EFFECTS OF REPRESENTATIONS IN ENGINEERING IDEA GENERATION PROCESS

A Thesis

by

VIMAL KUMAR CHERICKAL VISWANATHAN

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

December 2010

Major Subject: Mechanical Engineering

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Approved by:

Chair of Committee,	Julie Linsey
Committee Members,	Daniel McAdams
	Steven Smith
Head of Department,	Dennis O'Neal

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ABSTRACT

Effects of Representations in Engineering Idea Generation Process. (December 2010)

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Chair of Advisory Committee: Dr. Julie Linsey

In today's competitive market, it is essential to be innovative and creative for an industry to sustain. Industry need to introduce new products to the market. Engineering idea generation plays a vital role in the development of new products. This research study is focused on the engineering idea generation. The representations of ideas have an important impact on the idea generation process. Design concepts may be represented in a variety of forms like sketches, physical models or computer based models. The goal of this research is to understand how these various representations affect design cognition. In this thesis, three studies showing the effects of two different representations in the idea generation process are presented.

The first study focuses on the effects of physical models in engineers' design cognition. This preliminary study investigates two different hypotheses: (1) Physical models supplement and improve designer's mental models and (2) Physical models induce design fixation. The results show that physical models supplement the designer's mental models but fail to enhance them. No evidence of design fixation is observed.

The second and third studies investigate the effects of computer-based idea generation software on design cognition. The research questions investigated in this

study are: (1) How does the use of this software tool assist design cognition? (2) How can the software interface be improved so that designers can generate ideas more easily? To answer these questions, a between-subjects idea generation experiment is conducted. In the experiment, the participants are asked to generate ideas to solve a design problem with and without the software. The results show that participants who generated ideas with the help of the software tool have less quantity of ideas compared to the control group. This may be due to the design fixation induced by the concepts presented.

In the third study, the opinions of the participants for the improvements of the software interface are collected. Results show that participants do not have any preference of one way of clustering the concepts over the other. The results of this study also provide creative input for the future improvement of the software.

ACKNOWLEDGEMENTS

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I am grateful to all the students who participated in my studies. This would not have been possible without them. I would like to thank Susanna Schmidt, who conducted half of the experiments in the second and third studies presented here. I would like to thank my other lab mates for their support and encouragement. I would also like to thank Texas A&M University and the Department of Mechanical Engineering for giving me an opportunity to be a part of it.

Thanks also to all my friends and colleagues and the department faculty and staff for making my time at Texas A&M University a great experience.

Finally, I would like to thank my parents and sister for their encouragement and love.

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CHAPTER I

INTRODUCTION: ROLE OF REPRESENTATIONS IN ENGINEERING IDEA GENERATION

Innovation and creativity are highly sought after skills in the engineering design process. Still there exists no formal method to support these. These are viewed to be very complex skills which are obtained through the past experiences of the designer. In the current market scenario, designers need to be highly innovative and creative to be successful in their career. Industry needs to introduce new products to the market to capture customer attraction. Hence it is not practical to be completely dependent on designers' experience alone for innovative and creative ideas. Designers also need improved tools and methods for enhancing idea generation. We need to investigate methods to spur creativity and innovation in a designer. Physical models and computer-aided tools are possible support tools. This thesis investigates the effects of these tools on designers' cognition.

Physical Models in Idea Generation Process

A physical model is the representation of a product that is built using various materials and it approximates certain aspects of the product (Otto & Wood, 2001). Physical models range from very rough mock-ups to completely accurate, fully functional

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This thesis follows the style of *Artificial Intelligence for Engineering, Design, Analysis and Manufacturing*.

prototypes. They provide a three-dimensional realization of the idea to the designers, which leads them to identify the possible avenues of innovation and improvement (Otto & Wood, 2001). In industry, physical representations are implemented throughout the process and they assist designers with evaluating and improving their ideas. Figure 1 shows the various stages of physical models used in the development of OJex Manual Citrus Juicer. Physical models are widely implemented in the development of complex structures like a space shuttle. For example, Figure 2 shows a set of physical models built by NASA for a lunar lander project. A survey of engineers also supports the fact that physical models are widely implemented as tools for the engineering design process (Römer et al., 2001).

Unfortunately, there is little guidance available for a designer on when to use particular types of physical representations and when their use will be beneficial for the idea generation process. Empirical and anecdotal evidence provide very conflicting views and guidelines for the use of physical representations.   The frequent use of physical models is advised by Tom Kelly of the very successful product design firm, IDEO (Kelley & Littman, 2001). Baxter warns that the designer should think carefully before building prototypes as it can be a waste of time and money (Baxter, 1996). Cost and the cycle time are two major factors driving the development of physical models (Otto & Wood, 2001). Christensen and Schunn, in their observational studies on designers point out the fixation aspect of physical modeling (Christensen & Schunn, 2007; Christensen & Schunn, 2008), which is another matter of concern. In light of these conflicting recommendations, it is of interest to identify when to implement physical models as an aid for idea generation.

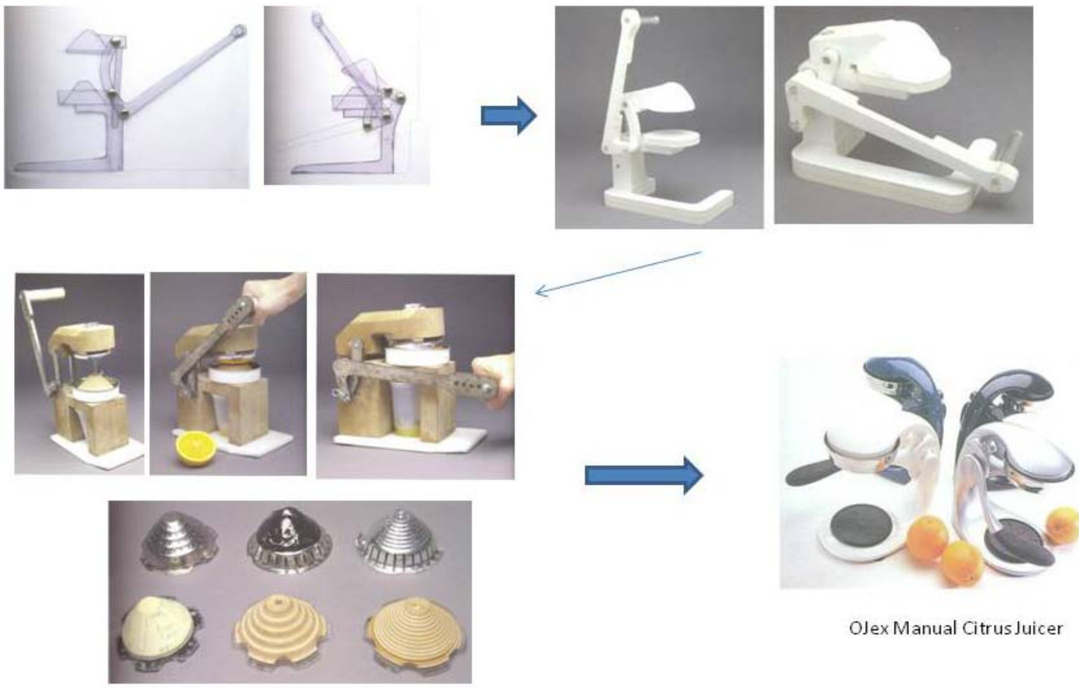

Figure 1 Various physical models ranging from 2-d motion studies to fully functional prototypes are employed in the development of OJex Manual Citrus Juicer (IDSA, 2003)

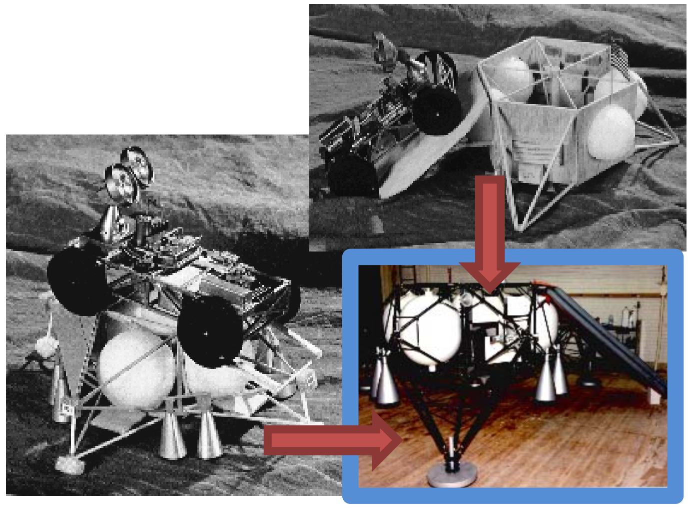

Figure 2 A set of Styrofoam and wood physical models built by NASA during the early phases of designing the next lunar lander (NASA, 1993)

The first experiment described in this thesis seeks to evaluate two hypotheses: (1) Fixation Hypothesis- Physical models cause design fixation. (2) Mental Models Hypothesis- Physical models supplement and improve designer's mental models. To explore these hypotheses, a between-subjects experiment is conducted. The background section in Chapter II describes the motivation for this study and the related prior work. In the Chapter III, the experimental approach is described in detail with the metrics and analysis. The results are evaluated and conclusions are drawn.

Information Technology in Idea Generation Process

Advances in Information Technology (IT) have enabled us to do things more quickly and efficiently. Most streams in science and technology make use of the enormous capabilities of IT for their benefit. Engineering design is a field which has not utilized the power of IT to the maximum possible extent. The possibility of creativity tools for engineering design powered by IT has not been given a serious thought until recently. With the availability of design repositories, functional modeling tools and visualization tools, the concept of an IT-enabled platform to support designers' cognition process took its birth. Visualize IT is such a platform that presents designers with a number of ideas based on design repositories, which will help the designers think outside the box and come up with novel solutions to design problems. This platform is developed as a result of the combined efforts of the researchers at Oregon State University, University of Texas at Austin (Bryant et al., 2005a; Bryant et al., 2005b), Penn State University, Virginia Tech, University of Buffalo, Bucknell University and Texas A&M University (Shooter et al., 2005).

Since this is an early attempt to implement IT enabled tools for creativity and innovation, its effect on design cognition remains largely unknown. The second and third experiments detailed in this thesis deal with this issue. Experiment 2 tests whether the Visualize IT software can support designers' creativity, while Experiment 3 tries to derive guidance from the users on how to improve the interface of the software.

CHAPTER II

BACKGROUND

This chapter discusses relevant prior work in the field of physical models and computer-aided tools in the engineering idea generation process. The various technical terminologies are explained and background information required is presented.

Physical Models in Idea Generation Process

Physical models are widely implemented as tools for idea generation in the early stages of the design process. “A prototype is a simple, incomplete model or mockup of design which provides the designer insight into the real world design requirements” (Lidwell et al., 2003). Prototypes are very useful to simulate the actual idea without investing a lot of time and money into the final production (Houde & Hill, 1997). Their use is highly encouraged in industry, but we know very little about how they help us to solve design problems (Brereton & McGarry, 2000).

Despite physical models being very popular in the engineering idea generation process, there are many conflicting findings about their use. Romer, *et al.* hypothesize, from survey results on product representations, that physical models provide memory relief (Römer et al., 2001). Ward et al. (Ward et al., 1995) in an observational study done at the Japanese automobile company Toyota, describe the use of physical models in Toyota and how it helped them to save work later. On the other hand, Vidal et al. (Vidal et al., 2004) found no difference between idea generation with or without the use of physical models. Christensen and Schunn found evidence for fixation and warned about the high degree of fixation caused by physical models (Christensen & Schunn, 2007; Christensen & Schunn, 2008). Consistent with this, Yang found that students who generate ideas with less detailed prototypes produce a higher quality final product (Yang, 2005). Houde and Hill mention that choosing the right kind of prototype for communicating the various aspects of the idea to the different audiences is an art which requires careful attention (Houde & Hill, 1997).

Another important aspect of physical models in the idea generation process is their role as boundary objects. The concept of boundary objects was introduced by Star (Star, 1990). They are described as objects shared across the boundaries of different problem solving contexts. Carlile (Carlile, 2002) explains the role of boundary objects in easing the communication between designers in a new product development process. Engineering drawings are widely accepted boundary objects in new product development (Henderson, 1991). Physical representations are also strong candidates for good boundary objects. They allow ideas in a designer's mind to be represented, learned and communicated in a group idea generation process and thereby act as potential boundary objects (Carlile, 2002). They provide concrete means to identify the differences and commonalities in their designs.

Mental Models and Naïve Physics

The area of mental models and Naïve Physics seeks to understand how people mentally understand and represent the physical world around them (Gentner & Stevens, 1983). Mental models are naturally evolving and usually incomplete (Gentner & Stevens, 1983). Studies in this area have some important implications for engineering design. An interesting study by Kempton (Kempton, 1986) shows how people's mental models about home heat control can be inaccurate and this leads them to use it inefficiently and waste resources. Many people believe home heat thermostat operates like a car's accelerator, the higher the setting, the faster the house heats. Similar observations of inaccurate mental models have been made on highly trained scientists (Hutchins & Lintern, 1996).

If designers' mental models are inaccurate, their erroneous perception of the physical behavior of the device will lead to reduced number of functional ideas. The role of physical representations in supplementing and improving these inaccurate mental models is yet to be uncovered. The study presented in Chapter III is a preliminary attempt towards this direction.

Design Fixation

"Design fixation refers to blind, sometimes counterproductive, adherence to a limited set of ideas in the design process" (Jansson & Smith, 1991). Many studies in psychology show the constraining effects of presented examples and initial ideas on the idea generation process. This constraining effect is termed as design fixation. Previous works in the field of design fixation show that the designer's ability to come up with novel solutions is adversely affected by the introduction of pictorial examples of existing solutions to the problem (Cardoso & Badke-Schaub 2009; Cardoso, Badke.-Schaub & Luz 2009; Chrysikou & Weisberg, 2005; Jansson & Smith, 1991; Marsh et al., 1996;

Purcell et al., 1993; Smith et al., 1993). The observational studies done by Christensen and Schunn (Christensen & Schunn, 2007; Christensen & Schunn, 2008), show that the introduction of physical models in the idea generation process likely introduce a high degree of fixation. There are very few changes made to the idea after the introduction of the physical prototype.

Previous studies have explored two different kinds of fixation. Maier (Maier, 1931) described a type of fixation called "functional fixedness" in which the user cannot perceive any non-typical use of a device. Another type of fixation as explored by Luchins and Luchins (Luchins & Luchins, 1959), is called "mental set" in which the designer is unable to think of any new strategy to solve a given problem deviating from the well-known strategy.

Experiment 1 presented in this thesis investigates the effects of physical models in the designer cognition. This experiment studies how physical models help to supplement or improve designers' mental models and how they may cause design fixation. The hypotheses studied and the methods used are described in more detail in subsequent chapters.

Visualize IT: Computer-Based Platform for Idea Generation

During the idea generation process designers knowingly or unknowingly relate their solutions to the solutions they have seen or experienced. This process is widely known as "design by analogy" (Christensen & Schunn, 2007). Analogies inspired by nature have been a large part of this. Designers' ability to come up with novel solutions based on analogies depends to a large extent on the ease with which they can retrieve the related solutions from their memory. This retrieval of analogies is a difficult process, according to psychological literature (Gick & Holyoak, 1980). If designers' local environment provides them enough hints to remind them of these solutions, it may largely help them in the idea generation process (Clark & Chalmers, 1998). The purpose of the computer-based platform described below is to provide such a set of solutions to designers so that they can come up with more creative solutions.

The first step in the development of such a platform was to collect all the possible solutions to design problems and form a repository. This process was initiated by researchers in Oregon State University, University of Texas at Austin and National Institute of Standards and Technology (NIST) (Bohm et al., 2005). Later on Oregon State University expanded this repository in partnership with University of Texas at Austin, Penn State University, Virginia Tech, University of Buffalo, Texas A&M University and Bucknell University. This repository allows designers to store and retrieve their design knowledge.

To retrieve information from this design repository and to create new design concepts, empirical grammar rules (Kurtoglu & Campbell, 2009) were used. These grammar rules were formulated based on the component-function relationships obtained by the dissection of actual products. These rules helped to map functional models of the design problems to component flow diagrams (CFG's), which were the outputs from the software. These CFG's showed the various components in the proposed solution and the material/energy/signal flow between these components. Figure 3 depicts an example of

CFG. These were presented in both text form and graphic form with component pictures as shown in Figure 4. To provide consistency in results, functional basis (Hirtz et al., 2001) and component taxonomy (Kurtoglu et al., 2009) approaches were used.

The grammar rules generated a huge number of concepts for each design problem. Presenting all these concepts to the designers would overwhelm their memory. To avoid this, it was necessary to filter out a few very good ideas. For this purpose, clustering approaches were employed. Cluster analysis grouped available concepts with other similar concepts. Two different algorithms were tried for the clustering. The first one was the K-means approach (Backer, 1995) and the other one was Principal Component Analysis (PCA) (English et al., 2010). For the evaluation purposes, seven clusters with seven concepts each were presented to the users.

