domains (office products, toys, machine components, etc) so that domain would not be a factor. Analogues were defined to be items which contained a functional feature relevant to the design problem. For the problem used, the functional feature was energy storage and release through elastic deformation. Products without elasticity as a functional feature were considered noise.

Analogues

The experiment used five analogous products (Figure 5). Analogues were defined to be those items which had a functional feature that was relevant to the design problem. For the door lock problem, this feature was elasticity.

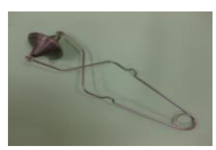
Sticky Note Holder Lid	Compression Spring	Flour Duster	Constant Force Spring	Bungee Blast
				

Figure 5 – Analogues: all products share elasticity as a functional feature.

For example, elasticity is a functional feature of the Bungee Blast since it requires the elasticity of a rubber band to function. The user pulls grips the red end and pulls on the rubber band. Upon release of red end, the Bungee Blast flies away. Similarly, elasticity is required for the other four items in order for them to function. As per the multiple analogues hypothesis, increasing the number of these items will increase the likelihood that the participant recognizes the high level principle.

Noise

True analogues are defined to be only those which share a deep similarity (i.e. functional feature) (Reeves & Weisberg, 1994). Thus, items which did not have elasticity as a functional feature were defined to be noise. For the analysis, the noise items were be further classified as pure noise (Figure 6) or noise with elasticity as a surface feature (Figure 7).

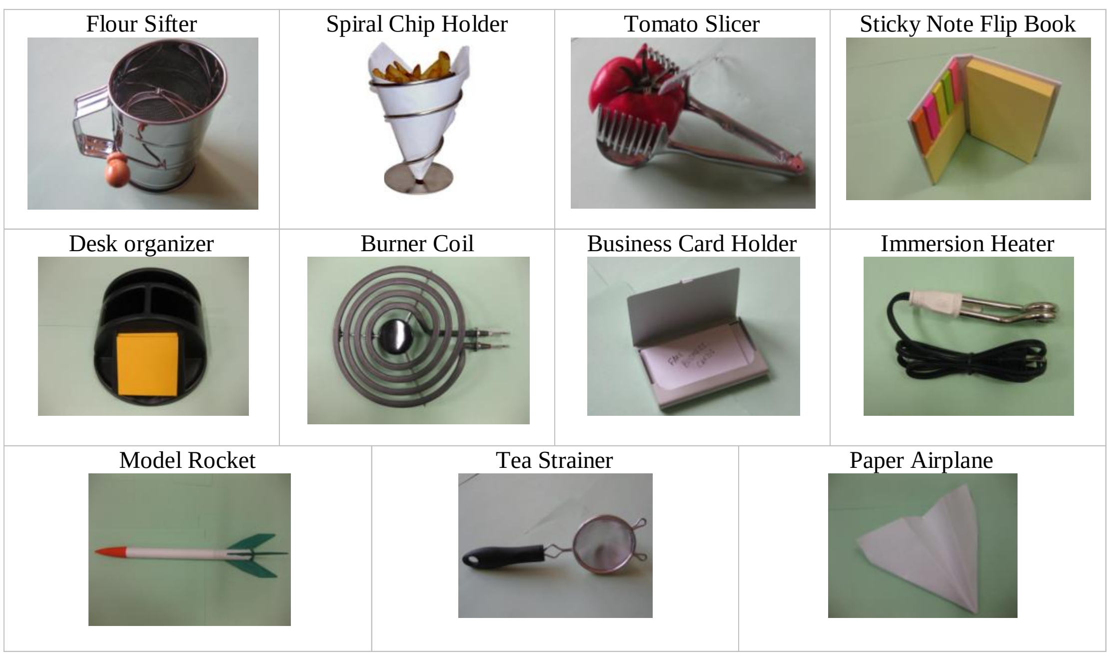


Figure 6 - Noise products: products do not have elasticity as a functional feature, nor a feature which is relevant to solving the design problem.

In principle, all items have some level of elasticity, that is to say, every material presents some elastic deformation. However, the average person is not likely to deem something as 'elastic' unless it deforms relatively easily by hand and returns to its original shape. With this in mind, only the items in Figure 7 were considered to have elasticity as a surface feature. These four could be easily deformed elastically by the participants. This was not the case for the pure noise items, which were very stiff and would bend permanently (plastically) or fail if the participants attempted to deform them.

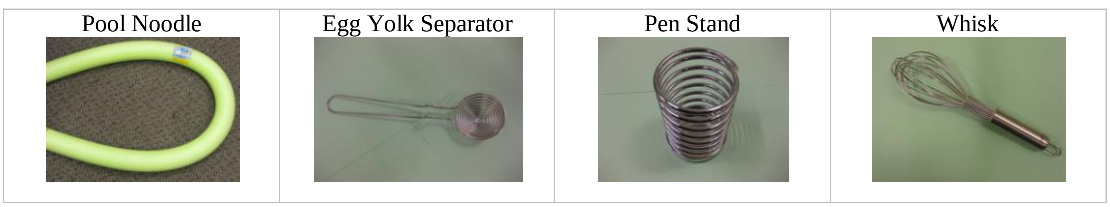


Figure 7 - Noise products with elasticity as a surface feature: these products present elasticity only as a surface feature.

The two noise product types were grouped together in the experiment design and the resulting data was analyzed to determine if this was appropriate. Table 2 shows the number of product types in each condition and Figure 8 shows the example products in each condition.

Table 2 - Number of each product type present in each condition.

	Condition No.	Number of Products		
		Analogs	Noise	Noise with Elasticity as Surface Feature
Analogies Only	1	1	0	0
	2	2	0	0
	3	3	0	0
	4	5	0	0
Noise & Analogies	5	1	3	0
	6	2	4	2
	7	3	7	2
	8	5	11	4
All Noise	9	0	11	4

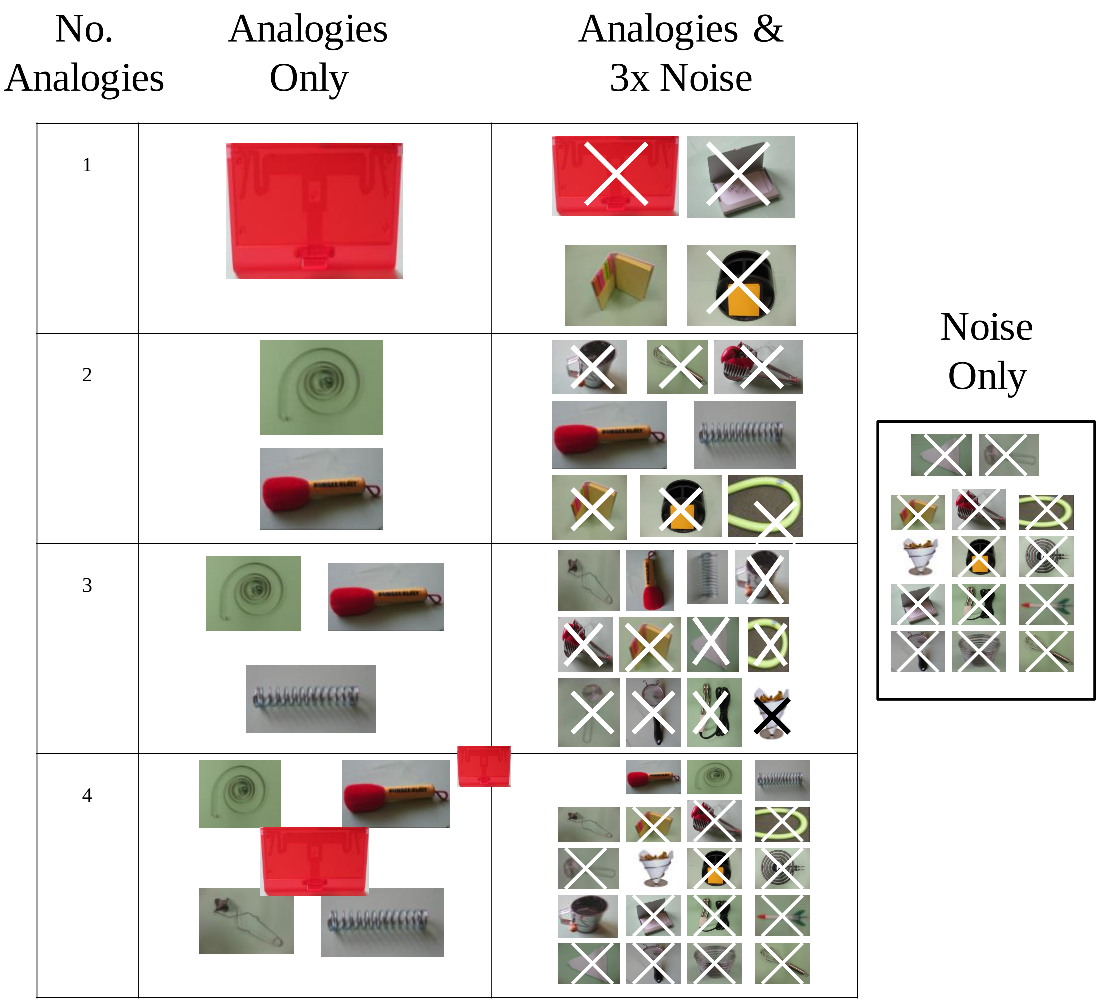


Figure 8 - Example products in each condition.

Materials

In addition to oral instructions, each participant is given a hard copy of the design problem and any other directions. In each condition, the participants received physical copies of the example products and were allowed to inspect them at any point of the experiment. A video projected on a wall in front of the participants described the example products. The products were shown in a random order and there was no indication of the product's type.

Participants were given several sheets with the drawing in Figure 4 and were encouraged to use them to describe their ides. This was done so that participants could spend less time drawing the repetitive parts of each idea. As mentioned earlier, if their designs required modifications they were allowed to make them. They could do this by modifying the drawing in Figure 4 or by using blank sheets of paper.

The questionnaires to characterize solutions as to obtain demographic information were given as hard copies at various points after the idea generation period. In order to determine at which point in time the participants generated a given solution and to assure they did not work on portions of the experiment after the assigned period the experiment exchanged the color of the participants' pens at predetermined times.

Procedure

Conditioning

As the participants entered the experiment room they were asked to place their belongings at the entrance and shown to their randomly assigned booths. Each booth consisted of a desk and chair, and two fabric walls to prevent any contact between participants. The desks were set up with the following:

- A pen
- A consent form
- The example products

- A sheet with the name and picture of each product
- A hard copy of the design problem
- A stack of blank sheets and sheets with Figure 4

The design problem and sheets with Figure 4 were stacked bellow the blank sheets to avoid early starts.

The example products were then introduced by stating that they “may or may not be helpful to generate solutions” and then described with a video. Once finished, the proctor asked the participants to find the design problem below the blank paper and read along as he read aloud.

Before the participants were instructed to begin idea generation, they were reminded that their designs were not limited by the example products or the current design. If their designs required it they could modify the current locking mechanism. At the end of each set of instructions the participants were asked if the directions were understood. Additionally, the participants were able to ask questions at any point in the experiment.

Idea Generation

Participants were then allowed to generate ideas for 40 minutes. This period allowed participants to exhaust their ideas, making the resulting solution set a better representation of each participant’s solution space. The rate of idea generation was traced by exchanging the participant’s pen colour at the 5, 10, 20, and 30 minute points.

Idea Feature Listing

After idea generation the students were asked to number each solution and mark with any X those which did not use one of the example products as a base analogue. For the ideas which used one of the example products, the participants were asked to list which example analogue was used and which features were mapped. In order to make these instructions clear they were given Burr and Velcro as example of analogous design. This was intended to determine which features were being mapped and to which analogue products were used. The data from this activity was intended to support the results from other parts of the experiment, but it has not analyzed.

Product Separation and Feature Listing

The experiment proctor asked the participants to separate the products used for idea generation by placing them on the left side of their desks. This was approximately the half way point of the experiment and the participants were allowed to take a five minute break to avoid fatigue. The product separation allowed the proctor to note which products were used. For each product used, the participants received a form (Figure 9) in which they were asked to list the features used and features not used for their ideas. The participants completed these forms at the restart of the experiment. Again, this was to determine which features were and were not mapped. Used features had already been noted by participants, but this sheet simplified the data coding process for the authors. The data from this activity was intended to support the results from other parts of the experiment, but it has not analyzed.

Bungee Blast

Features <u>not</u> used	**Features used**
A.	1.
B.	2.
C.	3.

Figure 9 - Product feature listing form.

Similarity Ranking

The next two tasks asked the participants to rank similarities. First, each feature used with compared against each feature not used (Figure 10). This was followed by comparing each idea with each example product (Figure 11). The second exercise was intended to capture a more objective perspective by the participant regarding which analogues had some mapping in each idea. Both exercises used a 1-9 scale. This exercise provided numerical data to verify that the mapped (used) features were very dissimilar to non-mapped (unused) features. The resulting similarity ratings for this activity should be very low. The data from this activity was intended to support the results from other parts of the experiment, but it has not analyzed.

Scale: 1= Low similarity - 9= High similarity

Flour Sifter

Feature **not** used	Feature used	Similarity Rating
A	1	
A	2	
A	3	

Feature **not** used	Feature used	Similarity Rating
B	1	
B	2	
B	3	

Feature **not** used	Feature used	Similarity Rating
C	1	
C	2	
C	3	

Figure 10 - Feature similarity rating. The letters of features not used and numbers of features not used correspond to the form seen in Figure 10.

Scale: 1= Low similarity - 9= High similarity

Your Idea no	**Name of Product**	**Similarity Rating**
1	Flour Duster	
1	Constant Force Spring	
1	Sticky Note Holder Lid	
1	Bungee Blast	
1	Compression Spring	

Your Idea no	**Name of Product**	**Similarity Rating**
2	Flour Duster	
2	Constant Force Spring	
2	Sticky Note Holder Lid	
2	Bungee Blast	
2	Compression Spring	

Your Idea no	**Name of Product**	**Similarity Rating**
3	Flour Duster	
3	Constant Force Spring	
3	Sticky Note Holder Lid	
3	Bungee Blast	
3	Compression Spring	

Figure 11 - Similarity rating form from the 5-analogues condition.

Instructions for the idea-product similarity activity asked participants to ‘leave unused boxes blank’, meaning participants only had to fill in the boxes for the number of ideas they generated. Unfortunately, some participants understood this to mean that products with the lowest similarity should not be filled in, or that products which were not used did not have to be filled in. For the analysis, ratings left blank by the participants were not taken into account at all.

Listing of High Level Principle

Identification of High Level Principle was determined with a two-stage exercise. The first stage participants were asked participants to determine if a set of the products they were given shared a common principle that could be used to solve the design problem. If any of their ideas used this principle, they were asked to mark them with a star.

In the second stage, participants were given a sheet with pictures of only the analogues. Again, they were asked to list the high level principle that these products shared in common and could be used to solve the design problem. If any of their ideas used this principle, they were asked to mark them with a circle. After the second stage, participants were asked to generate ideas using the listed principles for an additional 10 minutes.

Survey

The final activity was a survey to reinforce the results from the previous metrics and to gather demographic information. A five-level Likert questionnaire questioned the participants on the usefulness of the example analogues, whether or not they used them practicality, and the perceived difficulty of the rating task. The five answer choices were coded on an integer scale for analysis. Strong disagreement and strong agreement corresponded to -2 and +2 corresponding, respectively, and the other three options in between. The experiment concluded by reminding the students not to discuss the experiment with their peers.

Metrics

High Level Principle Recognition Rate

The primary goal of the experiment was to determine if analogous transfer was improved when using multiple analogues and if it deteriorated under noise. This was evaluated measuring the rate of participants accurately listing the high level principle in Stage I. Recall that Stage I asks them to list a useful principle from any set of analogues within their given examples, while Stage II asks them to list the useful principle for only the analogues. The principle listed by each participant was assessed by one of the authors and an independent third party using the following criteria:

Did the participant's listed principle show some level of abstraction which can lead to multiple solutions?

For example, if a participant listed ‘flexible beam’, this was not deemed to be the correct principle since it focuses on a specific solution. On the other hand, listing ‘the ability to flex and return to the original shape’ was considered acceptable. Although the participant did not explicitly list elasticity, this description of the high level principle can lead the designer to multiple solutions. Additionally, if the participant listed ‘spring-like’, this was accepted as correct since it does imply a specific solution, but rather a type of behavior. The results from Stage II were used to determine if pointing out which items were analogues increased the HLP recognition rate. The two evaluators rated all the data and obtained similar results. Their Pearson’s correlation factors were 0.81 and 0.87, for stages I and II, respectively. Only the results from one evaluator were used for the analysis.

Idea and Product Similarity Rankings

The idea-product similarity rankings were used to determine if pure noise products and noise products with elasticity as a surface feature should be considered as two different factors. If so, their ratings should be similar indicating that only functional features, not surface features, are useful to the designers.