The design repositories, grammar rules and clustering approaches combined with the visualization platform led to the Visualize IT software (English et al., 2010). The purpose of this software was to help the designer's creativity, but not to replace it. This software provided designers with a number of possible solutions that would help them to think in diverse directions, and come up with novel solutions to design problems. The preliminary version of this software contained two design problems, whose function structures were preloaded in the platform. The designers were able to select a design problem and its function structure, which gave them 49 conceptual designs in CFG form. A general layout of the working of Visualize IT platform is shown in Figure 5. In an ideal case, the designers would be able to upload their own functional models and obtain solutions corresponding to them. But an evaluation version was used for the experiments explained in the subsequent sections to verify how helpful the software was for the designers.

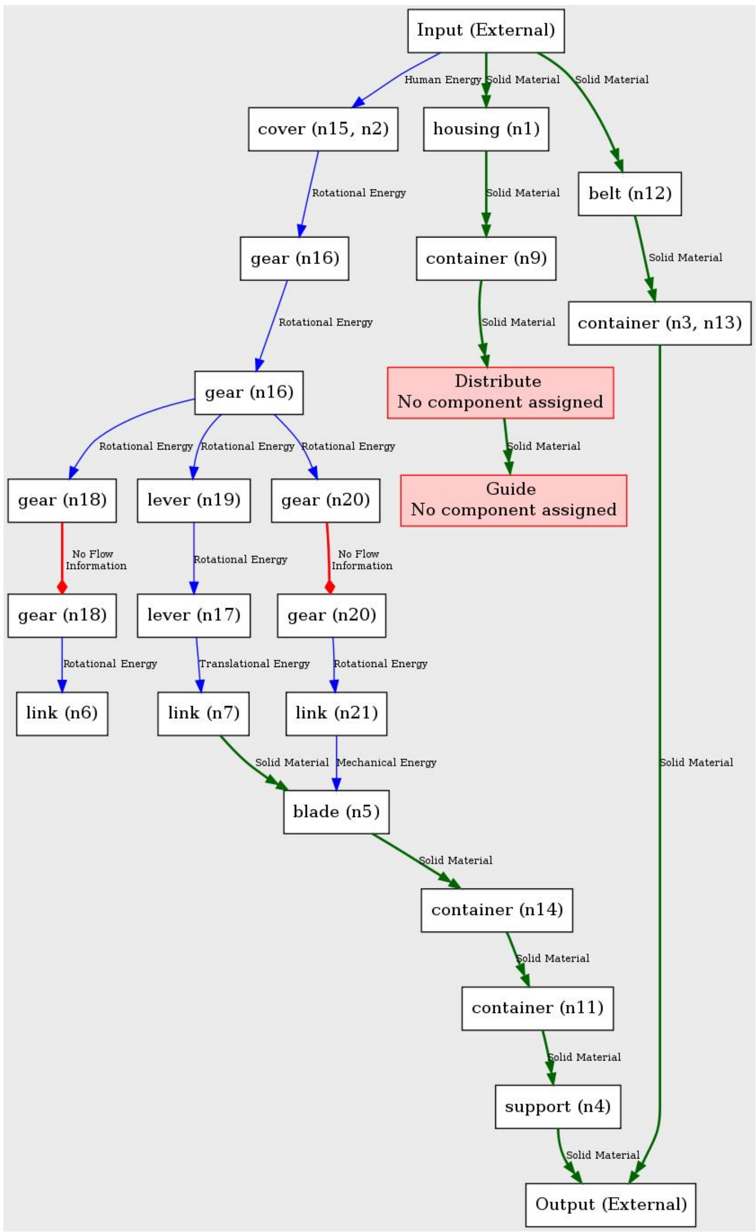

Figure 3 A conceptual solution generated by Visualize IT in the form of CFG for the Peanut Sheller design problem (textual form)

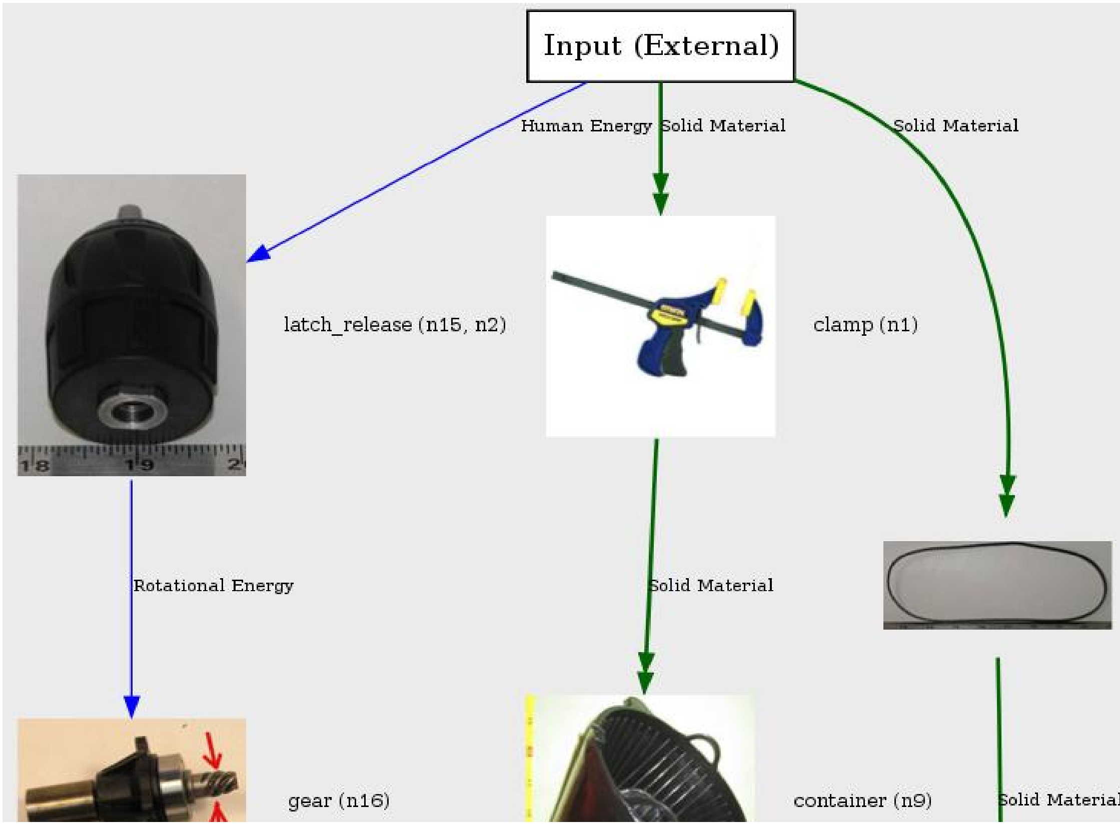

Figure 4 A conceptual solution generated by Visualize IT in the form of CFG for the Peanut Sheller design problem (graphic form)

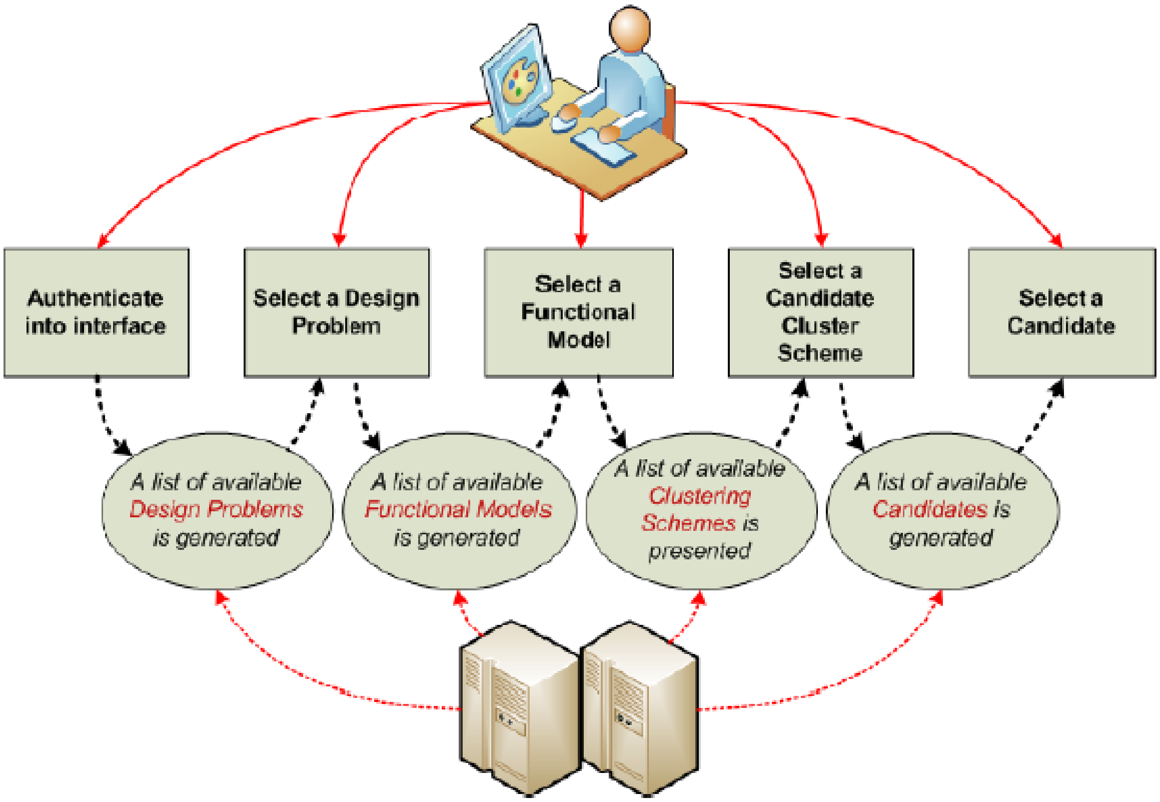

Figure 5 General layout of the working of Visualize IT (English et al., 2010)

The effectiveness of such a software platform to support designers' cognition is largely unknown. Experiment 2 and Experiment 3 described in the subsequent chapters aim to understand this. Experiment 2 is a between-subjects idea generation experiment that tested how effective the idea generation with the help of the software was, as opposed to the one without. The second experiment is mostly a survey, in which participants' opinions about various possible alternatives in the software are evaluated.

CHAPTER III

EXPERIMENT 1 – EFFECTS OF PHYSICAL MODELS IN ENGINEERING IDEA GENERATION

This chapter describes the preliminary experiment conducted to evaluate the possible effects of physical models on designer cognition. The hypotheses studied are presented along with the methodology followed and obtained results.

Hypotheses

Based on the background literature, two hypotheses are formulated and evaluated in this experiment. The hypotheses are given below:

Hypothesis 1: Fixation Hypothesis

Physical models used in the idea generation process cause design fixation.

Hypothesis 2: Mental Models Hypothesis

Physical models supplement and enhance designer's mental models during the idea generation process.

To evaluate these hypotheses, a between-subjects controlled laboratory experiment is conducted, which is described in detail in the subsequent sections of this chapter.

Method

An initial experiment was conducted to understand physical models' effect on the idea generation process. A between-participants experimental design was used with three conditions: sketching only, building and building & testing. In the sketching only condition, participants were allowed to generate ideas using only sketches as the medium of representation, while in the building condition they were given materials to build physical prototypes of their ideas. In the building & testing condition, the participants were allowed to build as well as test their ideas during idea generation process.

According to the first hypothesis, physical models cause design fixation. When designers fixate, they are unable to think of new ideas. Thus, few novel ideas and an overall lower variety of ideas indicates design fixation. Hence a higher level of novelty and variety was expected in the sketching only condition.

Meanwhile, a greater proportion of functional ideas were expected in the building and building & testing conditions, as building highlights flaws in the mental models of designers according to the second hypothesis. The participants were randomly assigned to one of the groups. They were told to generate the maximum number of ideas in three hours. The participants were compensated with payment or extra credit in their design class. All the participants were told that if they showed superior effort, they would receive bonus payment or extra credit. Since this was an initial experiment, this additional compensation was given to all participants.

Design Problem

The experiment presented all the participants with the same design problem. The design problem allowed participants to manufacture prototypes with simple resources including steel wire and simple tools (Figure 6). Also, to measure design fixation, it was preferable for participants to run out of ideas before the time limit so that the total number of ideas generated would indicate design fixation. Thus, the problem was kept simple, yet realistic with a very diverse set of solutions. The participants designed an object made out of steel wire to hold 10 pages of paper. There was a constraint that the paper should not be damaged. The exact design problem is shown in Figure 7. This problem was inspired by the design of the current day paperclips as explained by Petroski (Petroski, 1998). It was observed that the word “hold” created confusion for some participants and they ended up making tray-like devices. After three participants completed the experiment, we replaced “hold” with “bind” to guide the participants toward simple designs like a paperclip and a length constraint of 9” for wire was added. The final design problem used for the experiment is shown in Figure 8. Participants were asked to generate as many solutions as possible for the design problem. They were also instructed to sketch the idea even if it could not be built with the materials provided or if it did not satisfy the constraints of the problem. They were also encouraged to write down non-conventional or technically infeasible ideas.

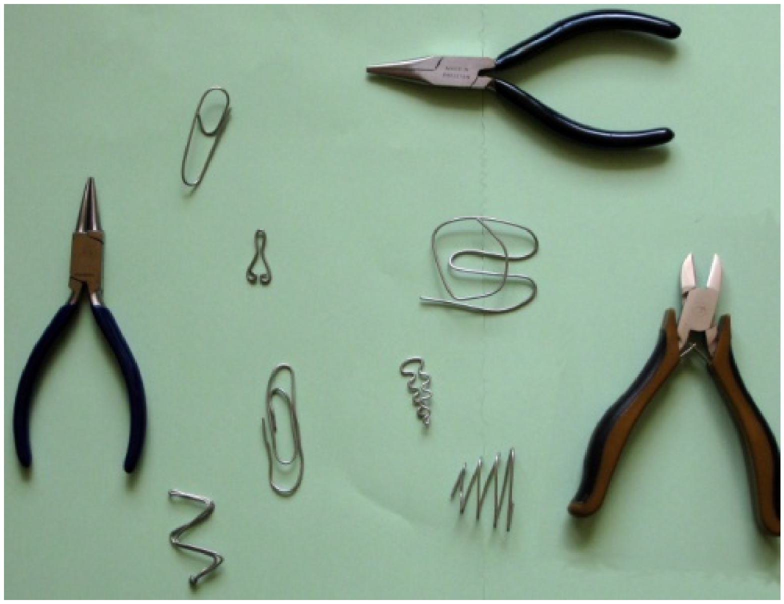

Figure 6 Tools provided to the participants and the sample solutions created by them

Design Problem: Design a mechanism made of only steel wire that secures papers together.

Requirement: The mechanism must securely hold 10 pages of paper together.

Constraint: The papers should not be damaged

- **Generate as many solutions as possible.**
- **Write down everything you can think of even if it does not meet the problem's constraints.**
- **The goal is to generate as many high quality solutions with as great of variety as possible.**
- **Nonconventional, technically infeasible, and far out ideas are also encouraged. This helps to generate unique feasible solutions.**

Figure 7 Initial design problem statement given to participants

Design Problem: Design a small object made of only steel wire of maximum 9" length to bind papers together. **Requirement: The object must securely bind 10 pages of paper together, without any damage to the paper.** • **Generate as many solutions as possible.** • **Write down everything you can think of even if it does not meet the problem's constraints.** • **The goal is to generate as many high quality solutions with as great of variety as possible.** • **Nonconventional, technically infeasible, and far out ideas are also encouraged. This helps to generate unique feasible solutions.**

Figure 8 Modified design problem statement provided to the participants

Participants

The participants for the experiment were mechanical engineering students from Texas A&M University (24 participants, 13 undergraduates and 11 graduate students). The students were recruited through posted flyers and announcement in senior undergraduate design classes. Monetary compensation or extra class credit were provided to them as compensation for doing the experiment. The participants were free to choose to opt out of the experiment if they wanted. The participants were from various cultural backgrounds and they were randomly assigned to various conditions to avoid any bias. The average age of the participants was 23.8 and one of them was a female.

Procedure

The participants generated ideas for the design problem in one of the three conditions (sketching, building, building & testing). The general setup used for this experiment is shown in Figure 9. A major portion of the three hours was spent on the activity suggested by the name of the condition. Due to practical experimental limitations, there was a time limit for each activity, but the participants were told that they could use the entire three hours for idea generation. The time limits for various activities are shown in Table 1. Participants moved on to the next activity either when they chose to or at the end of time limit. If they chose to end the idea generation, they were asked to write down the reason for doing so. Majority of them responded that they ran out of ideas.

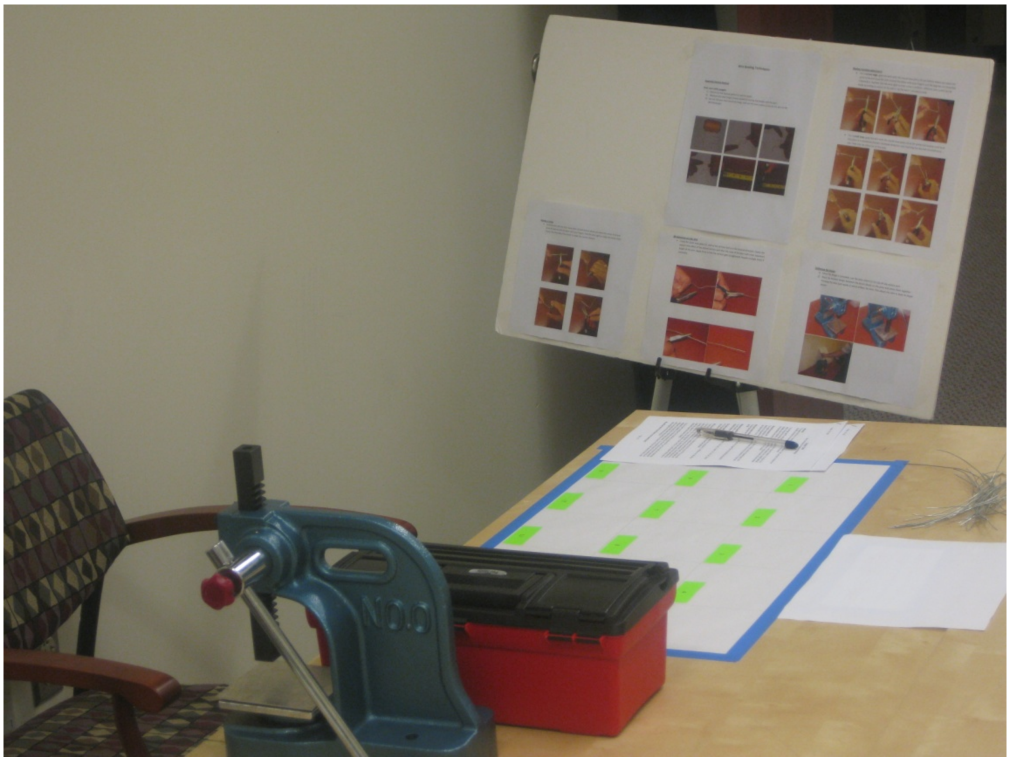

Figure 9 Experimental setup used for Experiment 1

To distinguish between ideas generated at different phases of the experiment, we provided multiple colored pens to the participants. We demonstrated tool usage at the beginning of the building activity. In all conditions, participants tested their design functionality using a stack of paper. The participants also marked all ideas satisfying the problem constraints. Finally in each condition, the participants circled the ideas they remembered seeing before. This was done to determine how much the designers were fixating on familiar paper clip designs. All the conditions ended with a survey. This survey asked the participants about their opinions of activities which helped them to generate the maximum number of solutions to the design problem, helped them to generate highest quality of ideas and ideas that functioned best. The exact questions are listed in the results section of this chapter. They were also asked whether they had heard of the design problem before and whether they ran out of ideas during the experiment. The survey also asked them to fill out some demographic information.

Table 1 Time limits of various activities in Experiment 1

Condition	Activity	Max. time (Hrs: Minutes)
Sketching only	Sketching	1:45
	Building	0:30
	Testing	0:10
	Building & testing additional ideas	Remaining time
Building	Building	2:20
	Testing	0:10
	Building & testing additional ideas	Remaining time
Building & testing	Building & Testing	1:35
	Follow up Sketching	0:35
	Building & testing additional ideas	Remaining time

Sketching Only Group

The participants in this group began by sketching their ideas. If the participant decided to end the idea generation session before the allotted time limit, he/she was asked to give the reasons for ending the idea generation session. They were then provided with materials to build prototypes of their ideas. After they ended this phase, they tested their design's functionality with a stack of paper and they marked the ideas that they could not build using the materials provided.

Upon completion of testing, they were told that most people can continue to generate ideas even after they think they have run out of ideas and then asked to generate more. If the participants did not finish building all their ideas in the available time, they were allowed to take the supplies home, build the prototypes and return them in a week. This was voluntary and more than 80% of participants did this if needed.

Building Group

The procedure for the building group was identical to the sketching group except the experiment began with the simultaneous building and sketching of their ideas.

Building and Testing Group

In this condition, the participants were allowed to build their ideas and test their functionality using a stack of paper in the idea generation process itself. This idea generation with building and testing was followed by a sketching only activity in which the participants were asked to sketch more solutions, without building them. The purpose of this follow-up sketching task was to understand the learning effect of physical prototyping on the designers' mental models. It was expected that their mental models would change and they would continue to create a greater proportion of functional ideas. After completing the sketching only task, they built prototypes of the newly generated ideas. In the next activity, they were again allowed to test those newly built ideas.

Metrics of Evaluation

Three metrics, percentage of functional ideas, novelty and variety were used to evaluate the hypotheses (Nelson et al., 2009; Shah et al., 2003). The first activity in each condition was designed to evaluate hypotheses and the subsequent activities like testing and marking the ideas that satisfied the design problem requirements facilitated the evaluation.

Expert judgment rating scales are a common approach to measuring a wide range of objects and processes in a range of fields including the social sciences, business, and psychology (Tinsley & Weiss, 2000). Rating scales are often employed when a more objective measure is not available. The three metrics used in this study are based on rating scales and criteria. For these types of metrics, their reliability is determined by measuring the inter-rater agreement between two evaluators measuring the data independently. This general procedure of implementing two (or more) evaluators with a defined rating procedure and scale is a common practice (e.g. (Cardoso, Badke.-Schaub & Luz 2009; Chrysikou & Weisberg, 2005; Smith et al., 1993)).

To evaluate the effects of physical models on designers' mental models, the number of functional ideas generated by each participant was counted. A functional idea is an idea that satisfies the entire design problem requirements. The participants were asked to test whether a particular idea was functional or not and mark the functional ideas. One of the authors also checked the functionality of each idea. The average Pearson's correlation between these two evaluations was 0.92, which was high enough, so only the participants' evaluations were considered. Since the amount of time required to build ideas was greater than the time required for sketching ideas and the time allowed for the idea generation in all conditions was not sufficient to exhaust their ideas, the number of functional ideas was normalized to the total number of ideas. The fraction of functional ideas with respect to the total number of ideas was considered as the metric of evaluation for the mental models hypothesis. If the physical models improved the mental models of the designers, a higher fraction of functional ideas was expected in the building and building and testing conditions.

The follow-up sketching activity in the building and testing condition measured changes in the designers' mental models (learning effects). Again, the percentage of functional ideas was used as the metric. This fraction was compared between the idea generation in the building and testing activity and the follow-up sketching activity. If there was a learning effect for the physical modeling, the fraction of functional ideas would have been approximately the same in both the activities.

For evaluating the fixation effects of physical models, novelty and variety metrics were employed (Linsey et al., 2005; Shah et al., 2000). If the physical models induced design fixation, then lower novelty and variety was expected. Another measure of design fixation was the total number of ideas generated but this metric could not be used for this study since more time was required for building and the participants' ideas were not exhausted. If participants had sufficient time to exhaust all their ideas in all conditions then the total number of ideas could be used.

The novelty score for each concept is the number of similar concepts divided by the total number of concepts. This can be measured as one minus the frequency of ideas in a particular bin (Equation 1).

$$\text{Novelty} \quad = 1 - Frequency = 1 - \frac{Number\ of\ ideas\ in\ a\ bin}{total\ number\ of\ ideas} \quad (1)$$

To efficiently measure novelty and variety, the prototypes made by all the participants were sorted by two independent evaluators who were blind to the conditions. They made the bins of similar prototypes for both the physical prototypes and the sketches resulting in two sets of novelty and variety scores. The variety score of a participant is defined as the fraction of the total solution space that the participants' ideas occupy (Shah et al., 2000). Hence in this case it is computed as the ratio of the number of bins that the participants' ideas occupy to the total number of bins.

Two independent raters sorted the prototypes into bins of similar ideas. The sorting was entirely based on their judgment and they were not given any details about the conditions or the purpose of sorting. The first evaluator made 30 bins and the second 19 bins. The Pearson's correlation between the raters was 0.82 for Variety and 0.75 for Novelty, which is acceptable as per the literature (Clark-Carter, 1997).

The novelty and variety metrics were also measured with the conceptual sketches rather than the prototypes. The trends in the results were very similar but Pearson's correlations between evaluators were a little lower than desirable at 0.67 for novelty and 0.63 for variety.

Results

Hypothesis 1-Mental Models: Proportion of Functional Ideas

The proportion of functional ideas shows a difference across the conditions (Figure 10). Since the data are not normally disturbed and the variances are not equal, a permutation test (D.C.Howell, 2007; Howell, 1997), which is analogous to one-way ANOVA, is used. There is a significant overall difference across the three conditions [Group: $F(2,23)=6.44$, $p=0.007$, and $MS_{error}=518$]. Post hoc tests are conducted using pair-wise permutation test, and the results are shown in Table 2. This shows that there are pair-wise significant differences between the sketching condition and the building conditions but not between the two building conditions. This supports the hypothesis that the physical models rectify the flaws in the designers' mental models leading them to produce a higher proportion of ideas satisfying the problem requirements.

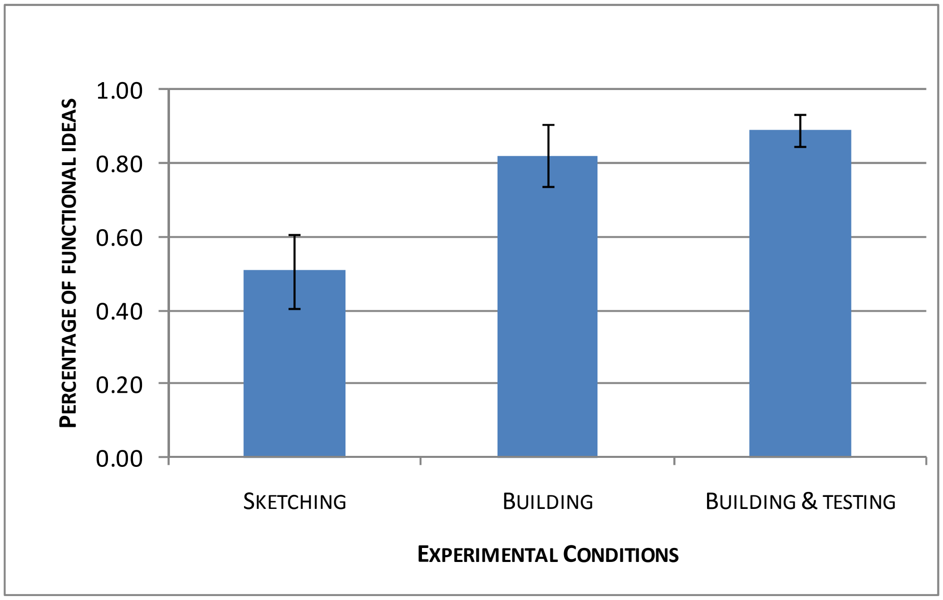

Figure 10 Percentage of functional ideas show significant difference across the conditions

Table 2 Pair-wise permutation test results for Experiment 1

Pair-wise Condition Comparison	F	Result
Sketching to building	5.6	p=0.03*
Sketching to building & testing	12	p=0.004*
Building to building & testing	0.55	p=0.47

* Statistically significant

Another interesting result observed is that in the building & testing condition. After the building & testing is done, when the participants sketch additional ideas, they create a lower proportion of functional ideas (Figure 11). A permutation test shows a significant difference between these two conditions. [Group: $F(1,15)=13.17$, $p=0.003$, and $MS_{error}=58.47$]. This suggests that the participants are not quickly learning the physical behavior of the wire and that the prototypes are supplementing their reasoning process. As seen by comparing the sketching and follow-up sketching (Figure 10 and Figure 11), some learning may be occurring but it is not statistically significant. This needs to be investigated further.

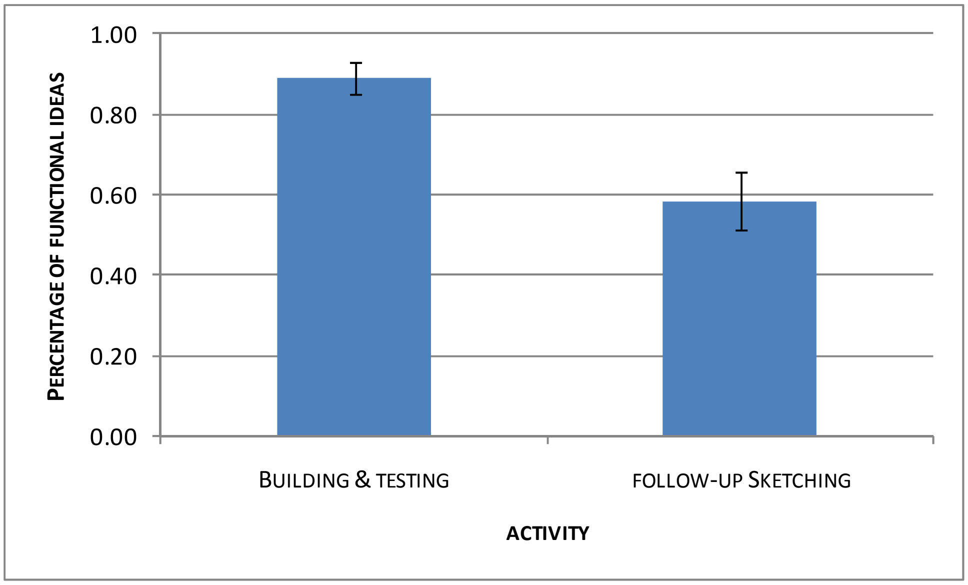

Figure 11 Percentage of functional ideas shows significant difference between building and testing and follow-up sketching activities

Hypothesis 2- Design Fixation: Novelty and Variety

The novelty and variety do not vary significantly across the conditions (Table 3, Figure 12, Table 4 and Figure 13). This indicates that the prototypes are not causing design fixation. If participants are fixating, a lower novelty and variety of ideas is expected. There is a limitation to the metrics. The measured novelty and variety is only for the prototypes that are built. There are some ideas that participants cannot build due to the material and process restrictions. To account for these additional ideas, the same metrics are measured with the sketched data. There are no significant differences between the various experimental conditions, as shown in Figure 14 and Figure 15. Similar trends are observed but inter-rater agreement is a little lower than desirable. As the sample size is too small, no final conclusion can be drawn from this, but the current results indicate fixation is not occurring. Further investigation needs to be considered.