Results and Discussion

The experiment was designed assuming that items which did not have a relevant functional feature that could be mapped to solve a problem could be grouped as noise. To confirm this assumption the product-idea similarity data was analyzed first. A full logistic regression analysis was not performed on the data because one of the conditions showed a 100% HLP recognition rate which causes quasi-complete separation making the results unreliable. This section concludes with an analysis of the post experiment survey.

Similarity Ratings – Product vs. Idea

The product-idea similarity ratings were analyzed first to determine if the two types of noise products could be grouped together in the other analyses. The participants rated the similarity of each of their ideas with each of the products in their condition. An ANOVA was used to determine if there was a significant difference for the average ratings of each product type. The individual scores used by the ANOVA were the average ratings given for a product by a participant across all of his ideas. This involved collapsing the similarity scores across participant's ideas (see for Table 3 example).

Table 3 - Similarity ratings for two of the seven participants in the five analogues condition. The column shows the scores collapsed across participants' ideas. These averages were the individual scores used in the ANOVA.

	Participant 20, 5 Analogs Condition							Participant 25, 5 Analogs Condition					
Idea No. →	**1**	**2**	**3**	**4**	**5**	**6**	**Avg.**	**1**	**2**	**3**	**4**	**5**	**Avg.**
Flour Duster	1	1	1	1	1	1	1.00	1	1	9	1	1	2.60
Constant Force Spring	1	1	1	1	1	1	1.00	7	1	1	9	1	3.80
Sticky Note Holder Lid	1	1	1	1	1	1	1.00	5	2	1	7	1	3.20
Bungee Blast	9	1	9	1	9	1	5.00	9	1	1	6	1	3.60
Compression Spring	1	1	1	1	1	1	1.00	4	1	5	3	3	3.20

Each average for each product for a given participant was grouped by product type (analogue, noise, and noise with elasticity as surface feature). The sample size allowed for robustness against violations of normality and homogeneity, so an ANOVA was appropriate. The means were found to be significantly different ($p<0.001$). The means are shown in Table 4 and Figure 12. A post hoc Tukey test determined the three product type means were significantly different from each other, and thus noise items should be broken up into two groups for analysis.

Table 4 - Idea v. Product similarity ratings grouped by product type. The mean ratings for each product type were found to be significantly different. Noise items with elasticity as a surface feature have to be treated as an independent factor.

		Product Average	Category Average
Analogies	Bungee Blast	3.29	2.43
	Compression Spring	2.68	
	Constant Force Spring	2.07	
	Flour Duster	2.02	
	Sticky Note Holder Lid	2.10	
Noise w/ Elasticity as Surface Feat	Egg Yolk Separator	2.03	2.26
	Pen Stand	2.62	
	Pool Noodle	2.46	
	Whisk	1.91	
Noise	Tea Strainer	1.50	1.61
	Business Card Holder	1.33	
	Flour Sifter	2.02	
	Immersion Heater	1.39	
	Model Rocket	1.97	
	Paper Airplane	1.18	
	Spiral Chip Holder	1.76	
	Sticky Note Flip Book	1.18	
	Desk Organizer	1.51	
	Tomato Slicer	2.36	
	Burner Coil	1.53	

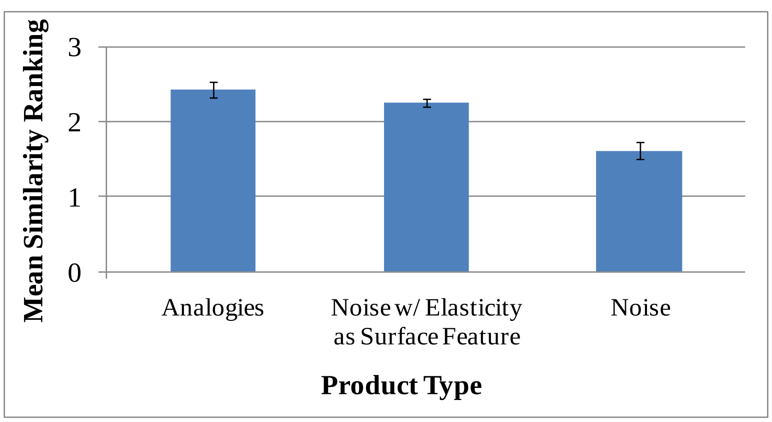


Figure 12 - The mean similarity rankings for the three product types were significantly different.

The analogies received a mean similarity rating of 2.43 compared to 2.26 for the noise items with elasticity as a surface feature. The analogies were rated with the highest similarity to participants solutions, confirming that functional features are mapped best. However, the noise items with elasticity as a surface feature received a score of 93% that of analogies, indicating that participants are able to recognize a surface feature as relevant to the problem at almost the same level as a relevant functional feature. As expected, pure noise items received the lowest score meaning that in general the participants did not deem them to have features which were mapped to the problem solutions.

High Level Principle Recognition

Recall that Stage I asked participants to determine if a set of the products they were given shared a common principle relevant to the design problem. If so, they were asked to list it, and an independent evaluator determined if the principle was correct. This section analyzes the rate of HLP recognition first as originally designed: as a function of the number of analogies and noise, with both noise items grouped together. This is followed by an analysis where the noise products with elasticity as a surface feature are partially counted as analogues and partially as noise. Lastly, the results from the post experiment survey are shown as support for the other metrics.

High Level Principle Recognition for Original Experiment Design

The experiment was designed to determine if increasing the number of analogies is always beneficial for analogue transfer and if this holds true under the presence of noise. Although the product-idea similarity ratings showed that the noise products and noise products with elasticity as surface features should be treated separately, some insight could be gained by analyzing the data as originally intended. Figure 13 - Percentage of participants correctly identifying the high level principle at each condition. The analogues only showed the best results at the two analogue condition. Under noise, increasing the number of products initially improves HLP recognition rate, but when too many items were present the rate decreased.Figure 13 shows the percentage of participants correctly identifying the high level principle at each condition.

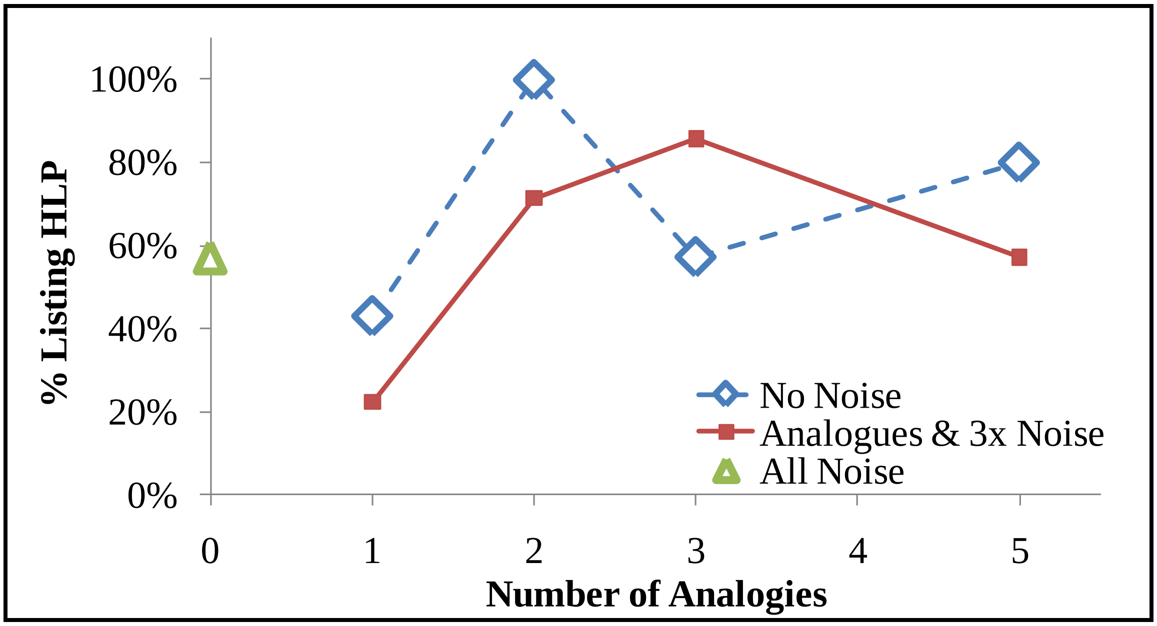


Figure 13 - Percentage of participants correctly identifying the high level principle at each condition. The analogues only showed the best results at the two analogue condition. Under noise, increasing the number of products initially improves HLP recognition rate, but when too many items were present the rate decreased.

High Level Principle Hypothesis: Increasing the number of analogues will increase the likelihood of identifying the appropriate high level principle.

The conclusion found in the literature (Gick & Holyoak, 1980; Keane, 1988; Markman & Gentner, 1993; Namy & Gentner, 2002) that two analogues are better than two are supported by the experiment. The overall trend in the analogies only-condition was an increase in the HLP recognition rate with increased numbers of analogies. However, the use of two analogues had higher HLP recognition rates than all other conditions. While the conditions with one, three, and five analogues showed a nearly linear increase for HLP recognition, the two-analogue condition had a higher rate than even the five-analogue condition. This suggests that using two analogues is ideal for grasping the high level principle. Under the presence of noise, increasing the number of analogies initially improved the high level principle recognition rate. However, once too many items were introduced the designers were likely overwhelmed and the HLP recognition rate decreased.

High Level Principle Recognition - Stage II

In contrast to Stage I, Stage II indicated to participants which of the products they received were analogues. The participants were again asked to list which principle, relevant to the design problem, was shared between the analogous products. Stage II was intended to determine if pointing out the analogues improved the HLP recognition rate. The results from Stages I and II are compared in Figure 14 (analogues only conditions) and Figure 15 (noise conditions). Pearson's chi square tests were performed for each condition to compare the results from Stage I to Stage II. None of the changes were statistically significant (lowest p value was 0.147 for the change in the one analogue and noise condition), likely due to the small sample size. Regardless, the resulting trends are described following the figures.

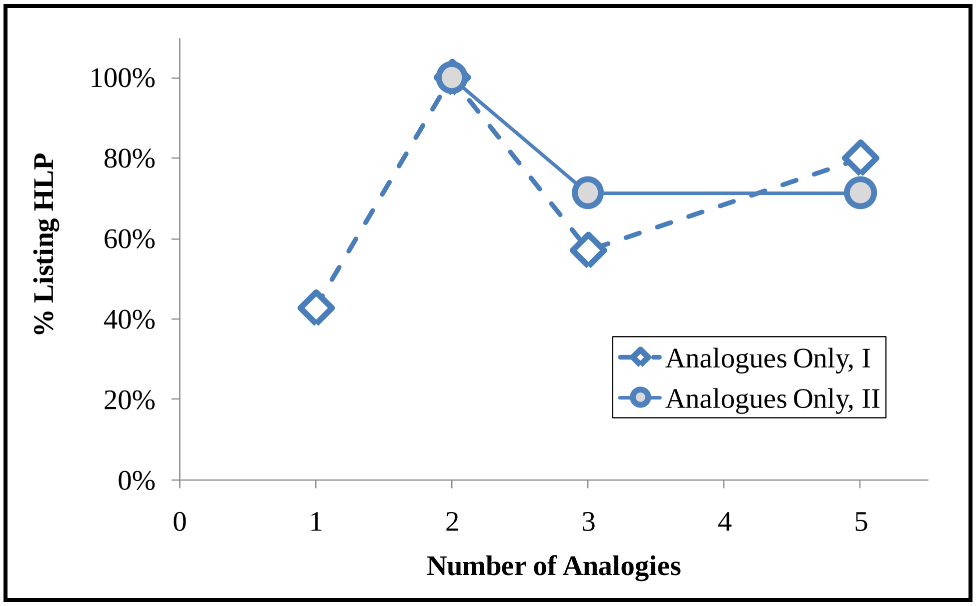


Figure 14 - Percentage of participants correctly listing the high level principle for the analogues only conditions (no noise) in stages I and II.

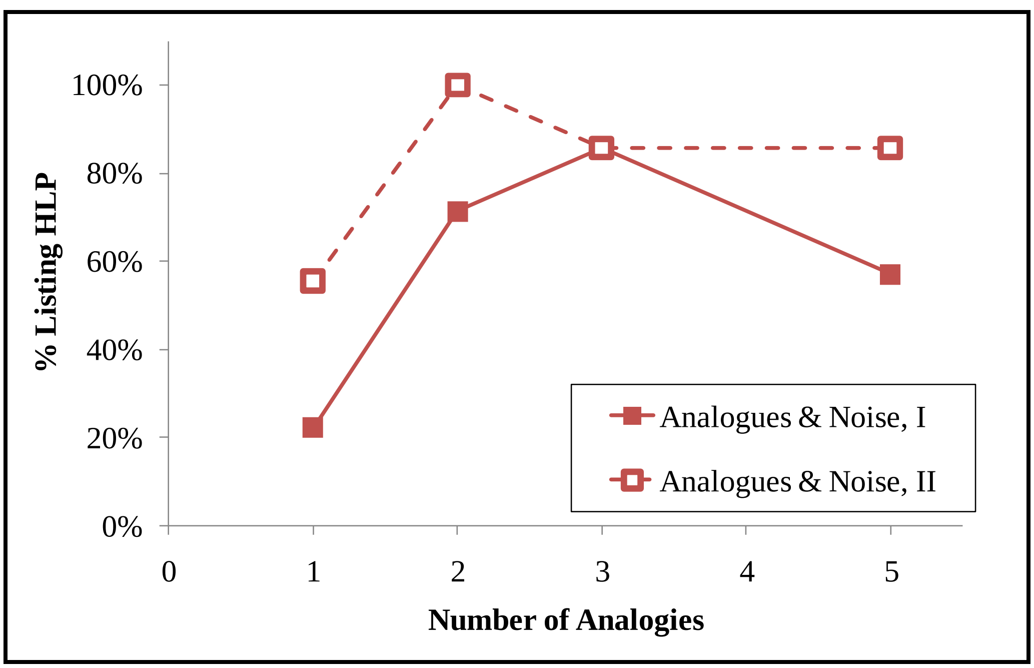


Figure 15 - Percentage of participants correctly listing the high level principle for the analogues and noise conditions in stages I and II.

In the analogues only conditions the participants showed an in increase in the HLP recognition rate only for the two-analogue condition. The HLP recognition rate remained the same for the two-analogue condition, and decreased in the five-analogue condition. The decrease in the five-analogue condition is likely just a result of randomness due to the small sample size. In the analogues and noise conditions the participants showed equal or improved HLP recognition rates for all conditions. This supports previous findings various authors (Gick & Holyoak, 1980), (Keane, 1988), (Gentner, 1983) that individuals are more likely to overcome the appeal of surface similarities when presented with two analogues and recognize abstract connecting principles. Stage two results for the noise and analogues condition with two-analogues (Figure 15) shows 100% recognition rate. This is similar to the two-analogue condition in Stage I. This again suggests that two analogues might be optimum for high level principle recognition and consequently for analogue transfer in design for creating new solutions.

Accounting for Noise with Useful Surface Features as a Third Factor

Noise Hypothesis: *The identification of a high level principle decreases under the presence of noise.*

The effect of product type on the rate of the high level principle recognition is difficult to visualize since three product types must be taken into account. Since the analysis only has one output variable (recognition rate of high level principle), and assuming that the effect of noise items with relevant surface features on the HLP recognition rate is somewhere in between the pure noise and analogies, we can reduce the number of variables to only noise and analogues. This can be accomplished by dividing the noise with elastic surface features products as part noise and part analogy, eliminating them as a factor. Table 5 shows an example of the variable reduction process and Figure 16 shows the results of this exploration.

Table 5 - Example of the process used to reduce the number of variables.

		Number of Products		
		Analogues	**Noise**	**Noise w/ Elasticity as surface feature**
	Actual -->	3	3	2
	As Noise	3	5	0
Noise w/ Elasticity	**As Analogues**	5	3	0
as Surface Feature	**1/2 Analogy + 1/2 Noise**	4	4	0

Using this, in the noise and analogues conditions there is an initial increase in the percentage of participants who recognize the high level principle, followed by a drop. This is true for the analogues and noise conditions regardless of whether noise products with elasticity as surface features are considered as noise or analogies. This supports the conclusion made from the analysis of the experiment as originally designed: under noise, increasing the number of analogues initially improves the high level principle recognition rate. However, once too many items are presented, the participants are likely overwhelmed and are less likely to find the useful principle within all the examples.