Table 3 Variety of built prototypes across the conditions

Condition	Mean Variety Score	Std deviation	Sample size
Sketching	0.27	0.15	8
Building	0.25	0.10	8
Building & testing	0.25	0.09	8

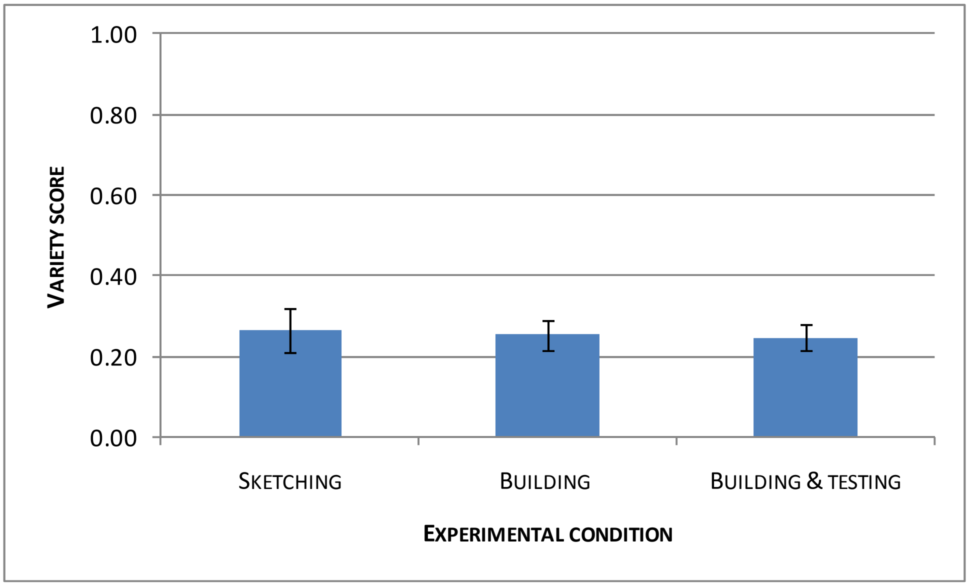

Figure 12 Variety of built prototype did not show significant difference across the conditions

Table 4 Novelty of built prototypes across the conditions

Condition	Mean Novelty Score	Std deviation	Sample size
Sketching	0.76	0.15	164
Building	0.79	0.12	142
Building & testing	0.76	0.21	96

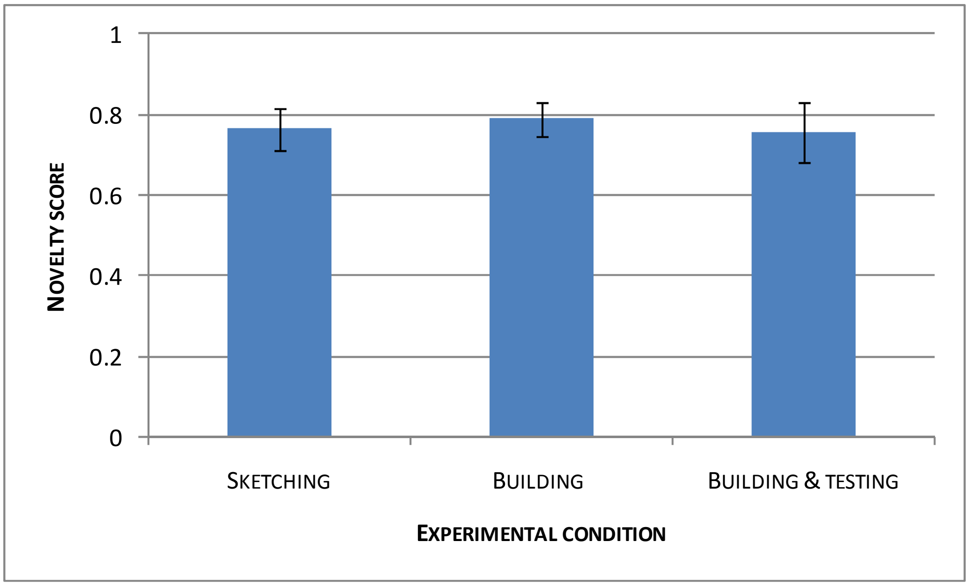

Figure 13 Novelty of built prototype did not show significant difference across the conditions

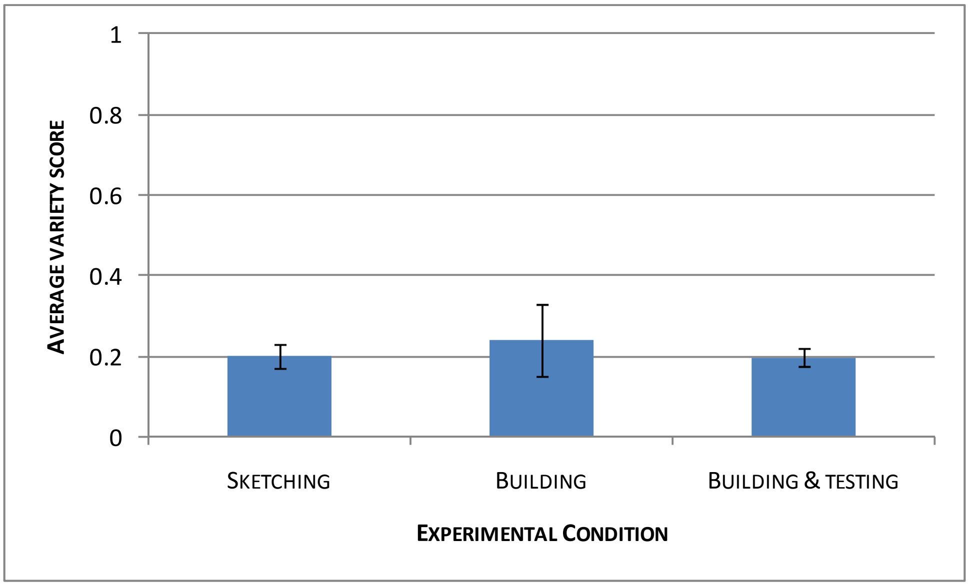

Figure 14 Variety of concept sketches did not show significant difference across the conditions

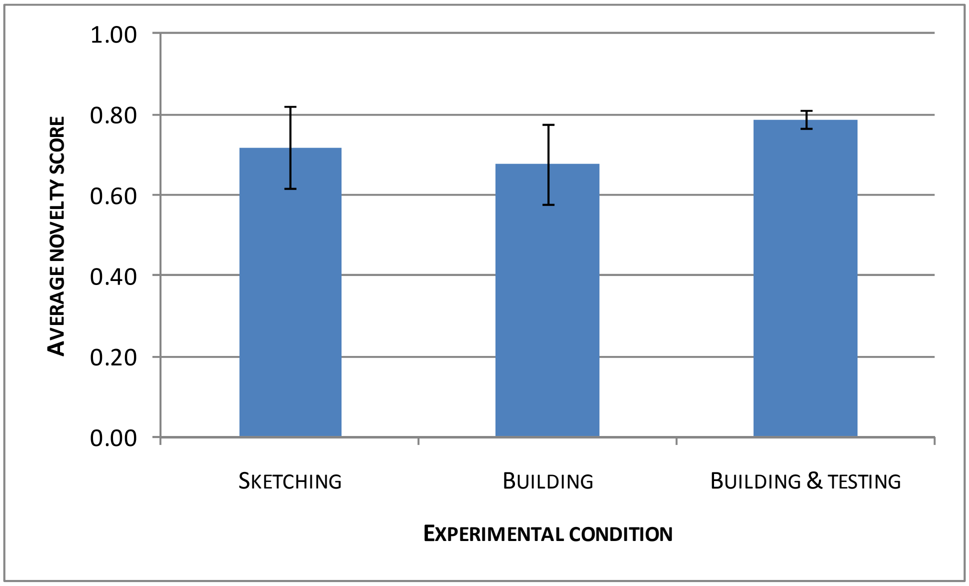

Figure 15 Novelty of concept sketches did not show significant difference across the conditions

Quantity of Ideas

The total number of ideas is observed to be significantly higher in the sketching condition as shown in Figure 16. This may be due to the lower time required to sketch ideas compared to building them. The average number of ideas is also higher in the sketching group, as shown in Figure 17.

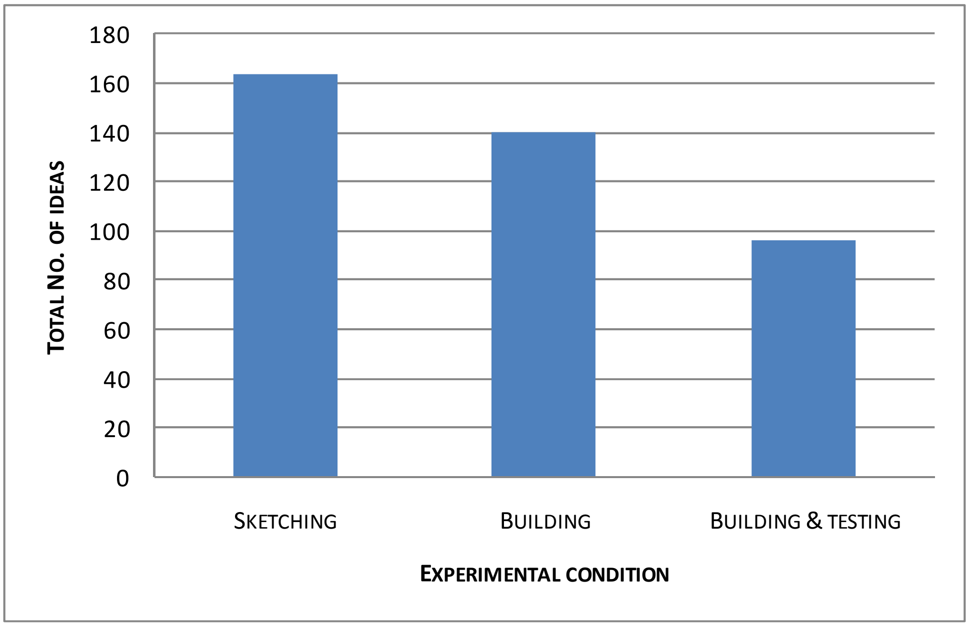

Figure 16 The total number of ideas is found to be much larger in the sketching condition compared to others

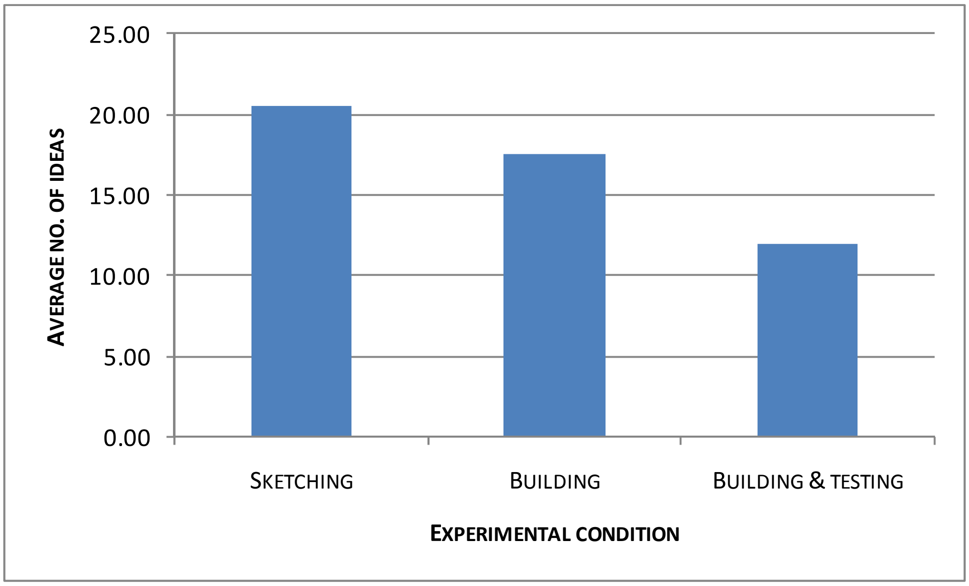

Figure 17 The average number of ideas is found to be larger in the sketching condition compared to others

Another interesting observation is that the total number of functional ideas is much larger in the building condition compared to sketching and building & testing conditions, as shown in Figure 18. The increase in the number of functional ideas from the sketching condition can be explained by the supplementing effect of physical models. In building & testing condition, participants spend a significantly lower amount of time generating ideas using building & testing. This might be the cause of the reduced number of total functional ideas in this condition. The average number of functional ideas (functional ideas per participant) is also found to be higher in the building condition compared to the other two, as shown in Figure 19. It is surprising that the average number of functional ideas is lower in building and testing condition, compared to the building condition. In the building and testing condition, the follow-up sketching activity may be the reason behind significantly lower average number of functional ideas in this condition, compared to the sketching only condition.

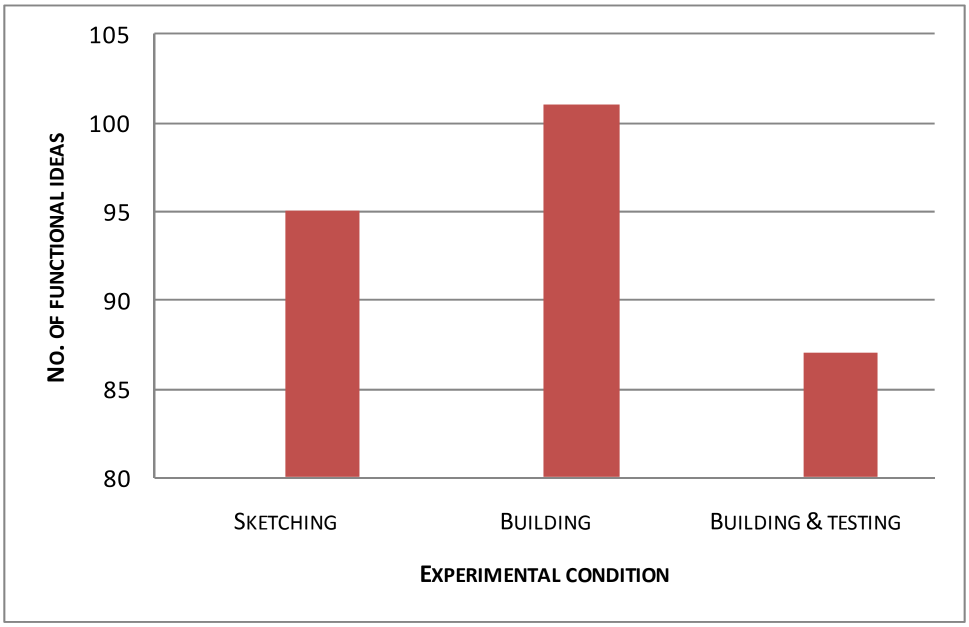

Figure 18 The total number of functional ideas was significantly higher in building compared to the other conditions

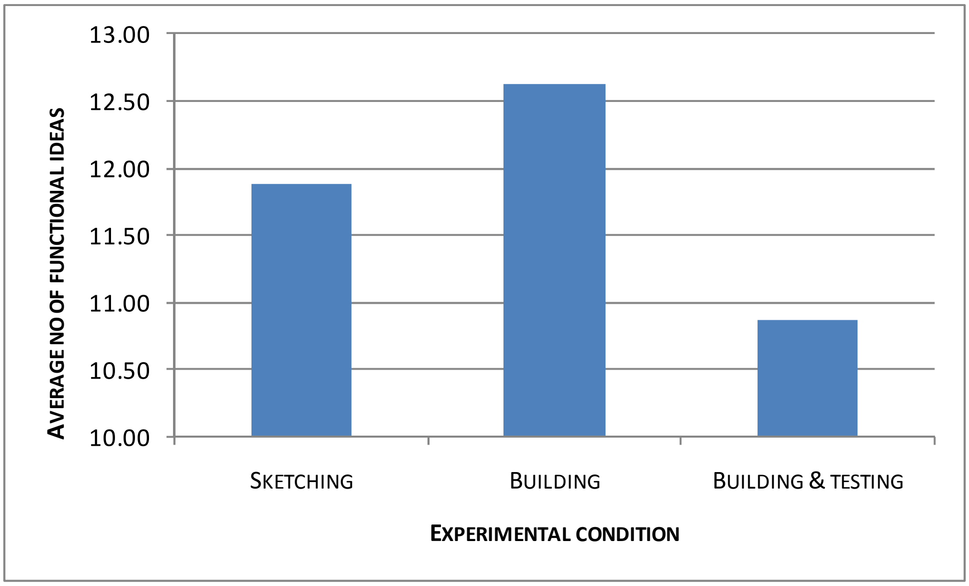

Figure 19 The average number of functional ideas was significantly higher in building compared to the other conditions

Survey Results

The survey given to the participants investigates the participants' opinion for the following questions:

1. "During which part of the study did you generate the most ideas?"

2. "During which part of the study you feel like you had the highest quality ideas?"

3. "Which method do you feel helped you to generate ideas that functioned the best?"

4. "Have you heard about this experiment or the design problem before coming to the study today?"

The results from this survey show that participants find the building activity most useful in all three categories. The results are shown in Figure 20.

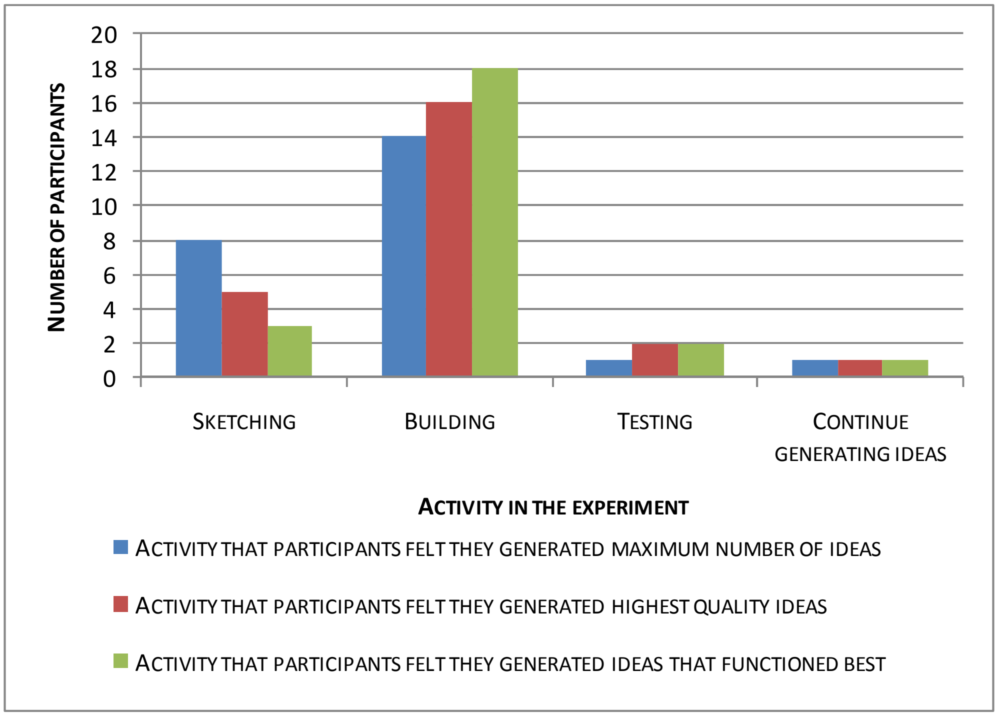

Figure 20 Results from the participants' survey shows that the building activity was the most productive activity in the experiment.

The participants are also asked whether they heard about the design problem before. None of the 24 participants' answers affirm that they heard about the design problem before. The participants are also asked whether they ran out of ideas and majority answer that they do not. These results are shown in Figure 21.

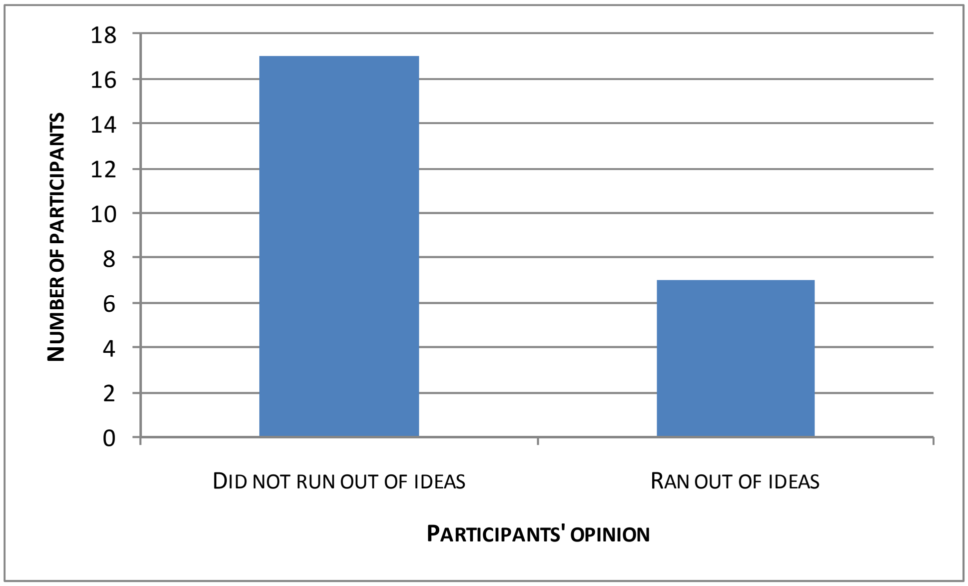

Figure 21 Majority of the participants did not run out of ideas during the experiment

Conclusions

The use of physical models throughout the engineering design process is an important topic to teach engineers. This will help them to be more innovative. Engineers need guidance on the effects of physical models and when it is appropriate to implement them. Unfortunately, there is little empirical data available on how physical models impact engineering design reasoning. This pilot study explored the effect of physical prototyping on the reasoning of designers. From the results of the experiment, it is clear that creating physical prototypes produces more ideas satisfying the design problem requirements. This suggests that the physical models assist in overcoming flaws in designers' mental models.

Another interesting result is that in the building & testing condition, when the participants are allowed to generate more ideas through sketching only, subsequent to building, they created a lower proportion of functional ideas. This likely indicates that the engineers are not significantly learning and modifying their mental models, but instead using the external physical representations to support their internal reasoning processes. This is an interesting result and needs further study.

Past research indicates physical prototypes cause fixation resulting in fewer concepts, lower novelty and lower variety of ideas. The novelty and variety measured on the built prototypes and sketches do not indicate this trend. Since the sample is small, a conclusion cannot be made and more work is needed.

CHAPTER IV

EXPERIMENT 2 – EFFECTS OF COMPUTER-BASED CONCEPT GENERATOR IN ENGINEERING IDEA GENERATION

The experiment described in this section tests how a computer-based automatic concept generator called "Visualize IT" affects designers' cognition. A between-subjects idea generation experiment is conducted to evaluate this. The question investigated and the method followed is described in more detail in the subsequent sections. This experiment was conducted by the author along with Susanna Schmidt, who was another graduate student in the author's lab at the time of the experiments.

Research Question

The purpose of this experiment was to identify any effects that Visualize IT has on the designer's cognition. The specific research question investigated in this study is stated below:

Does using the software Visualize IT lead to the generation of concepts that are superior in novelty, variety, quality and quantity over concepts generated in a control condition with only the basic function structure as reference?

To find out the answer to this question, a controlled laboratory experiment was conducted. The detailed procedure followed for the experiment is described below.

Method

The purpose of this study was to understand how computer-generated CFG's affect the engineering idea generation process. Hence, a between-subjects idea generation experiment was conducted in a controlled environment. The participants were randomly assigned to two different groups: A control group and a software group. In thecontrol group, participants generated ideas for a given design problem with the help of its function structure alone, whereas the software group was allowed to use the Visualize IT software which provided them with CFG's automatically generated. To avoid overwhelming the participants' memory, only 49 CFG's were provided to the participants at the time of the experiment.

The experiments were conducted by two experimenters, one male and one female. Both were non-native English speakers. Each experimenter completed approximately half of the experiments in each condition in Texas A&M University (TAMU). In University of Texas (UT), both the conditions were to be run simultaneously, hence one experimenter conducted experiments in each condition. As both the experimenters had equal experience in conducting experiments and reading the scripts, this was not expected to cause any bias to the data.

Design Problem

In both the conditions, participants were given the same design problem, the 'Peanut Sheller'. The exact problem statement provided to the participants is shown in Figure 22. The participants were provided with a print out of the design problem along with its function structure. The function structure was created by one of the experimenters. Figure 23 shows the function structure provided to the participants. In addition to this main design problem, another design problem called "Water Lifting Device" was used to train participants in the software condition. For this problem also, the participants were provided with the problem statement (Figure 24) and the function structure (Figure 25). The design problems were chosen so that senior mechanical engineering students could understand the problem and generate a good number of solutions without much difficulty. Also, Visualize IT could provide a multitude of conceptual designs for both these design problems.

Peanut Shelling Device

Problem Description:
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 of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Goals:

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

Figure 22 Problem statement of the Peanut Sheller design problem

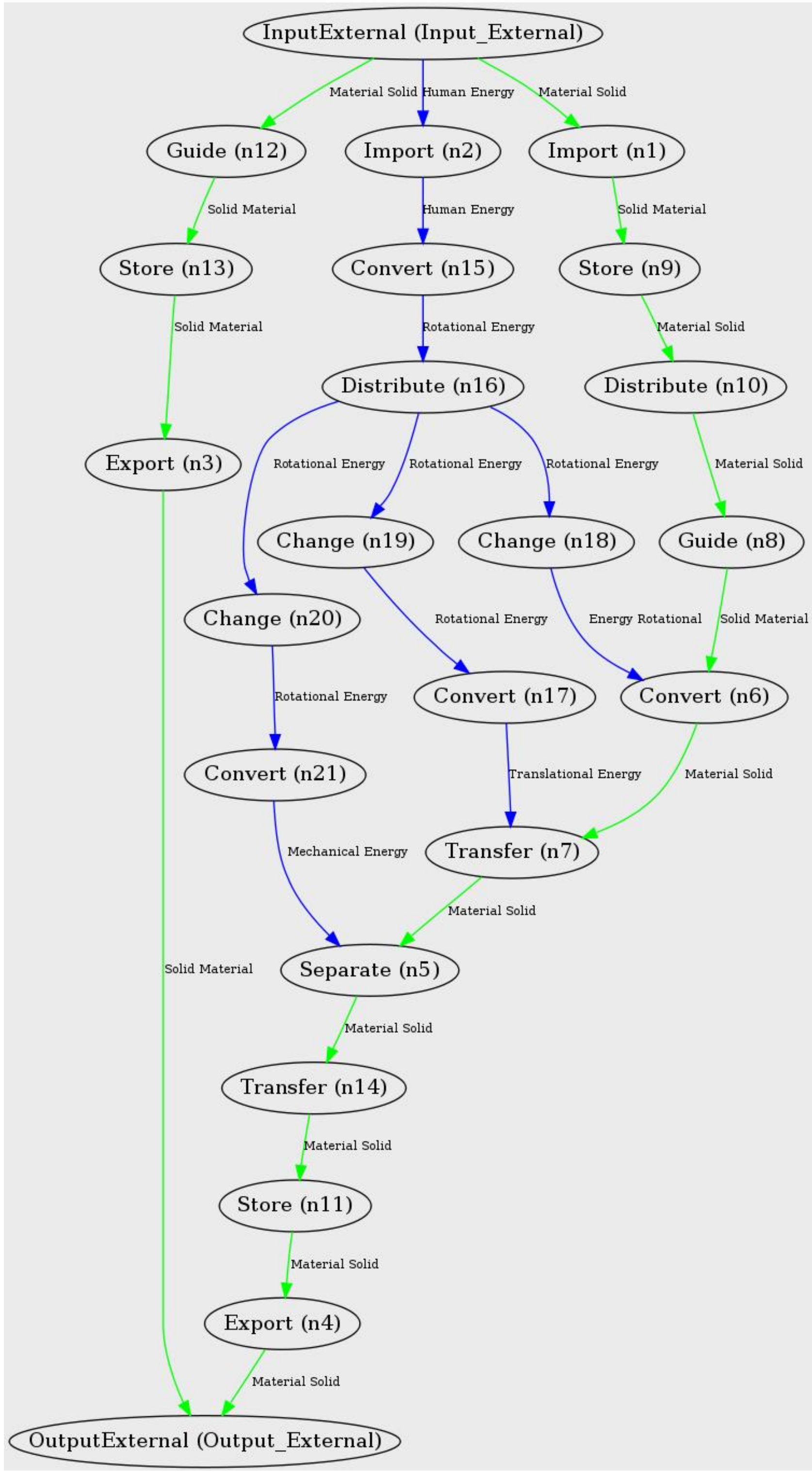

Figure 23 Function structure used for the Peanut Sheller design problem

Water Lifting Device

Problem Description:
For people living in rural areas in developing countries there is often the necessity to deliver the daily water supply for their own daily needs, their animals and their crop. Often all water needs to be lifted from a well, as rain may be scarce. This is a strenuous and time intensive task that sometimes puts restrictions on the size of the crops. Therefore a water-lifting device that eases the process of unearthing water is needed.

Goals:

- Low cost.
- Easy to maintain.
- Well depth about 10m/ 30feet

Figure 24 Water Lifting Device problem statement provided to the participants

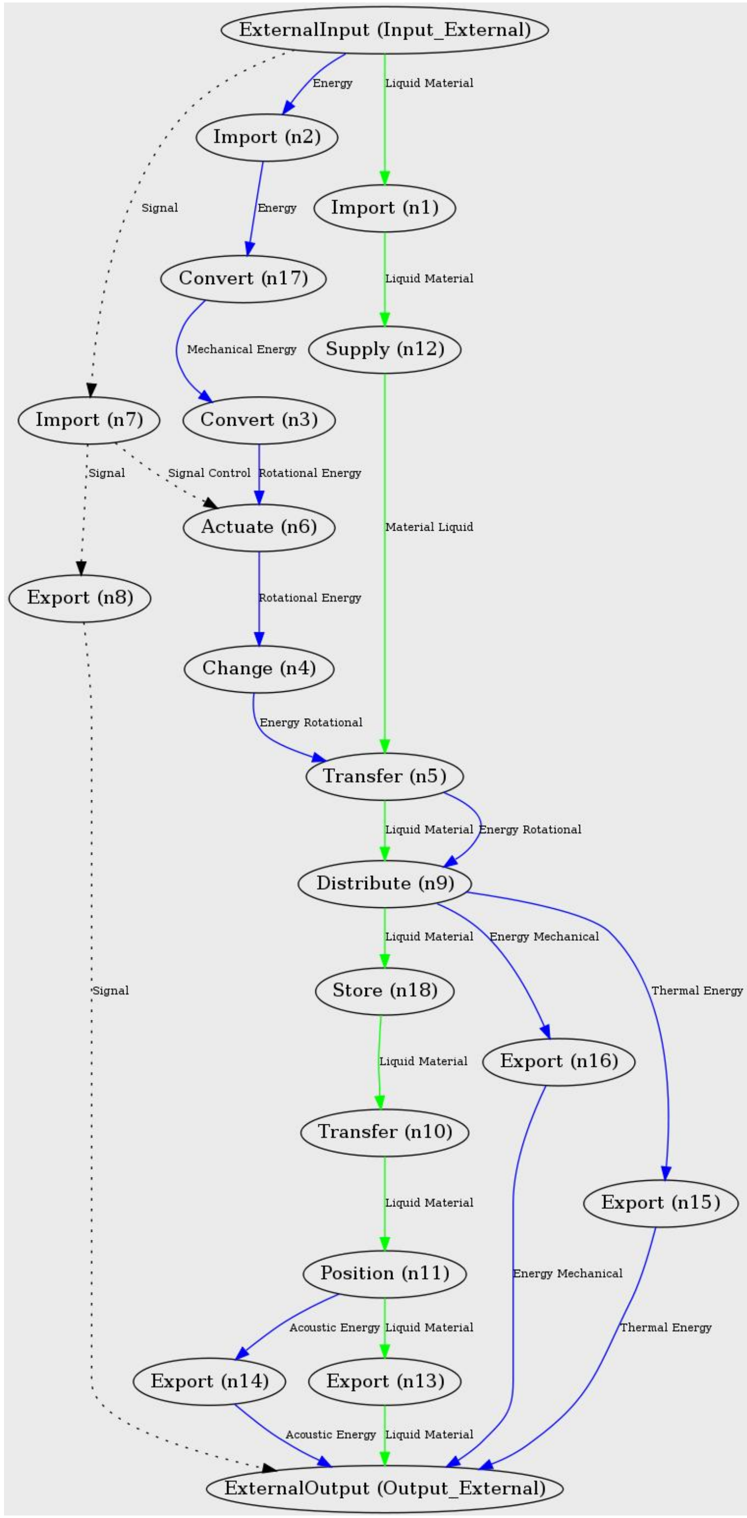

Figure 25 Function structure of the Water Lifting Device design problem provided to the participants

Participants

The participants were senior undergraduate design students from Texas A&M University (TAMU) and the University of Texas at Austin (UT). They were recruited from two different design classes in TAMU and one in UT. All participants were compensated with extra credit for their participation.

A total of 30 participants took part in the experiment equally divided between the two different conditions. The distribution of participants across the conditions is shown in Table 5. The experiment was conducted over 4 weeks. The average age of participants was 22.4 years. Out of 30, four were female participants.

Table 5 Distribution of participants across the conditions

	TAMU	UT
Control	9	6
Software	10	5

Procedure

Both conditions began by providing the participants a consent form. They were given an option to discontinue their participation at this point or at any other point in the experiment. A recap of the functional modeling was provided to the participants in the form of a recorded training. This recap was an important part of the experiment as the participants used functional models throughout the experiment. The lecture explained the definition of a function, followed by an explanation of black box models and a flow-based functional model of a product with a detailed deconstruction of the device. A Component Flow Graph (CFG) similar to the one shown in Figure 3 was introduced and explained. The lecture ended with showing the black box model, functional model, CFG, a conceptual sketch and actual diagram of the product on the same screen to clarify the connections between these various forms of representations of the product. A short quiz concluded the training part. The quiz tested the participants' understanding of the materials presented in the video.

After the training, the control group was directly given the training design problem. They were asked to generate as many solutions as possible to the water lifting device design problem within the available 20 minutes. For the software group, this idea generation activity was preceded by an introduction to the Visualize IT software. From this point, the software group had access to the software throughout the experiment. The main purpose of the practice problem was to give an idea to the software group about the workings of the Visualize IT software. The training session ended with a five minutes break.

The next activity in the experiment was idea generation for 50 minutes for the actual design problem, which was the Peanut Sheller design. The control group was asked to generate ideas for the design problem right away with the help of the functional model alone, while the software group was asked to compare and contrast various CFG's available for the problem in the Visualize IT software. They were handed pens to sketch their ideas after these ten minutes. Their pen colors were exchanged every ten minutes in both the conditions to keep track of the time at which the ideas were generated. At TAMU, the computer screens were recorded for the software condition to track the CFG's that the participants used. Camtasia was used for the recording purpose.

The last activity in the experiment was a three minute survey, which asked the participants about their demographic information and their perception about the software. They were asked whether they had heard of the Peanut Sheller design problem before. If they answered positive for this question, their data were to be discarded. However, none of them answered that they were familiar with the design problem. They were also asked which kind of representation they preferred for the CFG's, whether graphic or textual representation.

Due to space and time constraints, the procedure followed for the experiments at UT was slightly different from that followed at TAMU. At TAMU, one to three participants did the experiment at the same time and they were separated with dividers. At UT, the experiments were conducted as a class activity in a class room and a computer laboratory. Hence all the participants at UT did the experiment at the same time. The computer screen sizes and screen resolutions were different, but approximately the same portion of the CFG's was visible on screens. To finish the experiment within the available class time, the idea generation in control condition was shortened by five minutes for the experiments at UT. The idea generation was 55 minutes in TAMU and 50 minutes in UT. To avoid any bias, only the ideas generated in the first 50 minutes in the experiments at TAMU were used for analysis. The final survey was also modified slightly as some questions were specific to courses at TAMU. None of these changes were expected to bias the results.