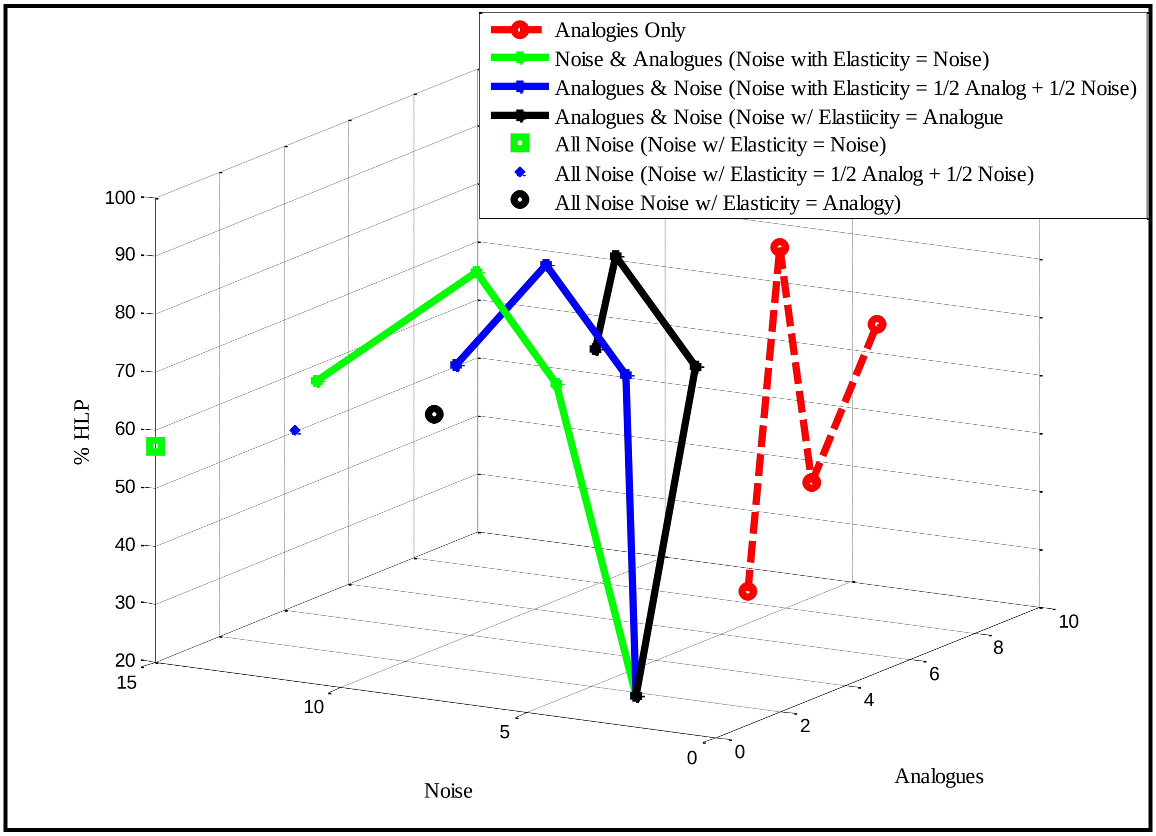


Figure 16 - 3D plot of the number of Noise and Analogue products and the resulting percent of participants who accurately described the high level principle. Noise items with elasticity as surface feature are counted as noise, analogues, or are split evenly between the two types.

The noise only condition has a higher HLP recognition rate than only the one analogue and the one analogue under noise conditions (Figure 13). Recall that the noise only condition has four products with elasticity as a surface feature. The results from the similarity exercise indicate that products with relevant surface features are rated at almost the same level of similarity as the products with relevant functional features. If we assume that these can be counted as at least half-analogues (blue dot, Figure 16), then it seems reasonable that its HLP recognition rate is higher than that of the first analogue and noise condition. The authors theorize that multiple analogues, even under slight noise, are better than a single analogue.

The Survey

Part of the post experiment survey was intended to characterize the participants' attitudes toward the products and reinforce the findings from the high level principle recognition exercise. The survey consisted of a total of three Likert questions:

(1) "The given products were useful to create solutions" (Figure 17)

(2) "I used the given products to generate solutions" (Figure 18)

(3) "I found the similarity rating task hard" (figure is discussed later in this section)

The five answer choices were coded on an integer scale for analysis. Strong disagreement and strong agreement corresponded to -2 and +2 corresponding, respectively, and the other three options in between. The results are shown in the following subsections.

Question 1- "The Given Products Were Useful to Create Solutions"

The participants' rated usefulness of the products in their condition are shown in (Figure 17). For the analogue only conditions the usefulness rating peak is at the 2-analogue condition, while conditions of 1-, 3-, and 5-analogues showed a nearly linear increase. The analogue only conditions showed an initial increase with an increasing number of products, then,, when too many items were present, the participants found the example products less useful.

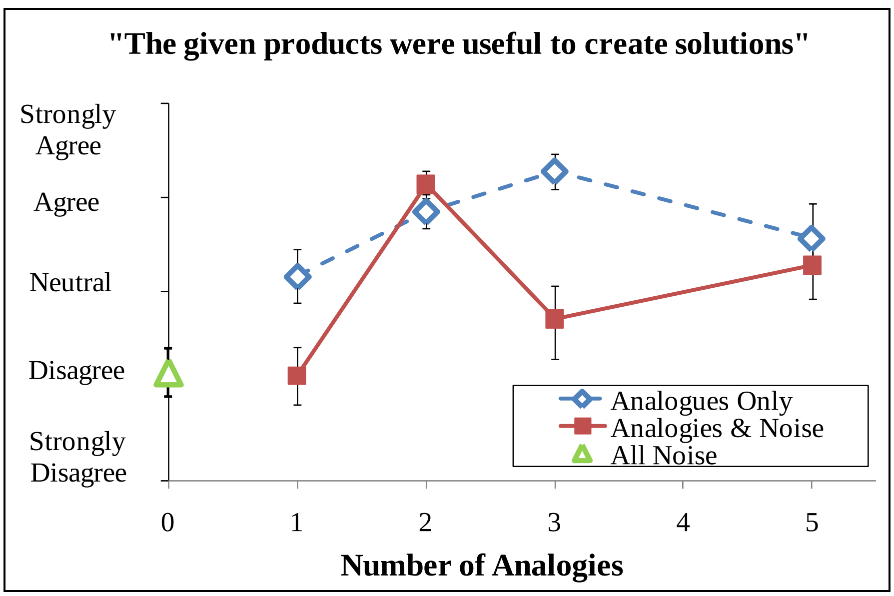


Figure 17 - The participants' rated usefulness of the products behaved similarly to the HLP recognition rate in Stage I: Without noise the usefulness rating peaks at the 2-analogue condition, and under noise there is an initially increase with increasing products and a decrease when too many items are present.

Question 2 - "I Used the Given Products to Generate Solutions"

The participants were also asked to rate their use of the products in their condition (Figure 18). In the analogue only conditions the usefulness rating is at the 2-analogue condition, while conditions of 1-, 3-, and 5-analogues showed nearly linear increases. For the analogue and noise conditions, the rated use of the products initially increased with increasing products, and then decreased when too many items were present.

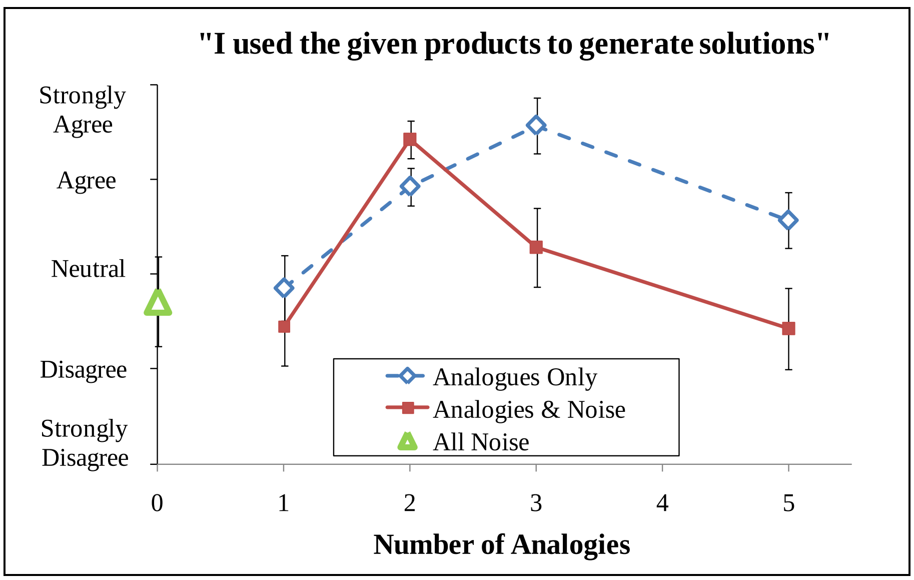


Figure 18 - The participants' rated use of the products behaved similarly to the HLP recognition rate in Stage I: Under noise there is an initially increase with increasing products and a decrease when too many items are present, without noise the peak usage rate is at the 2-analogue condition.

For both questions one and two, the sample size allowed for robustness against violations of normality and homogeneity so an ANOVA analysis was performed. It found a significant difference among the means in the all analogue and analogue and noise conditions for each question. Table 6 shows the calculated p-values.

Table 6 - P-values from an ANOVA of the mean responses to questions one and two in each set of conditions. The means within in set of conditions and for each question showed statistically different means (at an α=0.6).

	All Analogues	Analogues & Noise
Question 1	0.056	<0.01
Question 2	<0.01	<0.01

As expected, for a given number of analogues, the participants in conditions without noise deemed the example products as “more useful” and rated them to be used more. The only exception was the two-analogue condition. These differences were tested for statistical significance and the results are shown in Table 7. Again, this reinforces the previous results from Stages I and II of the HLP recognition section that noise is detrimental for analogue transfer.

Table 7 - The table shows whether the noise or no noise conditions for a given number of analogues were rated to be higher (grey box) for usefulness and usage. Statistical significance is shown in the bottom row.

	Were products useful?				Were products used?			
No. Analogues →	**1**	**2**	**3**	**5**	**1**	**2**	**3**	**5**
Analogues Only	■		■	■	■		■	■
Analogues & Noise		■				■		
Statistical Significance	x		x			x	x	x

Question 3 - "I Found the Similarity Rating Task Hard"

Participants were asked if they found the similarity rating tasks hard. Recall that the similarity task asked them to compare products vs. ideas and features used vs. features not used from the example products. The answer to this question would provide a clue as to whether the participants have a difficulty judging if two features are fundamentally similar (feature used vs. used) or if a two elements are fundamentally similar (product vs. idea). The mean responses did not show much variation and were somewhere between "neutral" and "agree" (Figure 19). The sample size allowed for robustness against violations of normality and homogeneity, so an ANOVA analysis was performed. It showed no significant variation for the mean rated difficulty of the rating task across conditions (p=0.56).

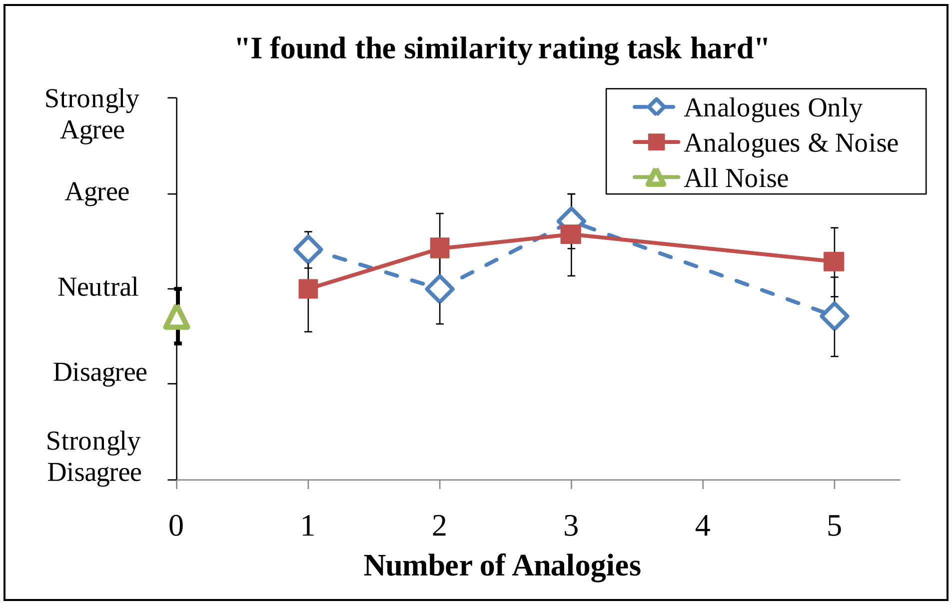


Figure 19 – There was little variation in the participant's deemed difficulty of the rating tasks. Interestingly, the all noise condition was rated least difficult.

The lack of variation suggests that participants find comparing elements on a one-to-one basis just as difficult weather there are few or many items to compare.

Limitations of the Study

The original experiment design did not differentiate between noise items and noise items with a surface feature relevant to the problem. The results from the similarity ranking exercise demonstrate this was a wrong assumption. The experiment design could have been improved by differentiating between the two from the outset. Despite this, the data gathered provides some important insights into the analogous design process.

CHAPTER V

EXPERIMENT 2 – DISTANT DOMAINS

Overview

A between-subjects experiment with four conditions (Table 8) evaluated both hypotheses. All conditions presented the participants with a design problem and two sets of useful analogies: one set from the problem domain and a second set from a domain of varying distance (Figure 20 through Figure 24). The participants began with an idea generation period followed by a series of questionnaires to characterize their ideas and obtain demographic information.

According to the Domain Distance hypothesis, increased semantic distances will force designers to use higher levels of abstraction in order to find the link between the example analogies. Higher levels of abstraction lead to more generalized guidelines to describe the mechanisms by which the example analogies achieve their purpose, expanding designer's the solution space. If this is correct, solutions from the condition with the largest semantic distance will contain a higher number of emergent features, more novel ideas, and a greater quantity of ideas.

Participants

16 senior undergraduates and one graduate Mechanical Engineering student from Texas A&M University participated voluntarily and were recruited through in-class announcements. Sixteen participants were compensated with a small amount of

extra credit in their design class and the remaining participant received $20. Participants who wished to earn extra credit but not participate in the assignment were offered an alternate assignment.

Fourteen males and three females enrolled with an average 22 years of age and 3.6 months of full time engineering work experience.

The participants were randomly distributed across the four conditions as shown in Table 8. The experiment was run in various sessions with one to four participants at a time. Only one condition was tested per session and care was taken to ensure participants did not interact with each other. At the conclusion of each session the participants were asked not to discuss any aspect of the experiment with their peers to avoid bias.

Table 8 - Summary of domains and number of participants present in each condition.

Condition	Problem Domain	Second Domain	No. of Participants
1	Nutcrackers-A	Nutcrackers-B	5
2		Food Peelers	3
3		Debarkers	5
4		Depilators	4

Design Problem

All participants were asked to devise methods or devices to quickly shell peanuts without the use of electricity and at low cost. This problem has been used in prior design research (Linsey, 2007; Oriakhi, 2010) because it is easily understood, it is unlikely the participants have any significant prior experience with the task, and there is a large set of potential solutions.

Along with the design problem, participants were shown two sets of three potentially useful analogies. A PowerPoint presentation described the working mechanism of each analogue and the two sets of analogues were explicitly stated to belong to two distinct domains.

The problem and example analogue introduction concluded by reminding participants their designs are not limited to the example analogues and they may adapt or combine features from the examples or create completely new designs.

Distant Analogous Domains

The four experiment conditions presented participants with example analogies from the problem domain and a second domain of varying semantic distance. The problem domain for the peanut sheller problem was “nutcrackers”. Potential second domains were found through the use of the WordTree method(Linsey, 2007), a graphical representation of potential analogies and domains presented as a hierarchical tree organized semantically. The tree was automatically generated using the WordTree Express software(Oriakhi, 2010). Several domains were researched and three were chosen based on how useful their analogues were for the experiment. The domain had to have several analogues which were clearly applicable to the problem and each analogue had to have very few features to prevent participants from focusing on inappropriate features. The domains chosen were, from closest to most distant: food peelers, bark removers, and depilation methods. Throughout the rest of this document each condition is referred to by the second domain (Table 8, column three). The analogies selected for each domain are shown in Figure 20 through Figure 24.

The distance of each domain was determined based on WordNet::Similarity (a software tool) and compared against participant rankings. Both of these are described in more detail in the 'Metrics' section.

Figure 20 - Example Analogies: Nutcrackers-A.

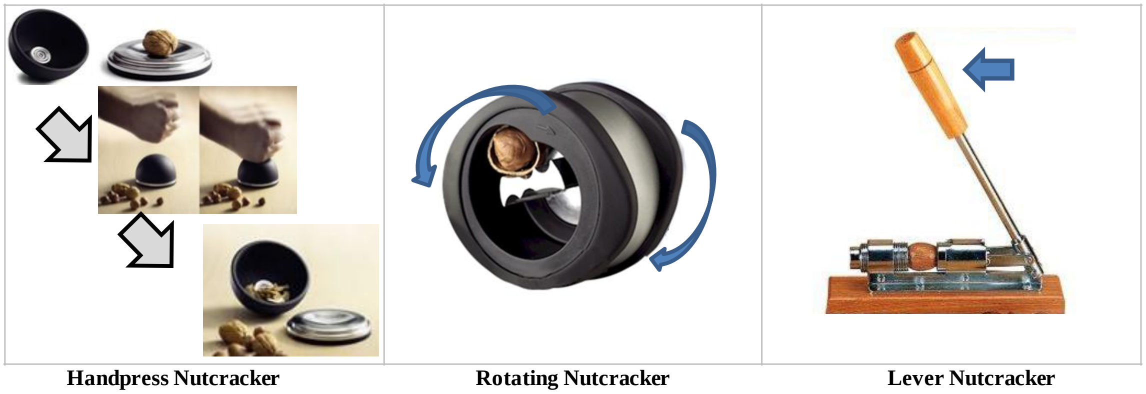


Figure 21 - Example Analogies: Nutcrackers-B.