Metrics of Evaluation

The quantity of unique ideas developed by the participants was used as the metric for evaluation in this experiment. A unique idea is defined as an entity that solves one or more functions in the functional basis (Hirtz et al., 2001). For each participant, the individual ideas corresponding to each function in the functional basis were collected and the redundant concepts eliminated. The remaining ideas were the non-redundant ones. The average quantity of the unique ideas was calculated by averaging over the individual quantity counts. This process was done by both the experimenters individually and an inter-rater agreement of 0.93 was obtained, which was satisfactory. Hence this metric was found to be reliable.

Results

The aim of this experiment was to determine how helpful Visualize IT was for designers in the idea generation process. In this experiment, the control condition and the software condition were separate, but in actual practice designers are supposed to come up with maximum number of solutions without the help of the software and then expand their solutions to new directions with the help of the software. The results obtained from this study gave some interesting insights. The quantity of ideas was greater in the control group than in the software group as shown in Figure 26 (t=1.8, df=28, p=0.08). There were no differences in the quantity across both the schools as shown in Figure 27.

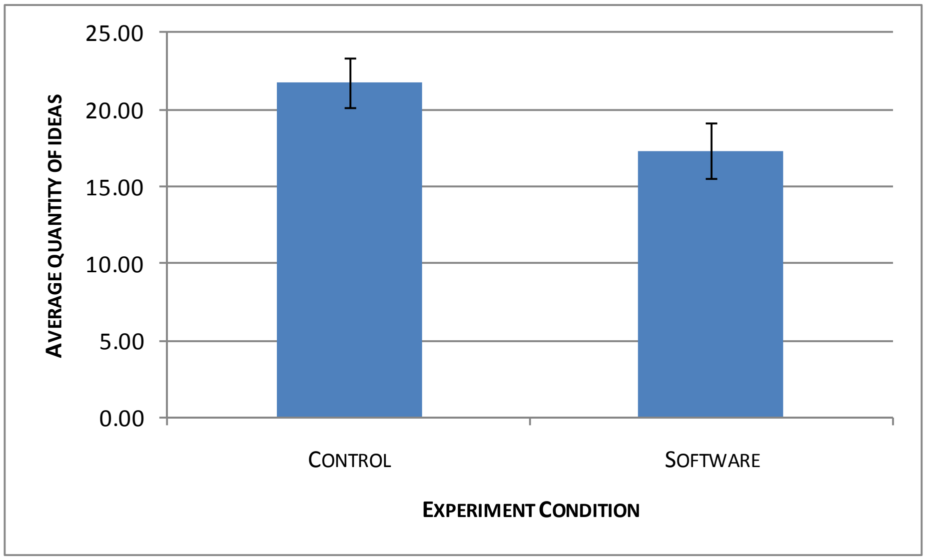

Figure 26 Average quantity of ideas was observed to be more in the control condition

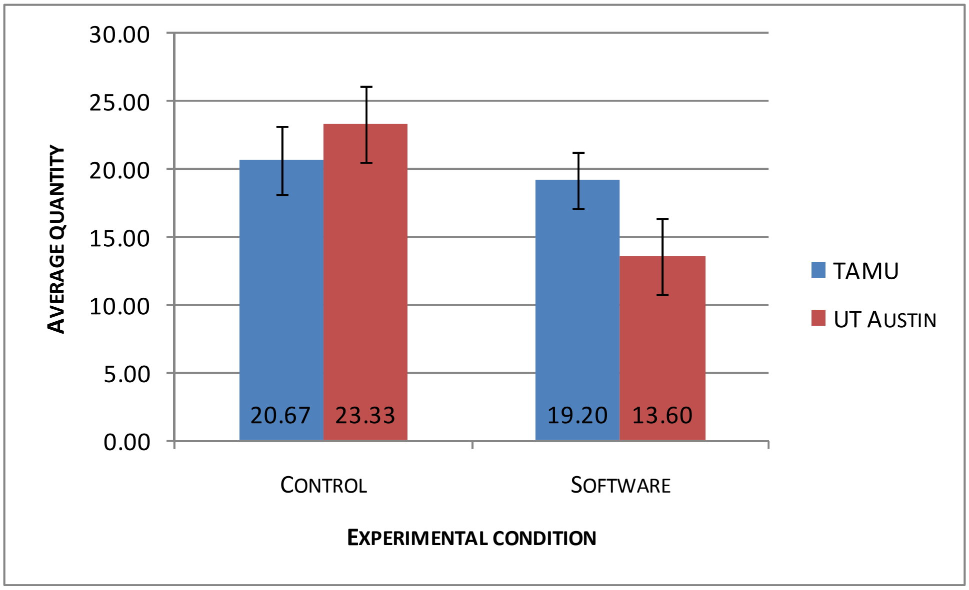

Figure 27 Average quantity of ideas showed no difference across the schools

Survey Results

The participant survey results showed that the majority of the participants preferred the picture based layout of the CFG's rather than the text based one (Figure 28 and Table 6).The analysis of the screen recordings also indicated that participants spent most of the time reviewing the picture based CFG's (English et al., 2010). This showed a possible reason for the lower quantity of the ideas in the software group. As the participants spent most of their time viewing the picture based CFG's, there is a chance that they were fixated to the common solutions presented in the CFG's. There is enough evidence in literature about the fixation caused by presented pictorial examples (Jansson & Smith, 1991; Purcell & Gero, 1996). Another important factor that might have influenced these results was the timing at which the ideas were presented. If the designers are presented with cross domain analogies at a point when they are stuck, they are most likely to use these analogies to solve the design problem (Tseng et al., 2008). In this case, all the CFG's were presented together to the designers, so their use was not guaranteed.

Table 6 Results from the participant survey regarding the type of representation of CFG

Survey Question	**Mean (Std. Dev.)** (Strongly Disagree =1, Disagree = 2 Neither = 3, Agree = 4, Strongly Agree = 5)
The word based CFG representation helped me generate ideas.	2.3 (1.0) Disagree
The picture based CFG representation (the candidates under the graph with component images tab) helped me generate ideas.	3.2 (1.4) Neither Agree nor Disagree

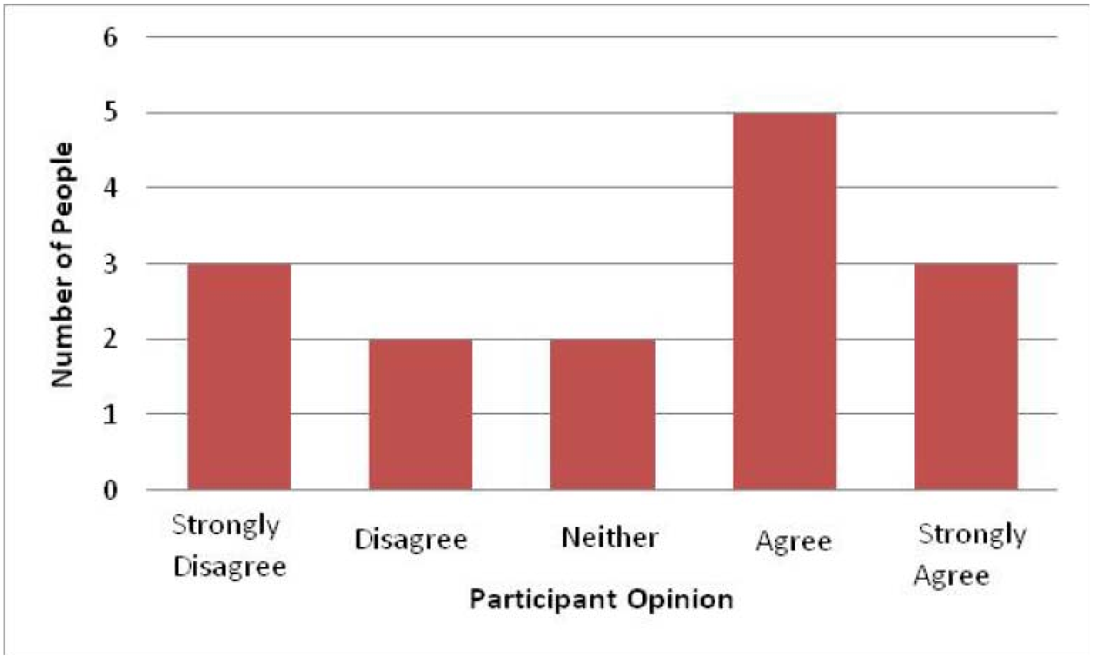

Figure 28 The participants were very divided about whether picture based representation of CFG helped them to generate more solutions. Many felt that picture based representation was more effective

Conclusions

Creativity and innovation are regarded as qualities that entirely depend on human ability. Until recently, no efforts were made to use power of information technology in this field to support conceptual design process. Visualize IT is a software platform that combines previously developed computational tools including the design repositories, grammar rules, clustering algorithms and visualization platforms to aid designers in their conceptual design. For this effort to be successful, it is essential to validate the software to know how effective it is in the engineering idea generation process. The experiment outlined in this chapter is an effort to evaluate this.

The results obtained from this experiment provide very valuable insights regarding the use of computational tools in the idea generation process. The number of ideas in the software group was less than that in the control group as shown in the results. This may be partially due to the fixation induced by the ideas presented by the software. Also the fact that all the candidate concepts were presented to the designers all together by the software might also have influenced their outcome. More detailed studies are required to derive any solid conclusions regarding this issue.

CHAPTER V

EXPERIMENT 3 – USER PREFERENCES FOR CLUSTERING APPROACHES IN VISUALIZE IT

For any new product to be successful, it needs to be user friendly and satisfy user requirements. The experiment described in this section tries to identify the user preferences for the Visualize IT software. This software is newly developed and it is important to know how its interface can be presented to users so that they can get the maximum benefit out of it. The sections below describe the process followed for this purpose and present the results.

Method

Experiment 3 collected preliminary data on the user preferences for the display of the component layouts in the software. An issue to be addressed was how the Visualize IT interface should cluster and display sets of concepts. The software generated thousands of solutions for the design problem based on the existing solutions, which was too many for the designer to evaluate. Hence, similar concepts needed to be clustered. The experiment explored three factors related to the display and clustering of the component layouts: (1) clustering algorithm used to group the component layouts, PCA or K-means, (2) number of component layouts displayed at the same time and (3) the number of component layouts per cluster for effectively representing the group.

Ideally, the three parameters listed above would be evaluated by having participants generate ideas in the various conditions and then objectively measuring their performance along with their opinions. As a preliminary evaluation, this experiment only explored the participant opinions.

There were various clustering approaches that could be used to group the thousands of component layouts generated by the software. But all the clustering approaches were computationally costly as the number of concepts was very large. There were two different clustering approaches implemented in the software at the time of testing: the principal component analysis (PCA) (Introduced by Pearson in 1901) and K-Means (Introduced by MacQueen in 1967). The experiment compared these two. The main aim of this experiment was to understand which one of these is preferable to the participants.

The representation of component layouts on the computer screen was another important factor. Humans can store a very limited amount of data in short-term memory, which makes side-by-side representation very effective for comparison. In addition, there was an open question about how many similar component layouts should be used to represent each cluster.

Participants

The participants were senior undergraduate design students from Texas A&M University (TAMU) and the University of Texas at Austin (UT). There were a total of 25 participants with 19 from TAMU. They were recruited from two different design classes in TAMU and one in UT. All participants were compensated with extra credit for their participation.

The participants were the same as those who participated in Experiment 2. This experiment was conducted as a supplement to Experiment 2 at TAMU and a separate one hour experiment at UT. The experiment was conducted over 4 weeks at TAMU. At UT, it was done on two class days with one day break between them. The average age of participants was 22.1 years. Out of 25, four were females.

Procedure

This evaluation was run after the controlled evaluation of the software so the participants were familiar with the component layouts. In the first section, participants compared the two clustering approaches used in the software. The participants were given two sets of component layouts each containing seven clusters, each with five component layouts, one bundle with PCA clusters (Figure 29) and the other with K-means (Figure 30). They were provided with another set as well, containing randomly selected component layouts. Participants were asked to review both sets and then rank the clusters in the order of most useful to least. Rank 1 was given to the one they liked most and 12 for the one they liked least. They were then also asked which clustering approach they preferred overall. The names of the clustering approaches were not provided to the participants; instead the clusters were color coded. In the next stage, the participants were given sheets containing one, three or five component layouts from the same cluster. Again, participants were asked their preferences. In the last section, the participants were given the same component layouts arranged in two different formats. In the first one, five component layouts were given side-by-side (Figure 31), whereas in the second one, they were given in the form of a bunch of papers stapled together. The participants were asked which representation they preferred. This opinion gave us an insight about how many component layouts were to be shown on the screen at a time. All the participant opinions were collected using opinion sheets. The experiment ended with a short survey. The survey asked about the demographic information of the participants and their enrollment in the various design classes.

Metrics of Evaluation

This experiment focuses on the opinion of the participants about the different features of the software. The participant rankings and overall opinions are the metrics for evaluation.

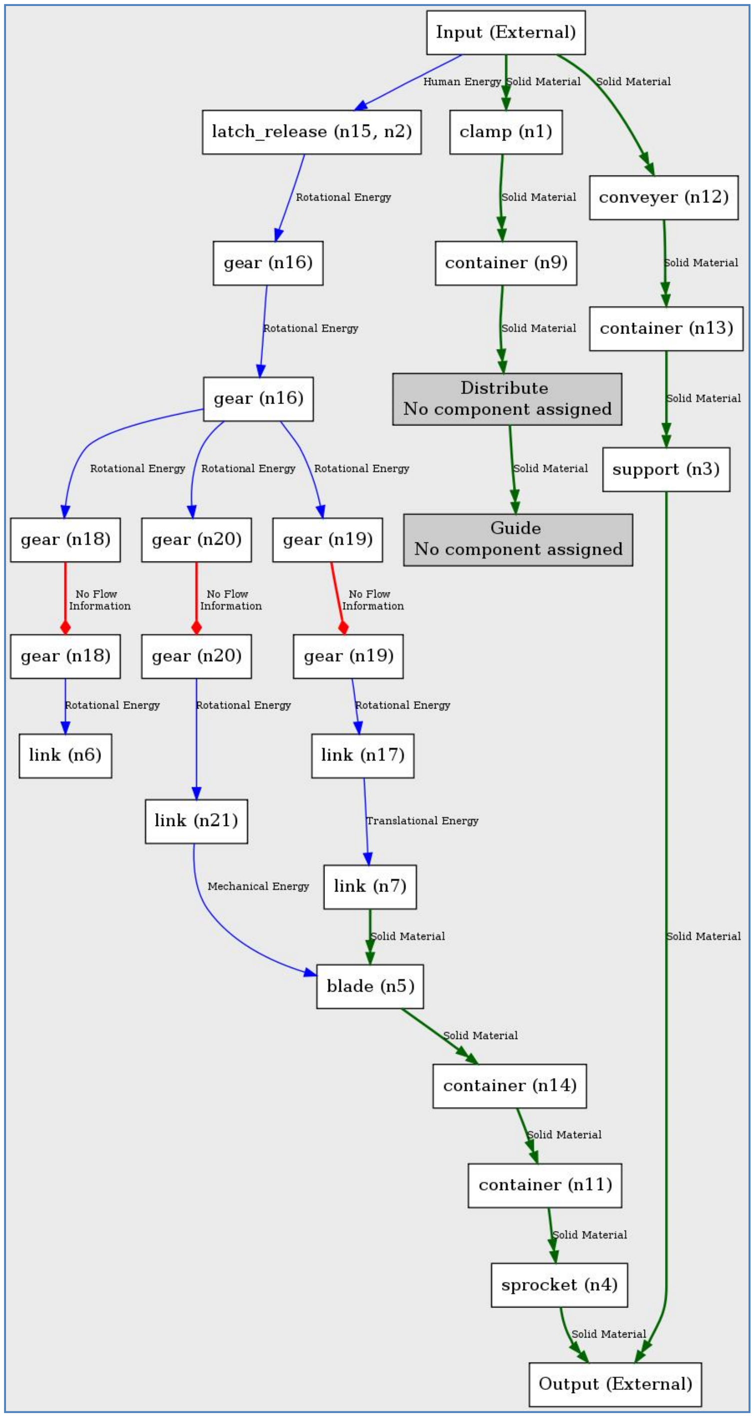

Figure 29 A sample from the concepts in PCA cluster for the Peanut Sheller design problem given to the participants