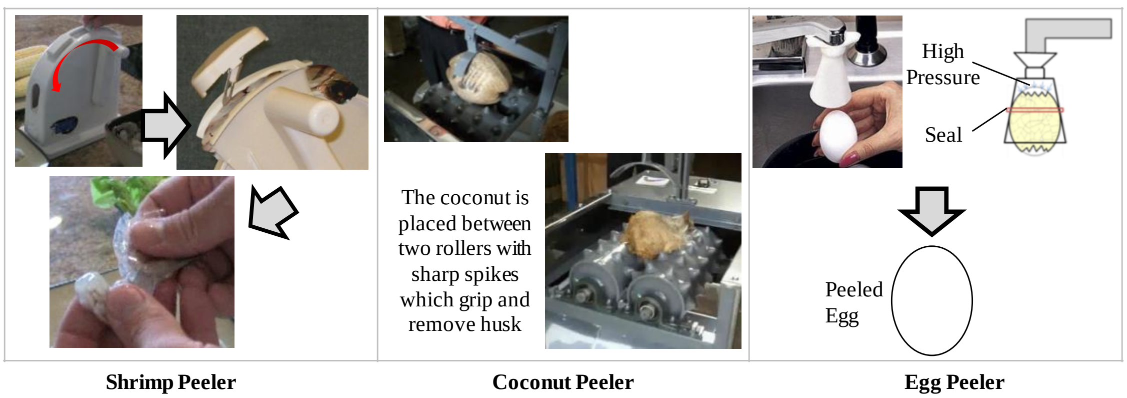


Figure 22 - Example Analogies: Food Peelers

Figure 23 - Example Analogies: Debarkers.

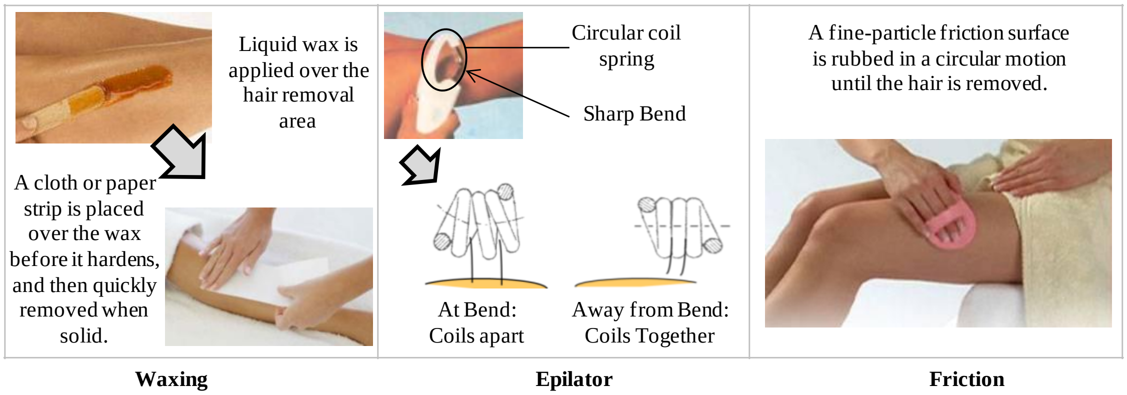


Figure 24 - Example Analogies: Depilators.

Materials

In addition to oral instructions each participant is given a hard copy of the design problem, PowerPoint presentation, and any other directions. The questionnaires to characterize solutions and to obtain demographic information were given as hard copies at various points after the idea generation period. In order to determine at which point in time the participants generated a given solution, and to assure they did not work on portions of the experiment after the assigned period. The experiment exchanged the color of the participants' pens at the 5, 10, 20, and 30 minute points, and at the start of each new exercise.

Procedure

As the participants entered the experiment room they were asked to place their belongings at the entrance and shown to their randomly assigned booths. Each booth consisted of a desk and chair and two walls to prevent any contact between participants.

The desks were set up with a pen, a consent form, and a stack of blank sheets with hard copies of the design problem the analogies description presentation below it. Only the consent form and blank sheets were visible to the participants to avoid early starts.

The experiment proctor then asked participants to find the design problem and analogies presentation below the blank paper and read along as he read aloud. Once the problem and analogies were explained, the participants were allowed to generate ideas for a 40 minute period during which different color pens were exchanged at the time points stated earlier.

After idea generation, the students were asked to number each solution and mark any which were based on example analogies with a check mark. Once analogous ideas were identified, the participants listed which example analogue was used and which features were mapped. In order to make these instructions clear they were given Burr and Velcro as example of analogous design. The end of this exercise marked the midpoint of the experiment and the participants were allowed a five minute break to avoid fatigue.

The experiment resumed with a questionnaire asking participants to rank the similarity of each of their ideas with the example analogies. This was intended to capture a more objective perspective by the participant regarding which analogies had some mapping in each idea.

The final activity was a survey intended to characterize their ideas and to gather demographic information. At the end, the students were reminded once more not to discuss the experiment with their peers.

At the end of each set of instructions, the participants were asked if the directions were understood. Additionally, the participants were able to ask questions at any point in the experiment.

Metrics for Evaluation

Four main metrics: total number of ideas, number of, number of non-analogous ideas, and number of emergent features, were used to test the Domain Distance Hypothesis. Evaluation of the Close Domain Preference hypothesis relied on the results from the post experiment survey. Both hypotheses were tested using various metrics for semantic distance of domain.

Total Ideas and Analogous and Non-Analogous Ideas

The total number of ideas, number of analogous ideas, and number non-analogous ideas was determined by the participants since students were instructed to describe only one idea per sheet and to label which example analogue, if any, was used for each idea.

Emergent Features

The number of emergent features was determined independently by one of the authors and a third-party. Emergent features were defined to be any feature present in the participant's ideas but not present or not dominant in the example analogies (Kerne, Smith, Koh, Choi, & Graeber, 2008). Additionally, emergent features were only counted once. A feature was not emergent if it was present in a participant's previously generated design. The two evaluators showed similar findings with a Pearson's correlation of 0.82, however only the results from one evaluator were used for the analysis. This multiple-evaluator procedure is a common practice for gauging the accuracy of subjective measures (e.g. (Linsey, 2007; Vishwanathan & Linsey, 2010)).

Semantic Distance

Semantic distances were determined using the software WordNet::Similarity (Pedersen, Patwardha, & Banerjee, 2005), an online tool based on Princeton's WordNet (Princeton_University, 2010) and capable of applying several semantic relatedness measures to any pair of words. This experiment used the path-length measure and two types of descriptors to assign a semantic distance to each condition: an action verb and noun descriptive of the subject matter.

The path-length measure makes use of WordNet's organizational structure. WordNet begins by differentiating parts of speech (i.e. verbs, nouns, etc). Words within parts of speech are organized in groups of synonyms (*synsets*) which are in turn related to other synsets through several semantic relations. A full description of all these semantic relationships is beyond the scope of this article, but the following two examples should provide a general overview of the structure:

- *Hypernyms* – synset Y is a hypernym of X if every X is a kind of Y
- *Troponyms* – synset Y is a troponym of X if every Y is a kind of X

The points at which synsets are linked together are known as nodes. The path-length similarity score is inversely proportional to the number of nodes along the shortest path between the synsets:

$$\text{Similarity} = 1/(\#\ \text{Nodes}_{\text{Min Path}}) \qquad (1)$$

The shortest possible path occurs when the two synsets are the same, in which case the length is 1. Thus, the maximum relatedness value is 1. The similarity scores for the experiment domains are shown in in the results section. This paper defines domain distance as follows:

$$\text{Domain Distance} = 1 - \text{Similarity} \qquad (2)$$

As per the definition of similarity, very similar domains will have distance values near zero and dissimilar domains will have distance values near 1.

Survey

Additionally, a survey was used to provide supporting information. A five-level Likert questionnaire questioned the participants on the usefulness of the example analogues, the effect of using analogies on creativity, and on the quality, practicality, and effectiveness of their resulting solutions. The five answer choices were coded on an integer scale for analysis. Strong disagreement and strong agreement corresponded to -2 and +2 corresponding, respectively, and the other three options in between.

Similarity Rating

The first similarity question asked participants to rate the similarity of the "nutcracker" domain (problem domain) and the second domain in their condition using a 1-9 scale.

Similarity Ranking

The second question asked students to rank the distant domains in each condition in order of similarity. This was a second approach to measure the participant's perception of the domain similarities. The question as seen in the survey is shown in Figure 25. Furthermore, since the question did not specify that each ranking (close, middle, distant) could be used only once, some participants used a ranking more than once. For the analysis, the responses were coded as 1, 2, and 3 for close, middle and distant, respectively. The survey ended with demographic information questions.

Rank the following domains as close, middle, or distant from the domain "Nutcrackers"

____ Devices to peel or shell food (ex. Coconuts, shrimp, eggs, etc)

____ Devices to remove bark from trees

____ Depilation (hair removal) methods and devices

Figure 25 – Question asking participants to rank the analogous domains. Participants responded with 'close', 'middle', or 'distant', and these were coded as 1,2, or 3, respectively for analysis.

The results of both the rating and ranking exercises were compared with the similarity values obtained from the WordNet::Similarity tool.

Results and Discussion

Domain Distance

Two different methods were used to obtain similarity ratings through the WordNet::Similarity software. The first described each domain with an action verb and the second described each with a noun representative of the subject matter. For example, for the problem domain the action verb was “shell” while the subject matter was “peanut”. The results from the two descriptor methods (action verb and subject matter) did not agree (Table 9).

Table 9 - Results from semantic distance analysis using the WordNet::Similarity tool (word definitions can be found in the footnote). The average rankings by the participants (column 6) match the results from the Subject Matter Descriptor.

Descriptor	Condition	Problem Domain	Second Domain	Semantic Distance	Participant Rank
Action Verb	**Nutcrackers**	Shell[1]	Shell	0.00	
	Foop Peelers		Peel[2]	0.75	Near
	Debarkers		Bark[3]	0.75	Middle
	Depilators		Depilate[4]	0.67	Distant
Subject Matter (noun)	**Nutcrackers**	Peanut[5]	Peanut	0.00	
	Foop Peelers		Food[6]	0.24	Near
	Debarkers		Bark[7]	0.91	Middle
	Depilators		Hair[8]	0.94	Distant

The action verb criteria deemed the depilators domain as closest, followed by the food peelers and debarkers (which received equal scores). The subject matter method, on the other hand, concluded the food peelers domain to be closest, followed, in order, by the debarkers and depilators domain. The similarity of the debarker and depilator

[1] shell (v) - remove from its shell or outer covering; "shell the legumes"; "shell mussels"

[2] peel (v) - strip the skin off; "pare apples"

[3] bark (v) - remove the bark of a tree

[4] depilate (v) - remove body hair; "epilate her legs"

[5] peanut (n) - widely cultivated American plant cultivated in tropical and warm regions; showy yellow flowers on stalks that bend over to the soil so that seed pods ripen underground

[6] food (n) - any substance that can be metabolized by an animal to give energy and build tissue

[7] bark(n) - tough protective covering of the woody stems and roots of trees and other woody plants

[8] hair (n) any of the cylindrical filaments characteristically growing from the epidermis of a mammal; "there is a hair in my soup"

domains was also tested in the subject matter criteria using the words "woodworking"[9] (similarity = 0.053) and "depilation"[10] (similarity = 0.048), respectively. The similarity scores were different, but the order remained the same.

Based on the literature a decision was made to use the results from the subject matter method for two reasons. (1) Semantic domain is more closely related to surface elements(Reeves & Weisberg, 1994); and (2) Surface features have a greater influence in analogue selection than do deep similarities (Lopez de Mantaras, et al., 2005; Reeves & Weisberg, 1994). Nouns corresponding to the subject matter are better characterizations of surface features.

Domain Distance Hypothesis

The number of ideas, analogous and non-analogous ideas and emergent features metrics were analyzed for significant differences across conditions. All results were tested for Normality and Homogeneity using Levene's Test and Shapiro-Wilk, respectively. If these conditions were met, the differences across conditions were evaluated using an ANOVA. Because this is a pilot study, the small sample size meant this was often the case. Furthermore, the sample size was not large enough to provide

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[9] woodworking (n) - the craft of a carpenter: making things out of wood

[10] depilation (n) - the act of removing hair (as from an animal skin)

[12] Kruskal–Wallis one-way analysis of variance by ranks is a non-parametric method for testing equality of population medians among groups. It is identical to a one-way analysis of variance with the data replaced by their ranks. Since it is a non-parametric method, it does not assume a normal population, unlike the analogous one-way analysis of variance.

robustness against violations of test assumptions. In these cases, the results were tested with a Kruskal-Wallis one-way analysis of variance[12].

Domain Distance Hypothesis – Total Number of Ideas

The mean total numbers of ideas across conditions are shown in Figure 26 in the order obtained from WordNet::Similarity using the subject matter criteria. Here, increasing semantic distance did not always result in a greater number of total ideas. The mean number of ideas peaked at the debarkers condition.

Figure 27 shows the same data, this time ordered using the results from WordNet::Similarity with the action verb criteria. Recall that the food peelers and debarkers received identical distance scores. Using this order the total number of ideas increases with increasing distance. The results using the action verb support the Domian Distance Hypothesis, and suggest that perhaps analogy retrieval tools could benefit from using this criterion. An ANOVA did not show a statistically significant difference for the mean total number of ideas across the experiment conditions, likely due to the low sample size.

Domain Distance Hypothesis – Number of Non-Analogous Ideas

Unlike the total number of ideas, however, semantic distance does not appear to have an effect on this metric. The means fluctuate only slightly at about 1.8 non-analogous ideas (Figure 26 and Figure 27). The means for the number of non-analogous ideas were not significantly different across the experiment conditions.

Domain Distance Hypothesis – Number of Analogous Ideas

The total number of ideas is the number analogous plus the number of non-analogous ideas. Since the number of non-analogous ideas remains nearly constant across conditions, the analogous condition follows the same behavior as the total number of ideas.

When ordered using the results from WordNet::Similarity with the subject matter criteria, increasing semantic distance shows a peak in the number of analogous ideas at the debarkers condition (Figure 26). When ordered using the action verb criteria (Figure 27), the number of analogous ideas increases with increasing distance. The means for the number of analogous ideas were not significantly different across the experiment conditions, again, likely due to the small sample size.

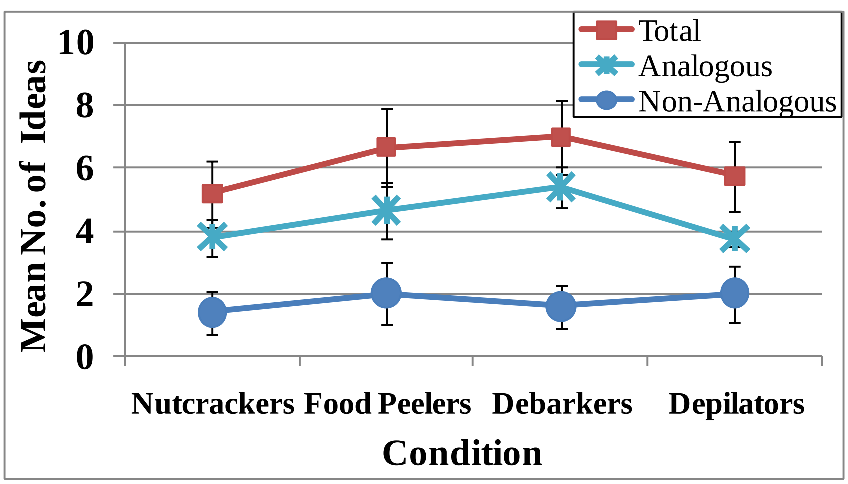

Figure 26 – Mean number of total, analogous, and non analogous ideas ordered by semantic distance as determined by WordNet::Similarity using the subject matter descriptor. The number of total and analogous ideas peak at the debarkers condition.