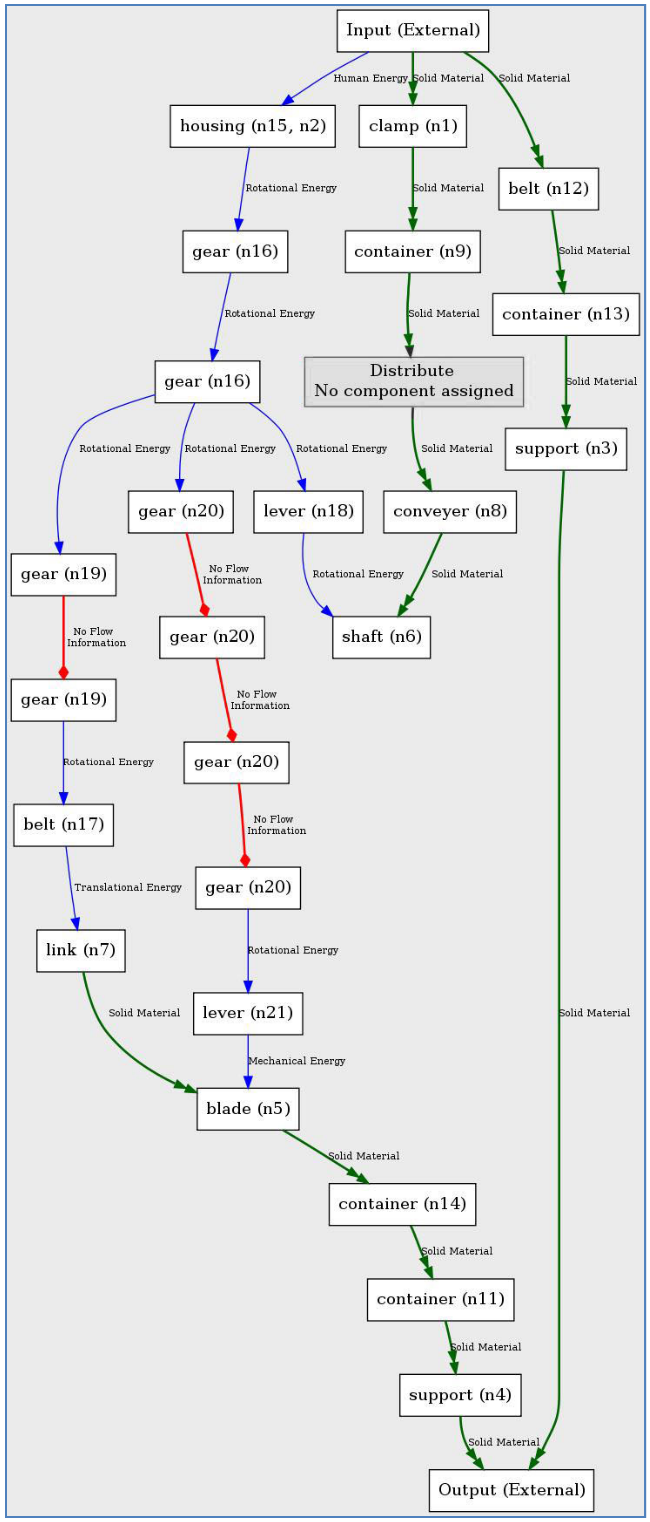

Figure 30 A sample from the concepts in K-means cluster for the Peanut Sheller design problem given to the participants

9

Figure 31 A sample from the side-by-side representation of the clusters given to the participants

Results

The aim of this experiment was to gain some preliminary insight about the user interface of the Visualize IT software. The results obtained from this study showed the user preferences clearly. Majority of the participants did not prefer one clustering approach over the other. The average ranking of both the clustering approaches and the random set of clusters were the same as shown in Figure 32, showing that participants did not bother about which clustering approach the concept came from. When participants were asked to pick the best candidate concept from the set given to them, majority said they found all equal, as shown in Figure 33.

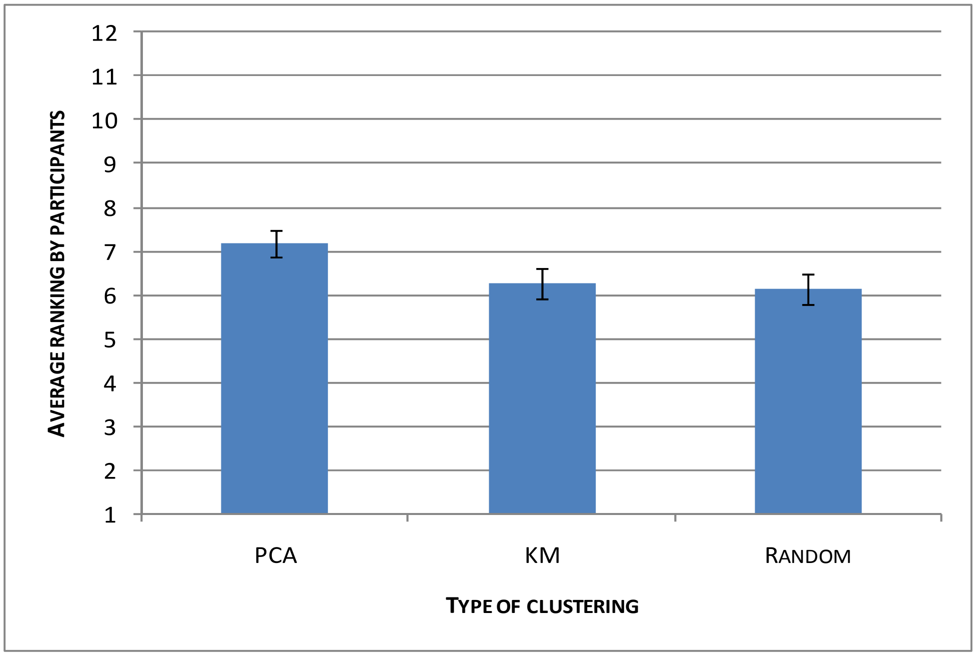

Figure 32 Average ranking given by participants to each clustering approach. One participant responded as no opinion

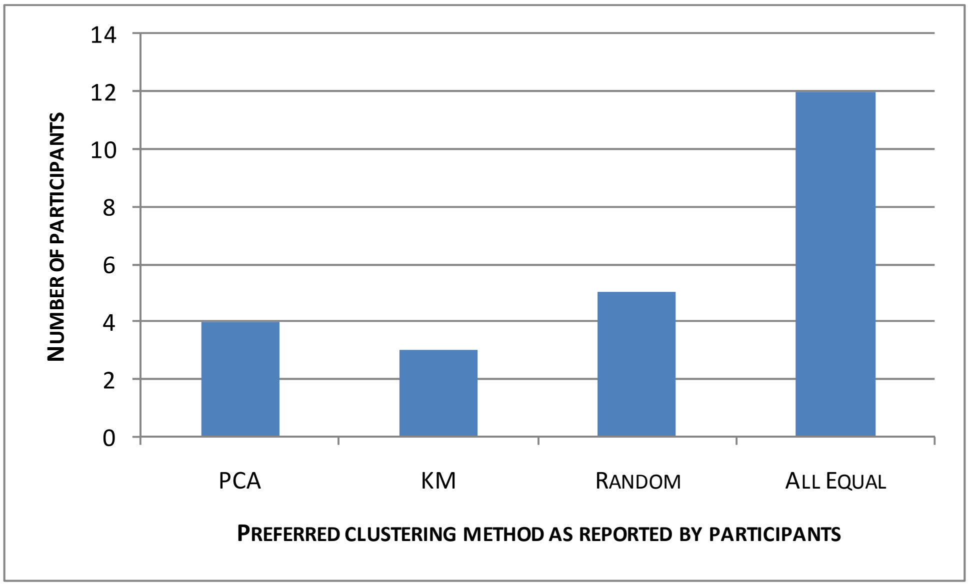

Figure 33 Majority of the participants found all clustering methods equal. Very few preferred one over the other. One participant did not give any opinion

The question was how users preferred to view the candidate concepts on the computer screens. There were two ways to display concepts available. In one case, participants saw concepts one by one as in separate tabs on a computer screen. In the second case, all were displayed together side-by-side. Majority of the participants preferred to see the concepts displayed side-by-side, as shown in Figure 34.

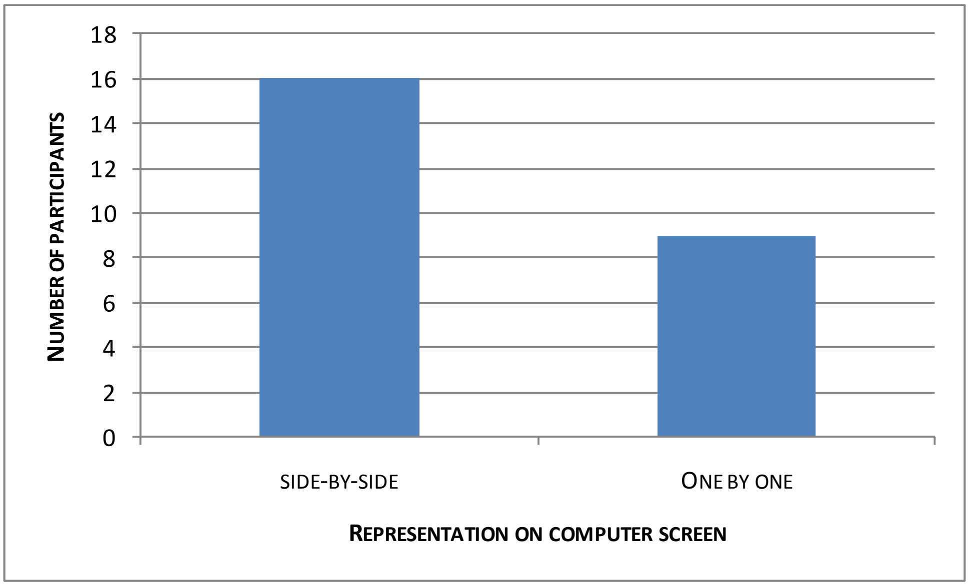

Figure 34 Majority of the participants preferred to see the concepts side-by-side on the computer screen

After understanding that participants preferred to view the candidate concepts side-by-side on the same screen, the next task was to understand how many concepts were to be displayed on the screen at the same time, so that participants could make maximum use of it. Participant opinions showed that they preferred to view three concepts at a time as shown by Figure 35. Most of them gave their opinion against displaying more than five concepts on the screen at the same time, as shown in Figure 36.

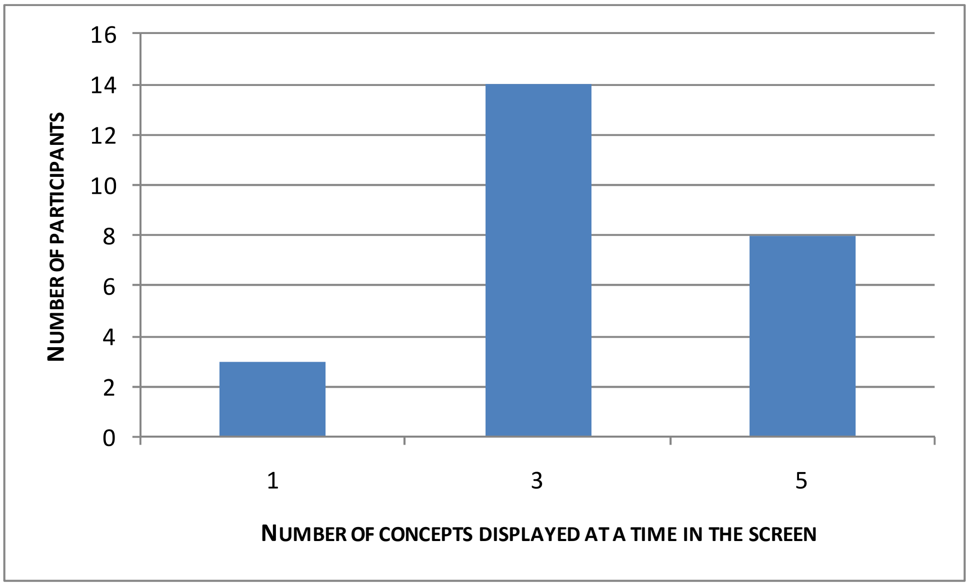

Figure 35 Majority of the participants preferred to see three concepts at a time on the computer screen

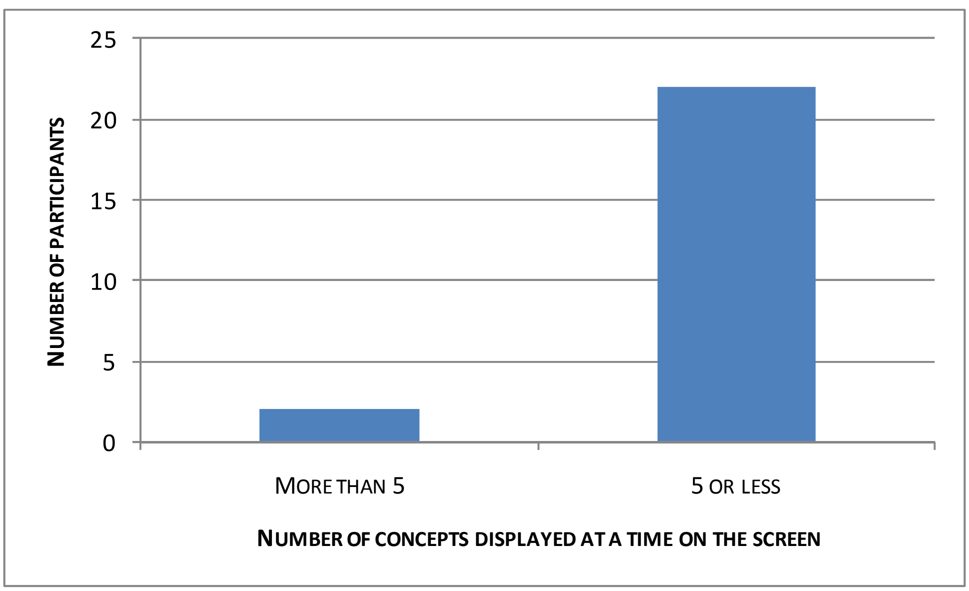

Figure 36 Vast majority of participants preferred less than five ideas to be displayed on screen at a time

Conclusions

For any product to be successful in the market, it needs to be user-friendly and satisfy most of the customer needs. Visualize IT is an effort from the part of a group of researchers to introduce a computer-aided platform to assist users in engineering idea generation. Since this software is in the very early stages of its development, it is essential to understand how customers want to see the candidate ideas on their screen. This experiment is an effort to answer these questions.

The results from participant surveys showed that users prefer to use a graphic interface for CFG's compared to a text-based interface. The users had no preference for one clustering approach over the other. Most of them preferred to see multiple candidate ideas together on the same screen, rather that browsing them through different tabs. Surprisingly, they wanted to see three ideas on the screen side-by-side at the same time and very few liked to see more than five ideas at a time. This information provides very relevant insights for the further development of the user interface of the software.

CHAPTER VI

CONCLUSIONS AND FUTURE DIRECTIONS

Creativity is an infrequently studied activity in engineering design. Some studies showed that spending more time in the early design phase of a project will help to reduce the overall project cost (Ward et al., 1995). For any industry, it is essential to come up with breakthrough products and ideas before their competitors do, to stay alive in the market. For doing this, the early design stage is a place where they can focus their attention. The quality of their final product may highly depend upon the quality of ideas at this stage. Hence idea generation is a very crucial activity which requires proper attention. The preliminary studies described in this thesis explore the effects of various representations used in the engineering idea generation process.

Physical Models in Engineering Idea Generation

The use of physical models is strongly recommended by famous product design firms, whereas the conflicting guidelines existing about their implementation make their use difficult. The first experiment described in this thesis explores two important aspects of physical models as an idea generation tool. The between-subjects controlled experiment sheds light on some of the possible effects of physical models on design cognition.

The results from Experiment 1 show that physical models supplement designers' incomplete mental models and thereby lead to a higher percentage of functional ideas. This implies that the use of physical models in the idea generation process may lead to a larger number of ideas satisfying the problem requirement. But once the provision of making prototypes is removed from the participants, their percentage of functional ideas decreases to the value in the condition where they use sketching alone as a medium of representation. This means that physical models fail to enhance designers' mental models permanently. The learning effects from physical models are very minimal.

Another aspect of physical models explored in this study is the potential role of physical models in fixating the participants to few of their initial ideas. Existing literature shows the fixation on presented examples, pictures and previously known functions of devices is common. One prior observational study has shown strong fixation caused by physical models in practicing designers. In contrast, the study in this thesis fails to replicate this result. The novelty and variety are observed to be the same across various conditions. This shows that no fixation is occurring across the conditions. However, the sample size is too small to make any solid conclusions about the presence or absence of design fixation in the engineering idea generation process with physical models.

There can be another possible reason for the significantly higher percentage of functional ideas in the building and building & testing conditions in the experiment. When the participants are provided with the materials to construct their ideas, they become aware of the implicit constraints imposed by the tools and materials on their designs. If they consciously try to address these constraints, they may try to create more ideas which satisfy the constraints. It may lead them to a higher number of ideas satisfying the problem requirements and hence the percentage of functional ideas may go up. Hence this factor needs to be isolated in future experiments. This will be explored more in future work. A new experimental condition will be added to the experiment, in which the participants will be told that they will build their ideas out of steel wire at a later stage of the experiment and then they will be asked to generate ideas using sketching. Before the idea generation process starts, they will be given necessary training for building, so that they will be aware of the implicit constraints imposed by the specific materials. If this condition gives better results compared to sketching, it may indicate that implicit constraints have some effect on design cognition.