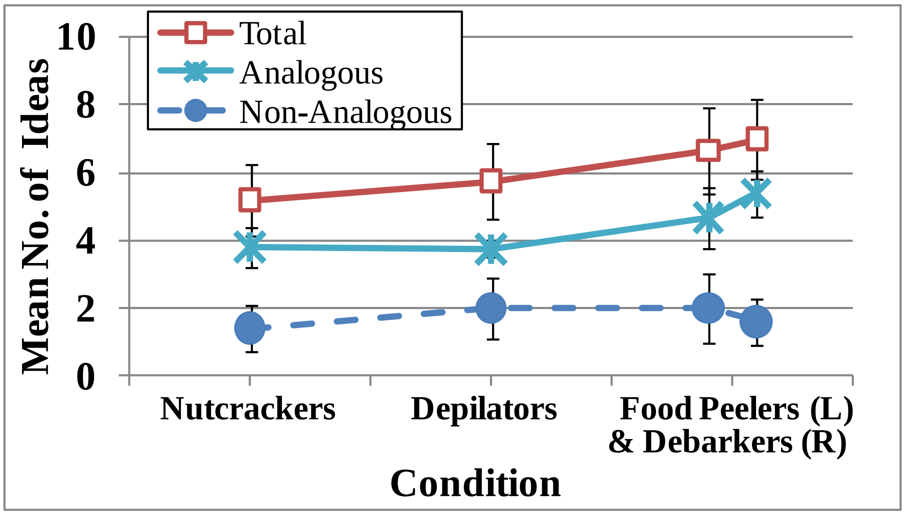

Figure 27 – Mean number of total, analogous, and non analogous ideas ordered by semantic distance as determined by WordNet::Similarity using the action verb descriptor. The numbers of total and analogous ideas increase with increasing distance.

Domain Distance Hypothesis – Number of Emergent Features.

A Kruskal-Wallis one-way analysis was employed and found no statistical significance for the number of emergent features across experiment conditions (Figure 28) but a trend is noticeable. A small increase for the number of emergent features is observed in the middle domain distances when using the action verb criterion. This result contradicts the hypothesis. An overall increase for the number of emergent features was expected with increasing domain distance.

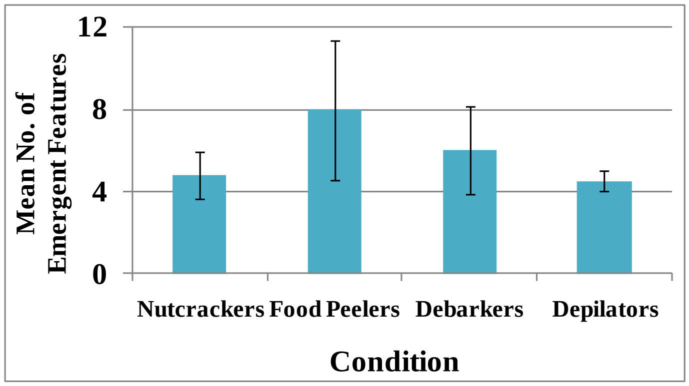

Figure 28 - The average number of emergent features did not present a significant difference across the experimental conditions.

Continuous Scale Analysis

The previously discussed metrics were also analyzed with a continuous-scale using the semantic distance scores from the WordNet::Similarity program (Table 9). Figure 29 through Figure 31 show the four metrics as functions of domain distance with their respective regression functions. Table 10 summarizes the regression lines and the resulting r^2 values. The r^2 values for the linear regressions indicate that the action verb criteria is more adept at predicting the metrics (total number of ideas, number of analogue and non analogue ideas, number of emergent features) based on the domain distance. This is especially true for the total number of ideas (r^2 = 0.69) and the number of non-analogous ideas (r^2 = 0.61). All but one of the regression lines showed a positive slope, indicating that all metrics improve with increased semantic distances between domains, regardless of whether the domains are described using an action verb or the subject matter. The action-verb distance method could be useful for analogue-retrieval software, since it seems to be able to predict improvement in the total number of ideas generated.

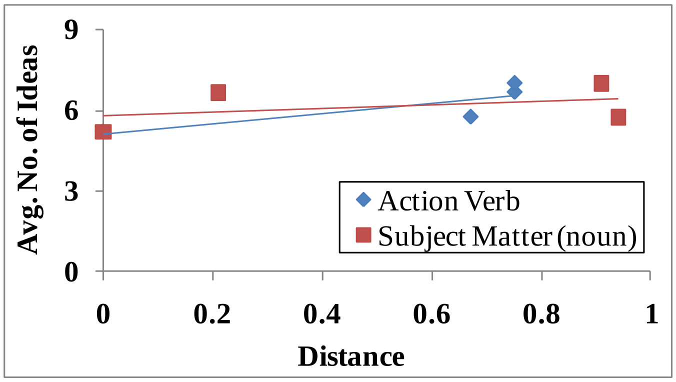

Figure 29 – The average number of ideas increased slightly as the domain distance increased when using the action verb criteria (Table 9).

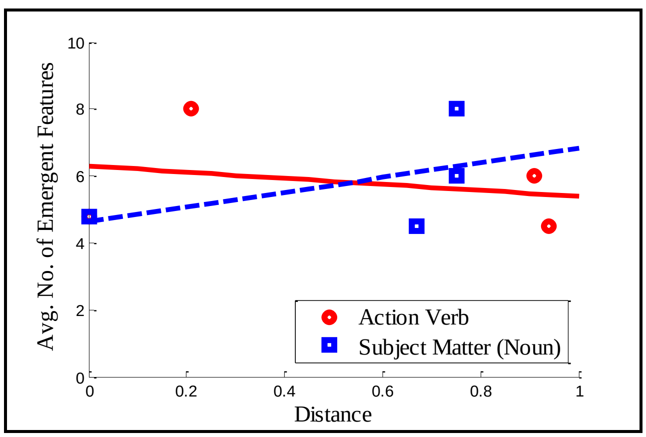

Figure 30 - The mean number of emergent features as a function of semantic distance between domains did not appear to be affected by the domain distance.

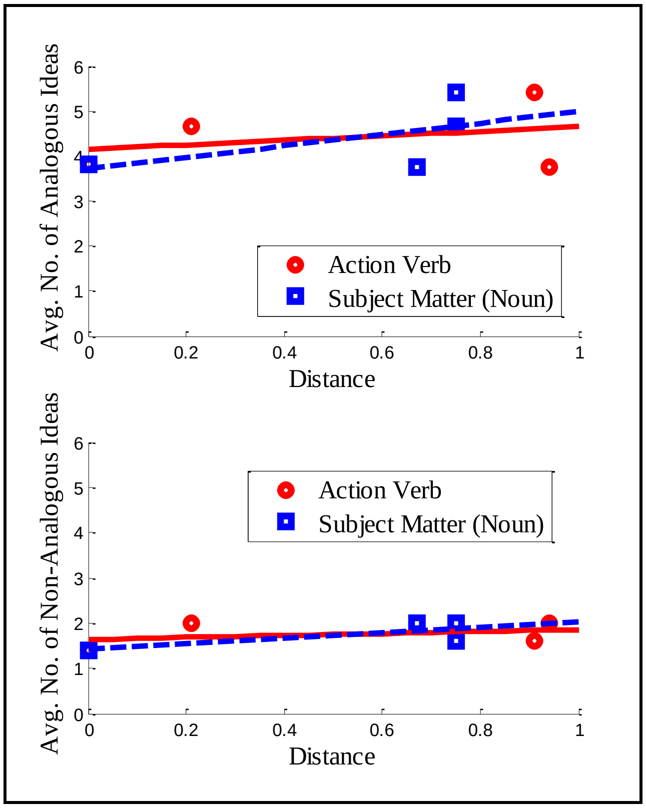

Figure 31 – The mean number of analogous and non analogous conditions as functions of semantic distance between domains.

Table 10 - Summary of linear regression results for continuous analysis of distance.

Independent Variable	Dependent Variable	Action Verb		Subject Matter	
		Slope	r^2	Slope	r^2
Semantic Distance	Total No. Ideas	1.89	0.69	0.71	0.17
	No. Analogue Ideas	1.28	0.35	0.50	0.09
	No. Non-Analogue Ideas	0.55	0.61	0.22	0.12
	No. Emergent Features	2.21	0.25	-0.91	0.08

Designers' Attitude toward Similarity of Distant Domains

In the food peelers, debarkers, and depilators conditions the participants were asked to rank the similarity to the problem domain (nutcrackers) and the second domain in their condition using a 1-9 scale. An ANOVA of the rankings across conditions was not statistically significant and further the average rank across conditions was nearly equal (Figure 32). This contrasts with the results from the rating question (Figure 25). When the participants were asked to rank the distant domains based on their similarity to the application domain they agreed on an order (Figure 33). This order matched the results from the WordNet::Similarity program when using the Subject Matter Descriptor (Table 9). This agrees with findings from previous studies (Lopez de Mantaras, et al., 2005), participants focus on the surface features (in this case, the subject matter) when determining the domain's similarity to the problem.

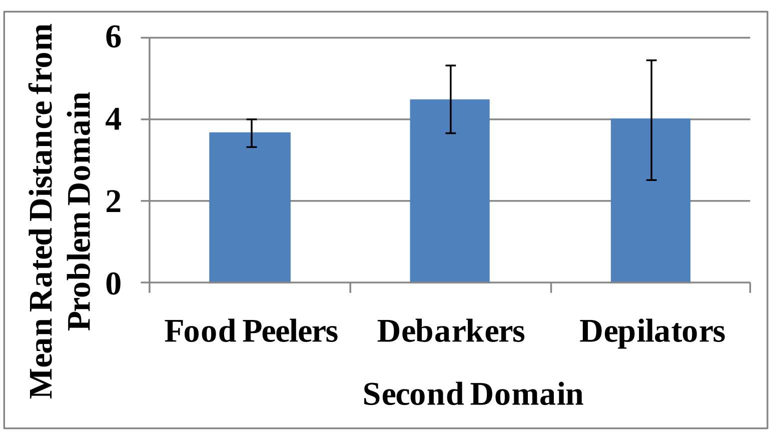

Figure 32 – When presented with only the application domain and the second domain the participants ranked the similarities to be nearly equal across all conditions.

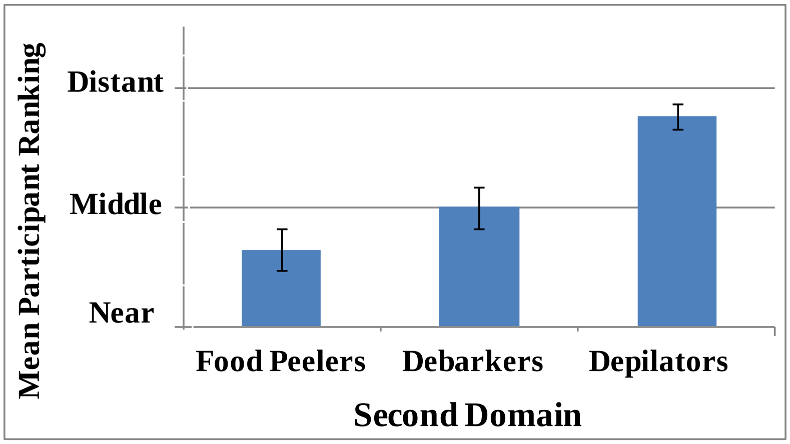

Figure 33 – When asked to sort the distant domains according to their similarity to the application domain the participants agreed on a definite order.

A Kruskal-Wallis test found a statistically significant difference for the sort order means. Additionally, the ranking order shown in Figure 33 was consistent within the individual conditions (Figure 34). Figure 34 consists of the same data as Figure 33, however here it is broken down by condition instead of shown as an overall average (Figure 33). It shows that within the individual conditions the participants agreed on the same order.

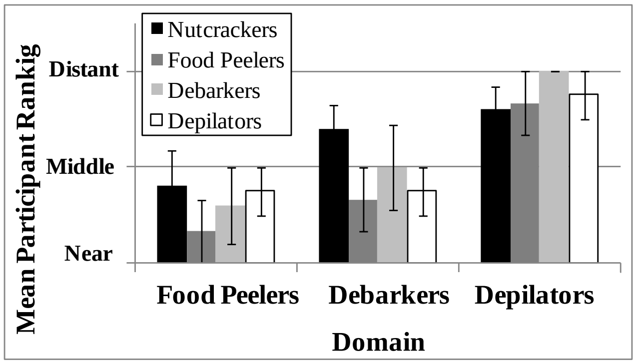

Figure 34 – The data from participants concluded on the same sorting order in each experiment condition. Figure 33 shows the condition averages of this data.

Metrics as Functions of Time

The experiment used pens of different color to trace the time at which a given idea was generated (Figure 35). Overall, the generation rate of non-analogous ideas increased with time while the rate for analogous ideas increased slightly.

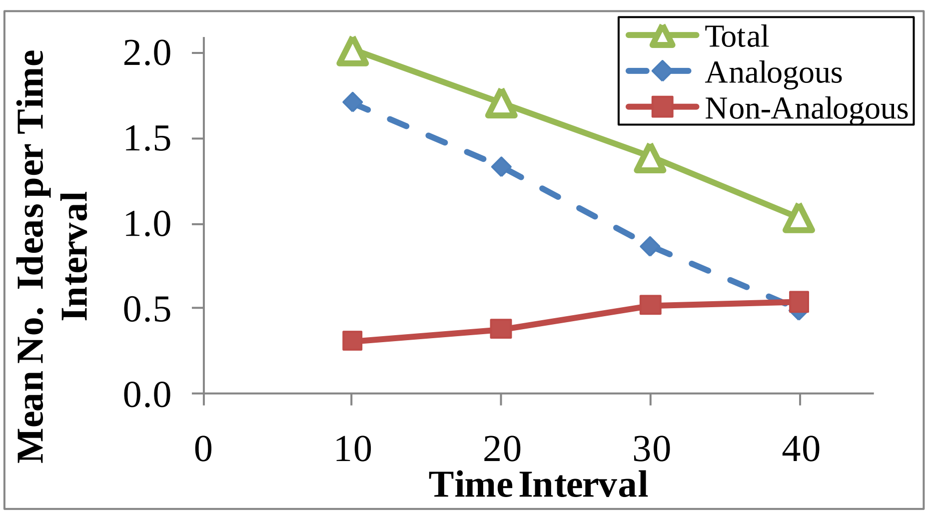

Figure 35 - Number of total, analogous, and non-analogous ideas at every ten minute time interval.

This indicates that participants begin by using the example analogues for inspiration and then turned to other sources. Each point in Figure 35 corresponds to the number of ideas per 10 minute interval. The analogous ideas line is always higher or equal to the non-analogous ideas line, meaning that the use of analogies provides faster idea generation rates.

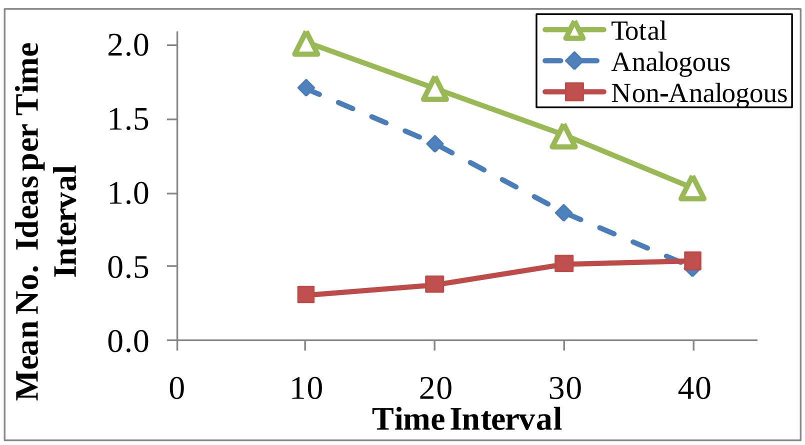

Figure 36 - The overall rates of total and analogous idea generation decreases with time, while the rate of non-analogous ideas increases slightly.

The generation rate of emergent features decreased with time (Figure 37). The fact that earlier designs are the ones which present the greater number of emergent features is unexpected, since these are mostly analogous designs (Figure 36). It should be expected that non-analogous designs would not present more emergent features, since they are not mapping features from the analogies. This is partly as a result of the definition used for emergent features. Once an emergent feature is used in a design, if the participant uses it again it is no longer emergent. He/she is only copying a feature from a previous idea. For this reason, repeated features are not considered emergent.

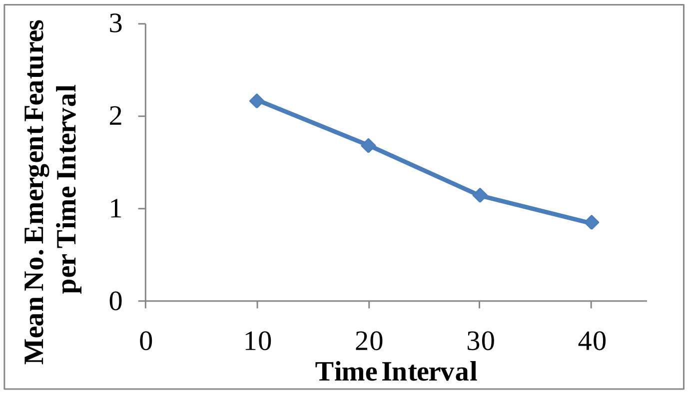

Figure 37 - The overall rate of emergent feature generation decreases with time. Individual conditions showed a similar behavior.

Close Domain Preference Hypothesis

The end of experiment survey was used to evaluate the Close Domain Preference Hypothesis. It used a series of Likert questions to assess the participants attitudes toward the usefulness of the example analogues, the effect of using analogies on creativity, and on the quality, practicality, and effectiveness of their resulting solutions. Three questions in particular showed interesting results (Figure 38):

(1) The given products were useful to generate solutions

(2) Solutions based on the analogies are likely to be effective

(3) Solutions based on the analogies are likely to be practical

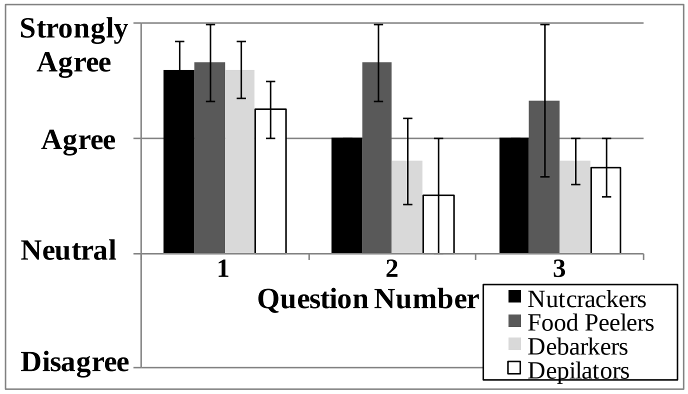

Figure 38 - Average results for questions 1-3 across experiment conditions.

(1) The given products were useful to generate solutions.

The designers tend to regard example analogies from more distant domains as 'less useful'. The number of solutions, number of new solutions, and number of emergent features across the experiment conditions do not support this assessment. The depilator domain,

(2) Solutions based on the analogies are likely to be effective & (3) Solutions based on the analogies are likely to be practical.

For Question 2, only the results from the second condition were significantly different than the others, while there is no significant difference in the Question 3 results.

Though not significant, a similar pattern is present in both questions. The participants deem solutions generated using the application domain and a near domain 'more effective' and 'more practical' than those generated using only the application domain. As the semantic distance of the second domain is increased, the students feel their solutions are ‘less effective’ and ‘less practical’.

The present analysis of the solutions did not have metrics for ‘effectiveness’ nor ‘practicality’, so participants attitudes toward these two facets could not be compared with their actual results. However, this could be addressed in the future work, possibly by using the ‘functional idea’ metric proposed by Vishwanathan (2010) (Vishwanathan & Linsey, 2010).

Usage Count of Domains

The Close Domain Preference Hypothesis is also supported by the usage count of the (Figure 39). On average, analogies from the problem domain were used more times than analogies from the second distant domains in all conditions.

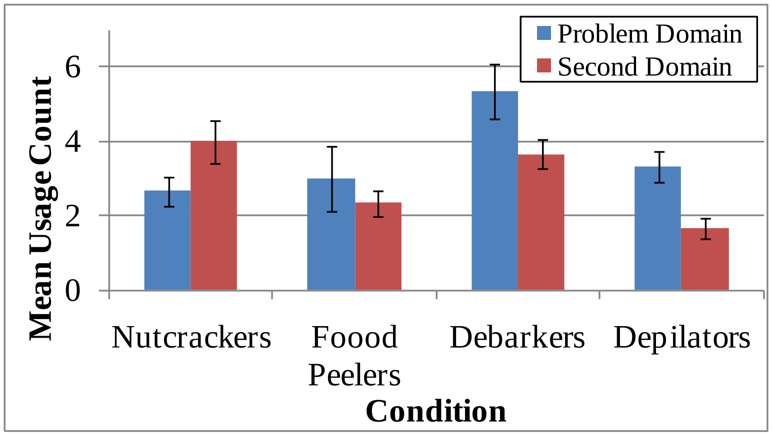

Figure 39 - Average use count for the two domains in each condition. In all conditions which used the problem domain and a second distant domain analogies from the problem domain were used more times.

Study Limitations

The design problem may not be an accurate representation of the difficulty of real-world engineering problems. It is possible that the complexity of the problem could be a factor in the outcome of idea generation. The example analogies were selected to have very few features aside from those which could be mapped to the problem. This was done so that the participants did not focus on inappropriate features. Despite this, some of the analogies were used less than others (Figure 40). This could be a random result or indication that the analogies selected are not entirely adequate for the experiment. The small sample size makes it difficult to determine a conclusion. Finally, the experiment is only a pilot study employing a small sample size. Many of the results showed promising patterns and further work needs to be done.

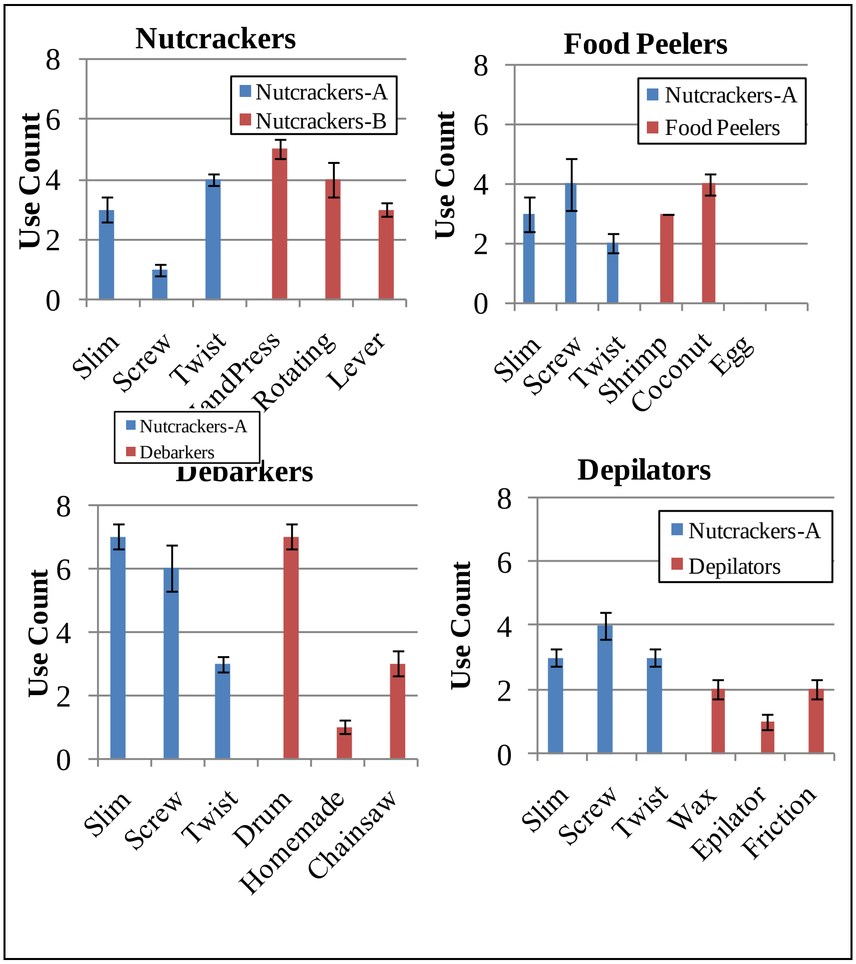

Figure 40 - Usage count of individual example analogies within each condition.

CHAPTER VI

CONCLUSIONS AND FUTURE WORK

The two experiments further validate design-by-analogy as a powerful tool to generate new and creative ideas and to enhance the design process.

Conclusions – "Analogies and Noise"

Analogies help stimulate idea generation, but it is often difficult to select the appropriate analogue. In real life, designers have massive selection of potential analogues from which to select an appropriate base analogue. The results from the Analogies and Noise experiment show that noise deteriorates designer's abilities to recognize useful high level principles (HLPs) from analogues.

Previous findings that the use of two base analogues is better than the use of one were found to be correct in the Analogies and Noise experiment. The overall trend in the analogies only-condition was an increase in the HLP recognition rate with increased numbers of analogies. However, the use of two analogues had higher HLP recognition rates than all other conditions. While the conditions with one, three, and five analogues showed a nearly linear increase for HLP recognition, the two-analogue condition had a higher rate than even the five analogue condition. This suggests that using two analogues is ideal for design. Results the post experiment survey also support this conclusion: the deemed usefulness for the 1,3, and 5 analogue only conditions increased linearly, but the 2 analogue condition showed the highest usefulness rating. It is important to note that the participants are in all probability familiar with the principle used for this experiment (elasticity). As a result, the optimal results observed when using two analogues might not be true for analogous design requiring principles which are not familiar to the participants.

Under the presence of noise, increasing the number of analogies initially improved the high level principle recognition rate. However, once too many items are introduced, designers are likely overwhelmed, decreasing the likelihood of recognizing the relevant information. Results the post experiment survey also support this conclusion. The participants' deemed usefulness of the given set of products in their condition followed the same behavior: it initially increased as the number of products increased, and decreased when too many items were present.

The number of analogues, the number of noise items, and the number of noise items which have surface features relevant to the problem all contribute to the likelihood of recognizing high level principles. The similarity ratings between products and participants ideas for analogue products, pure noise products (no useful surface or functional feature), and noise products with a relevant surface feature were all significantly different. As expected, analogies and the highest score while pure noise products had the lowest. Noise with useful surface features were in between, but their score was much closer that of the analogies (90%). This means that surface features can be nearly as useful as functional features to solve problems.

Future Work – "Analogies and Noise - Pilot"

The current experiment used a high level principle that was likely familiar to all participants (elasticity) and familiarity with the high level principle could be a factor in the results observed. Future experimentation with a more foreign high level principle could help determine if this is indeed the case, or if the use of two analogues is always optimal. The number of high level principles could also be a factor. It is possible that when given example analogues which have two or more types of useful features the participants will tend to overlook some of them. This experiment only used one HLP within the example products, and future experiments with multiple types of HLPs could give more insight into analogous design.

Some of the data in this experiment remains to be analyzed. To name a few, idea generation can be analyzed as a function of time, and the results from the feature used vs. feature not used similarity exercise remain to be analyzed. The data could also be analyzed with metrics that were not part of the original experiment design. For example, emergent features (features not present in the example products) can be compared at the various conditions, and the ideas could be measured using quality, novelty, and variety metrics (Shah, Kulkarni, & Vargas-Hernandez, 2000). The present experiment found that analogue transfer is enhanced by using more analogies and weakened by noise, but the resulting creativity and innovation remain be characterized

Conclusions – "Distant Domains"

Increasing semantic distances of base analogous domains resulted in an increased number of ideas and number of analogous ideas when the domain distance was measured using the WordNet::Similarity software and an action verb descriptor. The number of emergent features did not show this behavior, but there was a peak in the conditions using the middle-distant domain. For all metrics, the use of only application domain analogies resulted in the lowest or nearly lowest performance.

The follow up survey indicated that the participants deem more distant domains (as rated by the participants and by the WordNet::Similarity software when using the subject matter descriptor) as 'less useful'. This assessment is not supported by the outlined metrics: distant domains produced a greater number of ideas and similar numbers of emergent features. The results indicate that distant domains are at least equally useful as close domains in stimulating productivity and creativity. Designers should not limit their search of potential analogies to close domains.

When asked to rate the similarity of the problem to only one distant domain the participant in the three conditions had similar ratings, even though the domains were from different semantic distances. In contrast, when the participants were given all three domains and asked to rank them in order of similarity to the problem they agreed on an order. This means that, without a domain of reference, designers consider any distant domain equally useful unless they are presented with various domains. The order matched the results from the WordNet::Similarity software and the domains were described using their subject matter. This confirms that (1) designers focus on surface features when determining an analogue's similarity to the problem; and (2) as stated earlier, designers should not limit their search of potential analogies to close domains.

Future Work – "Distant Domains - Pilot"

It is essential that a larger sample size is evaluated to obtain statistical significance for the trends observed in this pilot. Some of the results appear promising but the small sample yields non-statistically significant results. Some of the example analogues were used much less than others. This could be a random occurrence due to small sample size, or it could mean that those analogues are not very useful for the problem. A future version of this experiment should re-evaluate each of the example analogues used and determine if they are adequate for the experiment.

Quality, novelty, and variety metrics (Shah, et al., 2000) could be used to characterize the solutions and be compared against the participants' attitudes toward distant domains. The continuous-scale analysis presented could be refined with the use of a transform function that spread dissimilar domains which are tightly grouped in the low-similarity scores could provide better results. The continuous scale analysis presented a linear regression for the metrics (total number of ideas, analogous and non analogous ideas, and emergent features) as functions of domain distance. Since for any given domain there are many more domains of low similarity than there are of high similarity, using a transformation function could spread dissimilar domains that are tightly grouped in the low-similarity scores and provide better predictions for the behavior of the metrics as functions of domain distance. This should be explored in the future.

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APPENDIX

Analogies & Noise - Experiment Script

<u>Consent</u>

- **Keep two copies of consent forms on the table**
- **Keep design problem, blank paper and paper with sketch for idea generation on top right corner and products on the top left corner of the table**

Black pen

As soon as each participant arrives:

Hello! You can put your back pack close to the wall and please turn off or silence your cell phones. Show the workplace. "Please take your seat. We are ready to begin."

You are being asked to participate in a research study on engineering design. Please read the consent form in front of you. You are not required to participate in this study and may end your participation at any time.

You will be asked to generate ideas for a given design problem and to complete a five minute survey at the end of the experiment. The study will require approximately two hours. Does anyone have any questions about the study?

(Answer)

<u>Allow participants to read the form, at least three minutes</u>. Answer all question s the participants ask. Wait until all all participants have finished reading before proceeding.

If you agree to participate please sign the consent form and keep a copy for your records.

I have one request before we begin: Please do not discuss the experiment with anybody in the Engineering Departments at TAMU until after Dec 31, 2010. If a participant knows what the design problem is or what the tasks are ahead of time it will bias the results.

Sign the consent forms and take them. If wished, sign copies for records.

<u>Design Problem: Door Pin Lock</u>

Your task is to generate as many solutions as possible for the given design problem. You have some products in front of you that may or may not help you to generate solutions. I'll briefly describe and demonstrate all the products.

Show the products and then describe and demonstrate

Demo all products in condition.

Now I will read out the description of the design problem for which you will generate solutions. A print out is available below the stack of paper on the top right corner of the table. Please flip the stack over and follow along as I read.

NASA astronauts are on a mission to Mars and a critical component has broken down; "Door Pin Lock" as shown in the handout. NASA engineers are anticipating this situation and want to design features into the parts ahead of time allowing astronauts multiple avenues to provide temporary solutions to the problem.

NASA is looking for innovative solutions to fix this problem. So, your task is to provide a temporary fix satisfying the following condition.

- **The door pin must automatically return to the locked position even when there is no electricity**

Since the parts are still being designed, you can add or remove features to the parts.

NASA will send supplies to the space station with the astronauts. The supplies will consist of a wide variety of materials and tools but NASA has not decided what materials and tools will be needed to solve the problem. It costs them millions of dollars per pound, so they want to send as little material as possible. Your solutions will help to determine what supplies to send.

There is one constraint:

- **You cannot use a metal coil spring. NASA is aware of this solution and needs others.**

Your task is to design a temporary mechanism to move the pin back to the locked position.

Generate as many solutions as possible for the given design problem.

Remember that the products in front may or may not help you to generate solutions. Use sketches and words to describe your ideas. There are sheets with the design problem sketch on it. So, please sketch one idea per sheet. You can also use the blank sheets for sketching your ideas. Write down everything even if it does not satisfy the constraint. I'll give you a warning 5 minutes before the time is up. We will be using different color pens to keep track of when the ideas are generated. I'll exchange your pen at regular intervals of time. Remember that you can add or remove features into the parts to allow for temporary solutions.

Are there any question?

Answer questions if any. (<u>Record the questions and answers</u>)

You may begin now.

Start stopwatch

<u>Script for pen change after every ten min:</u>

00-05 min: Black Pen "Five minutes are over. I'll exchange your pen now."

05-15 min: Red Pen

15-20 min: Green Pen

20-30 min: Blue Pen

30-40 min: Maroon Pen

Total	Start	End	Pen	
5	0	5	Black	"Five minutes are over. I'll exchange your pen now."
5	5	10	Red	
10	10	20	Green	
10	20	30	Blue	
10	30	40	Maroon	
		35		"You have five minutes left"
		40		"Your time is up"

Hand out: Burr/Velcro

Now I'll give you an example of analogy which will be helpful for doing the next task. Consider the example of a Burr and Velcro as shown in the hand out. The design of Velcro is based on an analogy to a Burr. Two strips of Velcro fasten together just like the spines on a burr.

Your next task is to number the ideas and put an X next to the ones that don't use any of the given products as analogies.

Let me know when you are done.

Once they are done, take back the pen.

<u>List of Features Mapped</u>

Water Dumbbell/Punching bag/ Air Mattress

Sheet with product numbers and names

Pen: Brown

The following example will help you in the next task:

Consider an air mattress. Various solutions are obtained based on this analogy taking into account its different features. Beginning from the top, the punching bag filled with water uses the inflate/deflate feature of the air mattress. The Water dumbbell is a collapsible weight. It is filled with water and emptied and stored when not in use. It uses the inflate/deflate and easy storage features from the air mattress. The body suit filled with water and punching bag filled with sand also use the inflate/deflate feature. So, looking at these solutions and features we can state the high level principle as:

- **Use of a substance available at the place where the device is to be used to make it functional.**

Your next task will be to list the name of the product you used to generate each of your ideas, and what feature of the product you used. Also, label the features on the sketch.

If you did not use one of the given products to generate your idea, please state that on your sheet.

The following area a few examples of product features:

Geometry/Shape, function, material, physical principles like friction, adhesion, Van Der Waals Force, energy, etc.

You'll have five minutes for this activity.

Are there any questions before we begin?

Answer questions if any. (<u>Record the questions and answers</u>)

You may begin now.

Start the stop watch. Stop when done.

<u>Product Separation</u>

From the set of products in front of you, please separate out the products that you used for generating ideas and place them on the right side of the table.

Break

You will now have a 5 minute break. The restrooms are there (point in direction), and a water fountain is around the corner from them. Please be back on time.

<u>Products Feature Listing Task</u>

Keep products that they used for idea generation separate and other products as earlier.

Pen: Violet

Idea Generation Sheet

Sheets for feature listing

The given sheets have a name and picture of the product and two columns for features not used and features used. For the products on the right side of the table, list the product features you used to generate ideas. Also, list five product features that you did not use. Please list and describe the features in words or sketches, and label the features on the picture of the product.

You will have 10 minutes for this activity.

Are there any questions before we begin?

Answer questions if any. (Record questions and answers)

You may begin now.

Start stop watch. Time the activity. Stop when done.

<u>Similarity Rating Task</u>

Give back sheets of paper from idea generation task (list of features mapped)
Sheet with product numbers and names
Sheet for similarity rating
Pen: Strawberry

Your next task is to compare each of the ideas you generated with each product and rate their similarity on a scale of 1-9, 1 indicating low similarity and 9 indicating high similarity. Please compare the ideas and products and rate their similarity in the respective columns on the given sheet and leave the unused boxes empty.

You'll have 5 minutes for this task

Are there any questions before we begin?

Answer questions if any. (Record the questions and answers)

You may begin now.

Start the stopwatch. Stop when done.

Similarity rating sheet (new)
Product feature listing sheets
Idea generation sheets
Pen: Red(sk)

The next task is to do a similarity rating on a scale of 1-9 between the list of features not used during idea generation and the features used, 1 indicating low similarity and 9 indicating high similarity.

Please compare the features not used with the features used and rate their similarity in the respective columns on the given sheet. Leave unused boxes empty. For example, you have to compare A-1, A-2, and so on……and B-1, B-2, and so on.

You'll have five minutes for this task.

Are there any questions before we begin?

Answer questions if any. (Record questions and answers)

You may begin now.

Start the stopwatch. Stop when done.

Idea generation sheets

High level principle listing task

Pen: Pink (sk)

1. **Some of the products share one principle in common which solves the design problem. Please list the principle or principles, and then draw a star on the ideas that use it. You'll have five minutes for this activity.**

   Are there any questions?

   Answer questions if any. (Record questions and answers)

   You may begin now.

   Time the activity. Once they are done stop the watch and collect the sheets.

2. **Now, you are given a print out with pictures of only some of the products. All these products share the same high level principle that can be used to solve the "door pin lock problem" given earlier in the experiment. Please list the principle that these products share in common on the page in front of you. Draw a circle on the ideas that used this principle.**

Idea generation
Design problem
Pen: Light Blue

Now, generate ideas based on the design principle or principles you have written down. The design problem is the same as before. Again, sketch and use words to describe your ideas, using one sheet per idea.

You will have 10 minutes for this activity. I'll give you a warning 5 minutes before the time is up.

Are there any questions before we begin?

Answer questions if any. (Record the questions and answers)

You may begin now.

Start the stop watch.

After 5 minutes

Pen: Orange

Time for next five minutes.

Stop stopwatch.

Your time is up now.

Collect the sheets.

<u>Survey</u>

Pen: Blue

Please fill out the survey.

Collect survey.

<u>Disbursement</u>

Thank you for your participation. Again, please do not talk about the experiment to anybody in the TAMU Engineering Departments until after Dec 31, 2010, as it will bias the results. You may choose to receive either the cash payment or the class credit, but not both.

CASH: Hand out payment slips, $20. Please fill in your name and UIN. In order to receive the cash please see Michelle Mitchell in the ME office, as stated on the voucher. Do you have any questions?

Extra Credit: Write name and class affiliation down. Do not write date or experiment number down.

Ok, you'll receive the extra credit.

Analogies and Noise – Survey

Survey Questions

Question	**Strongly Disagree**	**Disagree**	**Neither Agree nor Disagree**	**Agree**	**Strongly Agree**
I used the given products to generate solutions.					
The given products were useful to create solutions.					
I found the similarity rating task hard.					

1) What is your sex?
   a. Female
   b. Male

2) What is your age? _______________

3) Overall GPA ________________

4) GPA in Major ________________

5) Year in School
   Undergraduate:
   Freshman
   Sophomore
   Junior
   Senior
   Graduate:
   1st year
   2nd
   3rd
   4th
   5th or more
6) Country where your undergraduate university is located ______________________

7) Do you have engineering industrial experience (Not class projects or a Research assistantship), working **full-time** (including internships, co-ops)?
    a. Yes.
    b. No.

    ______________ Months ______________Years

8) Do you have engineering industrial experience (Not class projects or Research Assistantship), working **part-time**?
    a. Yes.
    b. No.

    ______________ Hrs/Week ______________ Months ______________ Years

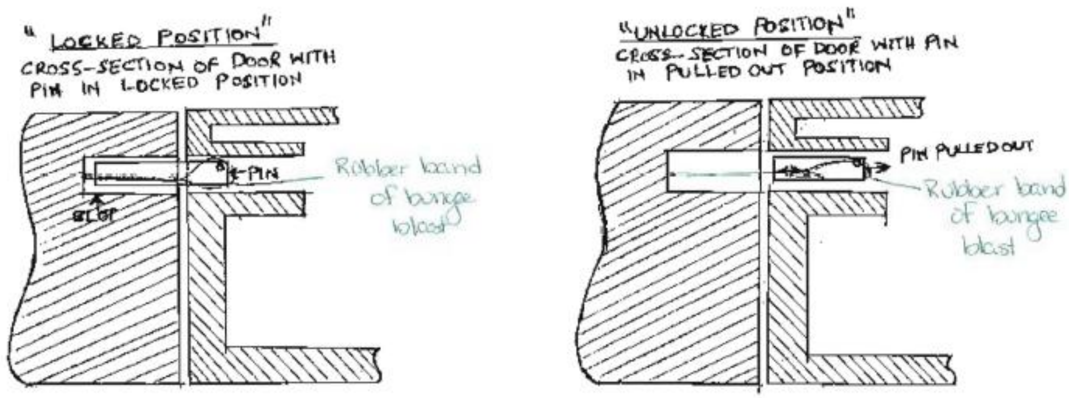
9) Had you heard about this experiment before coming to the study today? (Your answer does not affect your compensation in any way)
    a. No.
    b. Yes, but I did not know many details.
    c. Yes, and I had thought about potential solutions before coming to this study.

10) Had you heard about the design problem before coming to the study today? (Your answer does not affect your compensation in any way)
    a. No.
    b. Yes, but I did not know many details.
    c. Yes, and I had thought about potential solutions before coming to this study.

Please state any additional comments you have about the experiment. Use the back of the paper if needed.

Analogies and Noise – Sample Solution

Elastic Strain 2



1) Rubber band of bungee blast is attached to end of slot by staple?
2) Elastic energy stored in stretched band as pin is pulled out
3) when pin is released, elastic strain energy is released, forcing pin to return to original position

Analogies and Noise – Listing of High Level Principle (Stage I)

Analogs	Noise	Stage I	Stage II	High level principle (Yes/ no)
1	0	Elastic deformation. Once the forces are released {unreadable} they want to return to original shape	NA	1
		Automatic Retractability		0
		LightWeight, Elasticity, Latch,spring		1
		I used the torsional spring to solve the design product		0
		The wrapped coil spring that retracts the lid when latch is released		0
		The spring opens the case; The plastic being bent within to lock the door in; The arm that holds the face down.		0
		Uses a spring to translate to mechanical motion.		1
2	0	The principle of a spring-like or bungee mechanism which can retract easily.	?	1
		Elasticity	?	1
		Application of pressure via stored elastic energy	Application of pressure via stored elastic energy. (Same as before because these two productsa re the only ones given.)	1
		Elasticity	Elasticity	1
		A restoring force that causes compression or tension	A restoring force that causes compression or tension	1
		A reactive force that forces the pin back to locked position	A reaction force that causes it to go back to the same position	1
		All/most of the designs have or cause a force that resists the outward (unlocking) movement of the pin and tries to return it to it's initial position.	Principle: The object will resist movement and sotre the energy from the movement. The [spring/rubber band] item will then use the sotred energy to return the object to it's initial condition or placement.	1
		The locked position is equilibrium and the unlocked position removes the pin from equilibrium. Once the additional force of the person touching the pin is removed the pin returns to equilibrium and is in the lock position.	Remove from and return to equilibrium	1
		Elasticity -> The ability to flex and return to the originial shape	Elasticity -> The ability to flex and return to the originial shape	1
		Elasticity (bungee blast)	-> Ability to return to original shape when force is not applied	1
		Retracts back to original position when force is removed	Retracts back to original position when force is removed	1
		Elasticity, elastic deformation, store energy (potential energy), light weight, provide force, adhesion	elasticity, elastic defomration, stores energy, lightweight, provide force	1
		applying a force when loaded in tension	applying a force when loaded in tension	1
		Light weight	light weight	0

Analogs	Noise	Stage I	Stage II	High level principle (Yes/ no)
3	0	Uses main component from either: *Compression spring *Bungee blast *Constant force spring To force pin to locked position	Uses a type of force to move pin	0
		The ability to store potential energy. (and to convert it into kinetic energy). F=ma also. F=kx	Same, see previous page. They all use conservation of energy converting PE to KE.	1
		All products have a material that has a k constant, in other words can go through a lot of elastic deformation before their plastic deformation limit is reached. They can be stretched and compressed and still returen to normal shape and size.	Same principle as previous questions: springs!	1
		All products start at equilibrium, they encounter a force or change and try to return to equilibrium on their own.	All three products require a force to see a change. All three start in equilibrium, receive a force in put and attempt to return to equilibrium	1
		They have a hook wich uses the velocity of the door closing to stop the hook into place.	Hooke's Law. F=kx	0
		after applying a froce (fighting a coil, stretching a bungee, compressiong a spring) force is a reaction force	after applying a force (fighting a coil, stretching a bungee or compressing a spring) force is a reaction force.	1
		The ability to provide a constant force	still all able to provide a constant force	0
5	0	Ability to hold in locked position	hold lock in "locked position"	0
		Spring force	Spring force	1
		User generated potential energy stored in a material [generally compression (springs) or torsion(bungee)]	Stored potential energy	1
			Pushing/Pulling force	
			Elastic deformation and the materials desire to become neutral one again	
		spring forces, ability to return to natural state before they were deformed, ability to induce mostion from stored energy, ability to be reused, purely mechanical devices	ability to induce motion from stored energy	1
		They store energy by a means other than kinetic or gravitational potential energy	storage of strain energy	1

Analogs	Noise	Stage I	Stage II	High level principle (Yes/ no)
1	3	1. Most of the products contained sticky notes. The stickiness of the note can be used. 2. The products open as a traditional door. Two of the products contained latch mechanisms.	The same 3 as above can be used to solve the problem. The friction that is exibited by the rubber grips can be used. The torsional springs can be used. The internal workings of lid can be used. The form in which the lid opens can be used. The material of the lid can be used.	0
		They are all meant to be convienent for the user These are all meant to help the user organize their things They help compact items & make more useable/ease of use	All principles above can be used The concept was used in several of my designs In addition, the sticky note hoder uses some sort of mechanism that is "ready to spring" once the latch is hit/released.	0
		Elastic Energy	Stores Energy	1
		They all hold or contain cards or sticky notes	Energy release	0
		All of the products seem to use a valve where energy can be put in its place with some kind of adhesion by either a mechanical clip or some kind of sticky substance. And all of the products be to be manually operated meaning that it is used with the hands. Also, all the ideas have the principle that once somthing is put inside it, it is not coming out during use unless manually done so.	similar to that on the other sheet, this uses user interaction along with a mechanical spring system or movement system to open a volume for things to be stored it. This same system that works off of a rotary motion principle as the be used to close it. It also has a clipping mechanism that is used to hold it shut and let the user know it is closed. Once something is in, it is not getting out.	0
		Transfering force	the post it notes	0
		Use potential energy to trasnlate to kinetic energy and cause movement to occur.	Translate PE to a KE that drives motion in the part.	1
		I don’t know, they are all found in an office area?	spring, compression	0
		Sticky notes adhere to things… so any solution using adhesion shares this principle "stickiness" is a "pull" force, so magnetism would also share this trait The products did not (at least conciously) affect my solutions in any way. I am confident that without their presence I would have arrived at the same results.	This product uses a "spring" however this is a result that was already given. The principle upon which a spring works is elastic deformation to generate a "push force". There fore any idea that uses elastic defomration to give a "push" shares this trait.	0

Analogs	Noise	Stage I	Stage II	High level principle (Yes/ no)
2	6	One priniciple that many of the products share is the ability to be elastically strained and release that strain energy	The principle is the ability to be strained, store, and then release the energy.	1
		Convert Energy	Store energy	1
		Energy Storage	Energy Storage	1
		Use of different materials with various properties to achieve the same results	Energy transformation during deformation. They store energy when deformed.	0
		All products have some means of springing either by shape retainability or sticky resisting coming apart. There is something in tension in all products.	They both will provide a force through a spring (coil spring or rubber band)	1
		Most of the ideas have the idea of a locking feature (from geometry) that has the pin moved into a position whre it cannot easily go back to its original position.	They both have the ability to deform and then naturally return to their natural position.	0
		Most products used have a spring-like behavior	Both products have a tensional spring characteristic	1
3	9	Many of these products contain objects that behave elastically, or similar to that of a spring	The products all share elastic characteristics	1
		The ability to store potential energy.	[The products have] a spring that can be used to push the pin back into the locked position.	1
		Mechanical motion & functionality of product	Motion: extend collapse to allow for lock/unlock.	0
		Shape Memory	Shape Memory	1
		Material Properties - Elasticity (Able to return to original shape)	Elasticity (Able to return to original shape)	1
		Spring-loaded affect	They all use the effect of spring loaded	1
		*Spring force *Elastic Force *Rotation	Elastic Energy, potential energy, spring constant	1

Analogs	Noise	Stage I	Stage II	High level principle (Yes/ no)
5	15	Material properties (ie magnetic) rotating constant force chemical	Mechanic (OM) Material (Om) Spring (Os)	0
		1. Spring Like feature 2. Pressure (force exerted) 3. Elasticity	* Elasticity *Spring constant	1
		Material experiences high elastic deformation; metallic objects are often magnetic	High Elasticity: They have a large elastic deformation	1
		Pressure Change	Elasticity	0
		Spring like motion	All products can be configured to store potential energy	1
		Screw	Restoring force (such as what a spring does)	0
		Compressibility/springy/elastic tackyness/stickyness/adhesion	All thes products use springs or equivalent	1
0	15	Compressable substance to apply force	NA	1
		Metal wire arranged in a some what helical fashion When squeezed, return to the original shape	NA	1
		gravity	NA	0
		spring like	they are all flexible, but return to their normal state (spring like)	1
		A spring and a clamp could be important in solving the problem.	flexibility	1
		None listed		0
		The burner coil and immersion heater both use electrical energy to get out heat. Heat can change things and may cause a force at times. The business card holder encloses something the lets you see it when you want and plus it is slightly mechanical. flour sifter is mechanical. The flour sifter, tea strainer, and egg yolk separater all separate substances from each other. This idea can be used to separate or bring together something that will in turn cause a force.	[all but whisk] separating something. This may help in realizing that separating a substance then releasing it may cause a force that will move the pin.	0
			For the whisk, pen holder, noodle, yolk separator	

Distant Domains – Experiment Script

<u>Consent</u>

- Keep two copies of consent forms on table
- Black pen
- Keep design problem, blank paper, and analogue pictures on the top right corner.

Good Morning/Afternoon. You can put your backpack close to the wall and please turn off or silence your cell phones. You are being asked to participate in a research study on engineering design. Please read the consent form in front of you. You are not required to participate in this study and may end your participation at any time.

You will be asked to generate ideas for a given design problem and to complete a five minute survey at the end of the experiment. The study will require approximately two hours. Does anyone have any questions?

Allow participants to read the form, at least three minutes. Answer all questions the participants ask. Wait until all participants have finished reading before proceeding. Then say,

If you agree to participate please sign the consent form and keep a copy for your records.

I have one request before we begin: Please do not discuss the experiment with anybody in the Engineering Departments at TAMU until after May 31, 2011. If a participant knows what the design problem is or what the tasks are ahead of time it will bias the results

Sign the consent forms and take them. If wished, sign copies for records.

<u>Design Problem: Peanut Sheller</u>

Your first task is to generate as many solutions as possible for a design problem. A printout is available below the stack of paper on top right corner of the table. Please flip the stack over and follow along as I read.

In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal is to build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the peanut farmers. The target output is approximately 50kg (110 lb) per hour.

Customer Needs:

- **Must remove the shell with minimal damage to the peanuts**
- **Electrical outlets are not available as a power source**
- **A large amount of peanuts must be quickly shelled**
- **Low cost and easy to manufacture**

Functions:

- **Import energy to the system**
- **Break peanut shell**
- **Separate peanut shell form the nut**

To help you in your design, you have a sheet with pictures of helpful analogies:

I'll briefly describe and demonstrate each analogue.

Show videos/animations

Nutcrackers

1. **Slim nutcracker**
2. **Twist nutcracker**
3. **Lever nutcracker**
4. **Hand press nutcracker**
5. **Rotating nutcracker**
6. **Screw nutcracker**

You may adapt or combine features from these analogues to generate new solutions, or create completely new designs. Generate as many solutions as possible for the given design problem. Use the blank sheets to describe your solutions in words or sketches, using one sheet per solution. Remember that you are not limited by the given analogues.

You will have 40 minutes for this activity and I'll give you a warning 5 min before the time is up. We will be using different colors of pen to keep track of when the solutions are generated and I'll exchange your pen at regular intervals of time.

Are there any questions?

Answer questions if any. (Record the questions and answers)

You may begin now.

Start the stop watch

Total	Start	End	Pen	
5	0	5	Black	**"Five minutes are over. I'll exchange your pen now."**
5	5	10	Red	
10	10	20	Green	
10	20	30	Blue	
10	30	40	Maroon	
		35		**"You have five minutes left"**
		40		**"Your time is up"**

Red Sharpie

If you used one of the example analogues for your designs, draw a check mark on it.

Hand out: Burr/Velcro

Pen: Red Sharpie

Your next task is to number each of your solutions and put check mark on those which were based on one of the given analogues.

As an example of an analogy, consider the example of a Burr and Velcro. The design of Velcro was based on an analogy to a Burr. Two strips of Velcro fasten together just like the spines on a burr.

Let me know when you are done.

<u>List of Features Mapped</u>

Sheet with instructions 1

Pen: Brown

For those ideas which were based off of an analogue, list the name of the analogue and which of its features you used. Also, label the features on the idea sketch.

The following area a few examples of features:

Geometry/Shape, material, friction, elasticity, etc.

You'll have five minutes for this activity.

Are there any questions?

Answer questions if any. (<u>Record the questions and answers</u>)

You may begin now.

Start the stop watch. Stop when done.

<u>Break</u>

You will now have a 5 min break. The restrooms are right there (point in direction)**, and a water fountain is around the corner. Please be back on time."**

<u>Products Feature Listing Task</u>

Keep products that they used for idea generation separate and other products as earlier.

Pen: Violet

Idea Generation Sheet

Sheets for feature listing

The given sheets have a name and picture of the analogue and two columns for features not used and features used. For each analogue, list the features you did and did not use to generate ideas. You may use words or sketches.

You will have 10 minutes for this activity.

Are there any questions?

Answer questions if any. (Record questions and answers)

You may begin now.

Start stop watch. Time the activity. Stop when done.

<u>Similarity Rating Task</u>

Sheet for similarity rating

Pen: Strawberry

Your next task is to compare each of the ideas you generated with each analogue and rate their similarity on a scale of 1-9, 1 indicating low similarity and 9 indicating high similarity. Please compare the ideas and analogues and rate their similarity in the respective columns on the given sheet.

You'll have 5 minutes for this task

Are there any question?

Answer questions if any. (Record the questions and answers)

You may begin now.

Start the stopwatch. Stop when done.

Once they are done, stop the watch.

<u>Survey</u>

Pen: Blue

Please fill out the survey.

<u>Interview (Pilots only)</u>

"I'll ask you now some questions about your experience. This interview will take about 5 minutes."

1. What do you think about the experiment?
2. Was the design problem clearly stated?

<u>Disbursement</u>

Thank you very much for your participation in the experiment.

CASH: <u>Hand out payment slips, $20.</u> **Please fill in your name and UIN. In order to receive the cash, please see Michelle Mitchell in the ME office, as stated on the voucher. Do you have any questions?**

EXTRA CREDIT: Write name and class affiliation down. Do not write date or experiment number down. **OK, you'll receive the extra credit**

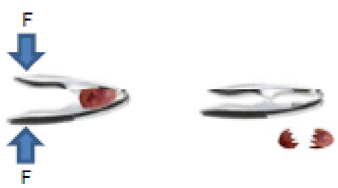
Then, thank you again for your participation. Please do not talk about the experiment to anybody in Mechanical until after May 31, 2011, as it will bias the results. Have a good afternoon/ evening.

Distant Domains – Presentations for Example Analogues

Example
Analogies

Nut Crackers:
Slim Nutcracker

Nut Crackers:
Slim Nutcracker



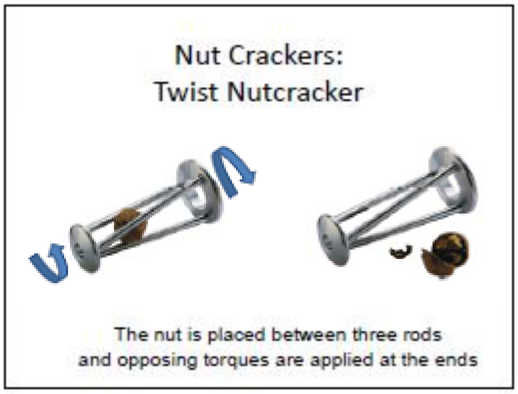
The nut is placed between the two arms
and a force is applied to close them.

Nut Crackers:
Screw Nutcracker

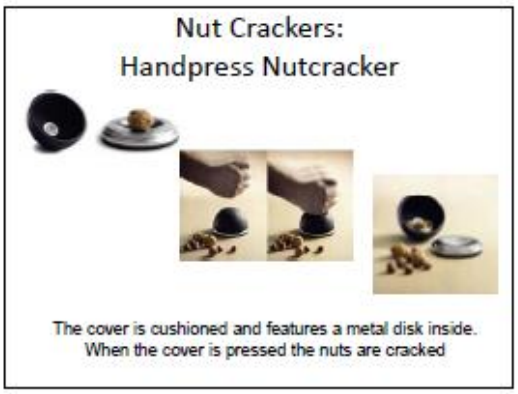
Nut Crackers:
Screw Nutcracker

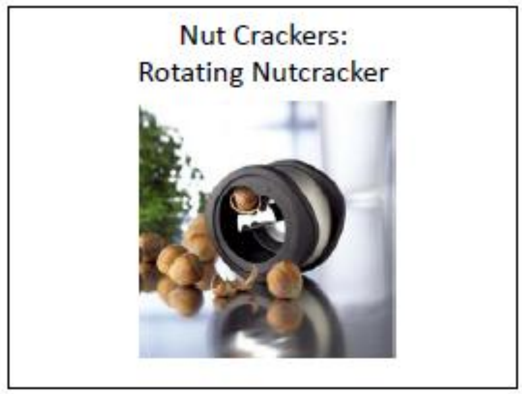
The nut is placed under the screw and a
torque is applied to lower it

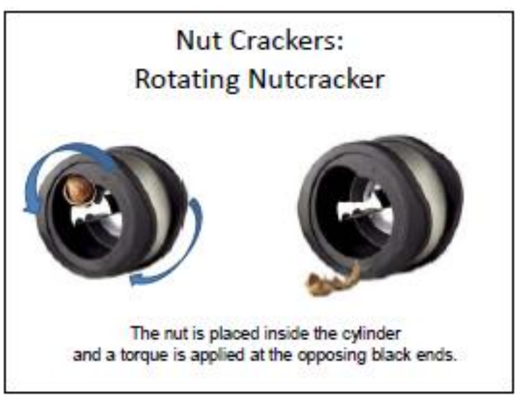
Nut Crackers:
Twist Nutcracker

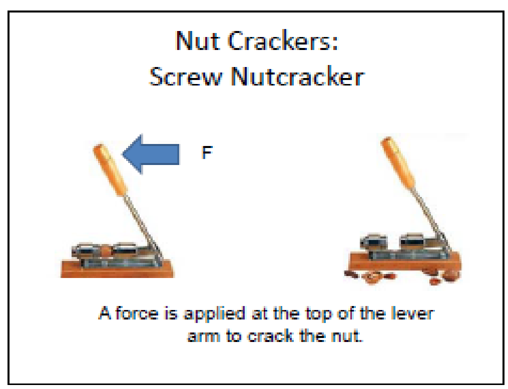

Nut Crackers:
Twist Nutcracker
The nut is placed between three rods
and opposing torques are applied at the ends


Nut Crackers:
Handpress Nutcracker


Nut Crackers:
Handpress Nutcracker
The cover is cushioned and features a metal disk inside.
When the cover is pressed the nuts are cracked


Nut Crackers:
Rotating Nutcracker


Nut Crackers:
Rotating Nutcracker
The nut is placed inside the cylinder
and a torque is applied at the opposing black ends.


Nut Crackers:
Screw Nutcracker
F
A force is applied at the top of the lever
arm to crack the nut.

Nut Crackers: Twist Nutcracker

The nut is placed between three rods and opposing torques are applied at the ends

Peeling Devices: Shrimp Peeler

Peeling Devices: Shrimp Peeler

The shrimp is placed in the top slit and the handle is quickly cranked a quarter turn.

Peeling Devices: Shrimp Peeler

The peeler uses two arms which grip the shrimp.

Peeling Devices: Shrimp Peeler

As the shrimp is moves it encounters a spring loaded blade which slices the shell.

Peeling Devices: Shrimp Peeler

Spring loaded blade

Peeling Devices:
Shrimp Peeler

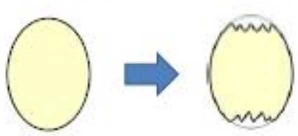
The result is a shrimp whose shell can be easily removed.

Nut Shellers:
Roller Coconut Sheller

Nut Shellers:
Roller Coconut Sheller

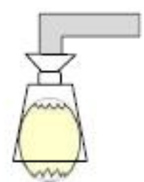
Peeling Devices:
Egg Peeler

Peeling Devices:
Egg Peeler



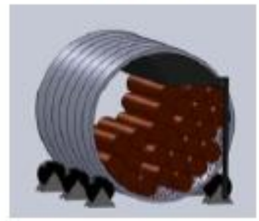
The shell tips are removed by hand

Peeling Devices:
Egg Peeler



The peeler is secured to a water faucet and the semi-peeled egg is placed at the other end.

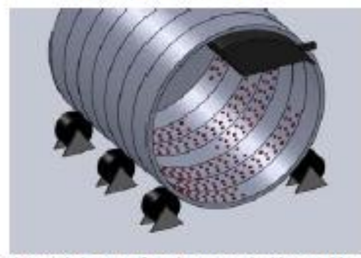
Debarking Tools: Drum Debarker



Debarking Tools: Drum Debarker

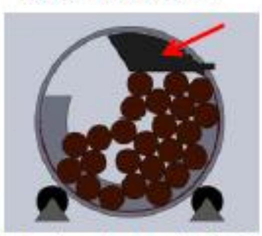
Logs are placed inside a drum.
The drum is rotated by external motors.

Debarking Tools: Drum Debarker



The internal drum surface is covered with metal bumps.

Debarking Tools: Drum Debarker



A stop is placed near the top point of the log travel.
This increases the pressure with which the logs press against the bumps, removing the bark.

Debarking Tools: Home Made Debarker

Debarking Tools: Home Made Debarker

It is composed of two bars of a strong material (wood, metal, etc), and a piece of piano or steel wire.

Debarking Tools: Home Made Debarker

The user grips the two handles, forces the wire slightly into the bark, and pulls along the longitudinal axis of the log.

Debarking Tools: Chainsaw Debarker

Debarking Tools: Chainsaw Debarker

The attachment is secured to a chain saw and is driven by the chain.

Debarking Tools: Chainsaw Debarker

The attachment has an element with sharp protuberances which dig into the bark and remove it.

Depilation Methods: Waxing

Depilation Methods: Waxing

Liquid wax is applied over the skin surface which needs hair removal.

Depilation Methods: Waxing

A cloth or paper strip is placed over the wax before it hardens, and it is quickly removed when solid.

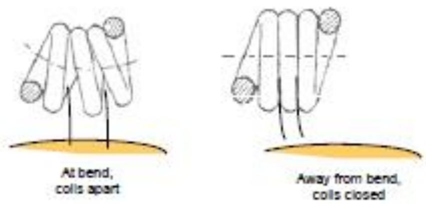
Depilation Methods: Epilators

Depilation Methods: Epilators

The epilator uses a circular coil spring.

At the point of contact with the skin the spring is bent.

Depilation Methods: Epilators



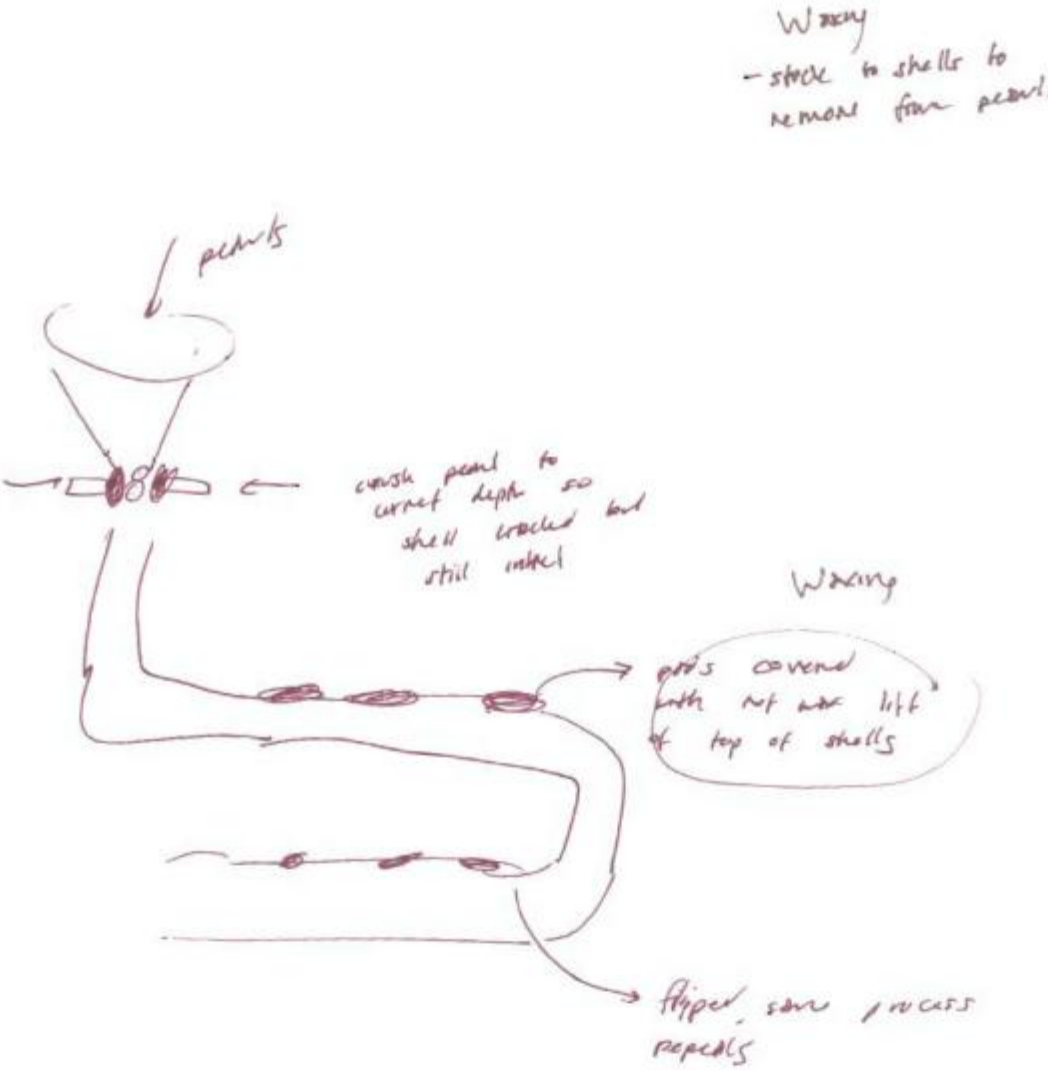
The bend causes the coils to spread apart. As the spring moves away from the bend, the coils close and grip the hair to pluck it.

Depilation Methods: Friction

Depilation Methods: Friction

A fine-particle friction surface is rubbed in a circular motion until the hair is removed.

Distant Domains – Example Solution



VITA

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