To generalize the results from this study, the experiments need to be done with a larger sample size. The controlled environment used for this study does not replicate the noise factors present in an actual industry environment or in a product design firm. It needs to be investigated that how physical models affect design cognition in these settings. This experiment is conducted in a controlled environment where most of the noise factors are controlled. Whereas, in a practical design situation, lots of noise factors will be present. It needs to be determined, if the noise factors also somehow contribute to the design cognition using physical models. Under these new environments, we need to study these results further to get completely generalized guidelines for the use of physical models. This is a topic for future research.

There is a possible reason why the fixation results in this study vary from that of the prior observational study. In the prior study, the participants are given a more complicated design problem, whereas in this case the design problem is very simple. The effects of complication of the design problem on the design fixation also need to be investigated. This can be explained using “Sunk Cost Effect” theory (Arkes & Blumer, 1985; Kahneman & Tversky, 1979) from behavioral economics. Applying this theory to the idea generation process, the participants are likely to be more fixated if they spend more time and effort on their initial ideas. In this experiment, the design problem is really simple and the participants need not spend lot of time to generate a new concept. Hence the Sunk Cost Effect may be comparatively lower and this may lead to lesser fixation compared to a case with a complicated design problem. In the cases where complicated design problems are employed, the participants may have a tendency to stick with the variations of their initial designs, instead of trying to find a solution from a rapidly new possible solution space. The presence of Sunk Cost Effect in engineering design needs to be investigated further.

The ultimate goal of this research is to provide few guidelines for designers to apply physical models without any confusion and come up with novel and creative solutions to solve their design problem. This study tries to pave the way for this. More factors affecting design cognition using physical models need to be identified and studied. Some of the open questions for future research are listed below:

1. Does allowing the designers to build prototypes from the beginning of the idea generation process affect the number of functional ideas they generate? Is there a specific time at which they should start using physical models?
2. The literature from sociology suggests the potential use of physical models as boundary objects, whereas there is no experimental evidence available to support this argument. Are physical models superior to sketches in idea exchange between various disciplines?

3. In an industry, when designers generate ideas for the design problems, there may be a lot of potential prototyping materials available to them. Does the choice of material cause implicit constraints? Does the choice of material for prototyping affect design cognition other than through the implicit constraints imposed by them?
4. At least a few of the famous incubation stories from history are driven by some kind of physical models distantly related to the final solution. For example, the famous Hubble Fix by James Crocker was inspired by the shower in his hotel room (Tatarewicz, 2010). Similarly, Archimedes discovered the famous Archimedes principle based on his observation of overflow of a bath (Rubin, 2010). Based on these examples, can the use of physical models enhance the incubation process? By teaching engineers to frequently use physical models and extract information out of them, can we enhance incubation?
5. Does the knowledge about the properties and characteristic of the material used for construction of prototypes also cause premature cognitive commitment? If yes, is it the same as the effects of implicit constraints imposed by physical models? Can this be avoided using CAD models where the participants cannot experience the material of construction directly?
6. How do physical models differ from CAD models as far as design cognition is concerned? Literature (Hannah, 2009) shows that the information that can be extracted from these two different kinds of models is different. In that case, which representation is superior?

Visualize IT in Engineering Idea Generation

Visualize IT is a software platform which utilizes the enormous power of information technology to support the engineering design process. It is an initial effort to create an automatic platform to generate conceptual designs to design problems based on prior design knowledge available in a design repository. The purpose of this platform is to provide designers an environment with candidate solutions based on information available in the design repository, which will remind them about distant analogies for the solutions and thereby help them come up with innovative solutions. Design cognition process is complicated and not yet completely understood. Hence it is important to evaluate the effects of such a tool on design cognition.

Experiment 2 described in this thesis tries to answer these questions through a controlled between-subjects idea generation experiment. The results from this study show that the quantity of ideas is slightly less in the group which used the software for idea generation compared to the group that does not. This may be due to the fixation imposed by the pictorial representations of the candidate solutions given by the software. Also all the ideas are presented to the participants at the same time and this may also have an adverse effect on the idea generation process.

Experiment 3 is an effort to identify the user preferences about the various aspects of the software interface. This software is in its early stages of development, and for its success it needs to be more user-friendly. Hence through this survey-based experiment, some data is collected so that the way data is presented on the user's monitor can be improved.

This study considers only the quantity of ideas generated by the participants. Possibly, the quantity of ideas in the software condition is adversely affected by the fixation induced by the pictorial representations. Participants spent most of their time looking into the pictorial representations of the CFG's. Hence it is important to separate out the results of fixation from these results. This needs to be explored further in future work.

Again, the effect due to the simultaneous introduction of all the CFG's to the participants also needs to be investigated further. It also needs to be determined whether there is an optimum time at which introducing the CFG's may result in a better quality and quantity of ideas.

Also, it will be interesting to explore the quality and quantity of ideas, if we are providing the pictures of components alone to the participants, instead of presenting the concepts in the form of CFG's. From the participant interviews, few of the participants found it difficult to understand the underlying candidate ideas from the CFG's. Many of them said that they generated their ideas based on the insights from the component pictures. The effect of this factor on the experimental results also needs to be explored further.

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APPENDIX A

MATERIALS USED FOR EXPERIMENT 1

<u>Experimental Script: Sketching only</u>

Items required for the experiment

- ☐ Participant consent forms (2 copies)
- ☐ Participant comments sheets
- ☐ Taped down Paper for sketching divided into multiple sections & numbered
- ☐ Taped down problem description
- ☐ Time Recording Sheet
- ☐ Survey
- ☐ Sheet for recording the questions and answers
- ☐ Stop watch utensils
- ☐ Multiple colored writing(black, blue, green, light blue, pencil)
- ☐ Paper
- ☐ Tape
- ☐ Extra paper
- ☐ Stapler
- ☐ Wire cutters
- ☐ Arbor Press
- ☐ Safety goggles
- ☐ String
- ☐ Numbered address labels
- ☐ Payment vouchers
- ☐ Prototype materials
    a. Wire
    b. Pliers (3)
    c. Arbor Press

International Student Protocol

To receive compensation for this study you must be a US citizen or currently on Texas A&M payroll. Does either of these apply to you? If they are international students not on the payroll then they cannot be paid for the experiment.

- ☐ Participant consent forms (2 copies)
- ☐ Black Pen
- ☐ Taped down paper
- ☐ Covered and taped down design problem instructions

Consent Protocol

1. As soon as participants arrive for the experiment hand out informed consent procedure (2 copies to each person).

2. Read the following statement:

   "You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.
   You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem with a short survey at the end of the experiment. The study will require approximately 3 hours. Please let me know if you have any questions about the experiment."
3. Wait until all of the participants have finished reading to proceed with the experiment. Then say**, "If you agree to participate please sign the form and keep the second copy for your records."**

4. Pick up the consent forms. **"Please put away your copy of the consent forms."**

Make sure that the participants are not having their own pens accessible to them during the experiment. Also make sure that they are not monitoring the time using their mobile phones.

Hello and thank you for taking time to participate in this research study today. Please turn off all cell phones.

This experiment has multiple activities and all three hours will be required. Your effort will be compensated with $25 paid out immediately after completion of all activities or extra credits for your design class. You must agree to not discuss any aspects of the study with other Texas A&M students until after May 1, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?
Record the questions and answers in case of any.

5. Uncover participant instructions

Make sure every participant has each of the materials

This study is seeking to understand the engineering idea generation process. Today your task will be to generate as many ideas as possible that could help to solve the given design problem. There is up to three hours time allotted for this activity, but other activities will fill any remaining time. While generating ideas, be sure to do the following:

- **Generate as many solutions as possible.**
- **Write down everything you can think of even if it does not meet the problem's constraints.**
- **The goal is to generate as many high quality solutions with as great of variety as possible.**
- **Nonconventional, technically infeasible, and far out ideas are also encouraged. This helps to generate unique feasible solutions.**

Sketch and add additional words as needed to describe your ideas. Put one idea in each box on the sheet of paper in front of you in the order of numbers given in the boxes. Various colors of pens will be used to keep track of when items are written. Please raise your hand if you need additional paper or have questions during the experiment.
The following design problem will be the basis for which you will generate solutions:

> **Design Problem: Design a small object made of only steel wire of maximum 9" length to bind papers together.**
> **Requirement: The object must securely bind 10 pages of paper together.**
> **Constraint: The papers should not be damaged.**

Different geometries are considered to be different ideas.

You may choose when to end the idea generation session and move on to the next task. When you are ready to move on to the next task please raise your hand.

You can use the entire three hours for idea generation.
Are there any questions?
Record the questions and answers in case of any.
You may begin.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**. or

Why Did you decided to Move on Sheet-Sketching
Record Time(Use the time recording sheet)
Hand over the corresponding participant comments sheet.
Please write down why you decided to end the idea generation session.

Building Prototypes
****????Break???***
Remove

- ☐ Black pen

Add

- ☐ Box of prototype materials
- ☐ Blue Pen

Your second task of the day will be to make physical prototypes of your ideas using the materials provided.

You will have up to the reminder of the three hours to build prototypes, but other activities will fill any remaining time. Remember, while generating ideas be sure to do the following:

- **Generate as many solutions as possible.**
- **Write down everything you can think of even if it does not meet the problem's constraints.**
- **The goal is to generate as many high quality solutions with as great of variety as possible.**
- **Nonconventional, technically infeasible, and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **Write down all your ideas even if it cannot be built from the materials provided. Put an "X" next to any of your ideas that cannot be built from the materials provided.**

Sketch and add additional words as needed to describe your ideas. Put one idea in each box on the page. There are supplies in front of you that will allow you to make prototypes of your ideas. For each idea, you should build a prototype of it. If you cannot build a particular idea then just sketch it and put an X next to the sketch.
demo(Use the script for demo)

If new ideas or modifications are thought of, sketch and build those ideas in the separate boxes on the provided sheet of paper, i.e. one idea with sketch (es) per box.

Please raise your hand if you need additional paper or have questions during the experiment.
You may choose when to end the idea generation session and move on to the next task. When you are ready to move on to the next task please raise your hand.
Are there any questions?
Record the questions and answers in case of any.
You may begin building now.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**. or

<u>Why Did you decided to Move on Sheet-Building</u>
Record Time(Use the time recording sheet)
Hand over the corresponding participant comments sheet.
Please write down why you decided to end the idea generation session.

<u>Testing the Designs</u>
Add

- Green pen
- 10 pages of paper

Remove

- Blue pen

The next task is to test your designs. Use the stack of paper to test the functionality of your design. Put a star next to the sketches of your designs that if built accurately would meet the design problem requirements. Put an X next to the designs that do not. Again, if new ideas or modifications are thought of, sketch, build and test those ideas as well.
Provide the numbers sheet.
When you are finished testing your ideas please attach the corresponding number to them. Please raise your hand when you are finished.
Record Time(Use the time recording sheet)
Help the participant in attaching the numbers.
(At the end of allotted time) **Please stop the activity**.

<u>Additional Idea Generation and Testing</u>
(Only if the participant is left out with extra time)
Remove
- Green pen

Add
- Light blue pen

Continue to generate ideas, build prototypes, and then test them. Most people can continue to generate new ideas even after they think they have run out of ideas.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**.

<u>Sketch examples of Wire paper clips</u>
Remove
- Green/Light blue pen

Add
- pencil

Please sketch examples of wire paper clips you remember seeing before other than the ones you have drawn already, build them, test them and attach the corresponding number to them.
Please raise your hand when you are finished with both tasks.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**.

<u>Survey</u>
Add
- Survey

This is the final part of the experiment. Please fill out the attached survey.

Wait for participants to finish the survey and pick them up.
Discuss informal survey questions.
This is a pilot experiment so I want to ask a few more questions to help us refine this study.
When you heard the design problem, what was the first thing that came to your mind?

In this study, we are expecting the participants to sketch various types of paper clips. Do you think changing the word "bind" with any of the following words will help in that respect?
Attach, secure, fasten, tie, join, connect

Do you think the design problem can be made clearer to you in any other ways?

You may take the steel wire and the instruments home and build the ideas you already generated. You will have up to a week time to return them. If you return your ideas built, that will be considered as superior effort and you will be paid a bonus of 10$ or given additional extra credit in your design class. This is fully voluntary.

Thank you for your participation and here is a voucher with payment information/I will make sure that you will receive your extra credit. To receive compensation, follow the directions on the voucher. This concludes your portion of the study. Please remember to not discuss this study with your classmates until after May 1, 2010 since this will bias the data. If you have any questions about this study I can answer them at this time.

Record the questions and answers in case of any.

Collect the e-mail id of the participant. At the end scan the drawing sheet and send them.

<u>Experimental Script: Building</u>

Items required for the experiment

- ☐ Participant consent forms (2 copies)
- ☐ Participant comments sheets
- ☐ Taped down Paper for sketching divided into multiple sections & numbered
- ☐ Taped down problem description
- ☐ Time Recording Sheet
- ☐ Survey
- ☐ Sheet for recording the questions and answers
- ☐ Stop watch utensils
- ☐ Multiple colored writing(blue, green, light blue, pencil)
- ☐ Paper
- ☐ Tape
- ☐ Extra paper
- ☐ Stapler
- ☐ Wire cutters
- ☐ Arbor Press
- ☐ Safety goggles
- ☐ String
- ☐ Numbered address labels
- ☐ Payment vouchers
- ☐ Prototype materials
    a. Wire
    b. Pliers
    c. Arbor Press

International Student Protocol

To receive compensation for this study you must be a US citizen or currently on Texas A&M payroll. Does either of these apply to you? If they are international students not on the payroll then they cannot be paid for the experiment.

- ☐ Participant consent forms (2 copies)
- ☐ Blue Pen
- ☐ Taped down paper
- ☐ Covered and taped down design problem instructions
- ☐ Box of prototyping materials

Consent Protocol

1. As soon as participants arrive for the experiment hand out informed consent procedure (2 copies to each person).

2. Read the following statement:

   "You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.
   You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem with a short survey at the end of the experiment. The study will require approximately 3 hours. Please let me know if you have any questions about the experiment."
3. Wait until all of the participants have finished reading to proceed with the experiment. Then say**, "If you agree to participate please sign the form and keep the second copy for your records."**

4. Pick up the consent forms. **"Please put away your copy of the consent forms."**

Make sure that the participants are not having their own pens accessible to them during the experiment. Also make sure that they are not monitoring the time using their mobile phones.

Hello and thank you for taking time to participate in this research study today. Please turn off all cell phones.

This experiment has multiple activities and all three hours will be required. Your effort will be compensated with $25 paid out immediately after completion of all activities or with extra credit in your design class. You must agree to not discuss any aspects of the study with other Texas A&M students until after May 1, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?

5. Uncover participant instructions

Make sure every participant has each of the materials

This study is seeking to understand the engineering idea generation process. Today your task will be to generate as many ideas as possible that could help solve the given design problem. There is up to three hours time allotted for this activity, but other activities will fill any remaining time. While generating ideas, be sure to do the following:

- **Generate as many solutions as possible.**
- **Write down everything you can think of even if it does not meet the problem's constraints.**
- **The goal is to generate as many high quality solutions with as great of variety as possible.**
- **Nonconventional, technically infeasible, and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **Write down all your ideas even if it cannot be built from the materials provided. Put an "X" next to any of your ideas that cannot be built from the materials provided.**

Sketch and add additional words as needed to describe your ideas. Put one idea in each box on the sheet of paper in front of you in the order of numbers given in the boxes. There are supplies in front of you that will allow you to make prototypes of your ideas. For each idea, you should build a prototype of it. If you cannot build a particular idea then just sketch it and put an X next to the sketch.

As a part of the experiment you are being asked to build prototypes of your ideas from wire. I will demonstrate the basic tools and materials you have in front of you.
script for demonstrating tools*

Various colors of pens will be used to keep track of when items are written.
Please raise your hand if you need additional paper or have questions during the experiment.

The following design problem will be the basis for which you will generate solutions:

> **Design Problem: Design a small object made of only steel wire of maximum 9” length to bind papers together.**
> **Requirement: The object must securely bind 10 pages of paper together.**
> **Constraint: The papers should not be damaged.**

Different geometries are considered to be different ideas.

You may choose when to end the idea generation session and move on to the next task. When you are ready to move on to the next task please raise your hand.

You can use the entire three hours for idea generation.
Are there any questions?
Record the questions and answers in case of any.
You may begin.
Record Time(Use the time recording sheet)
Check whether the participant has sketched all the ideas they build. If not ask them to sketch. Also, check whether they have built all the ideas they have sketched. If not ask them to build it.
(At the end of allotted time) **Please stop the activity**. or

Why Did you decided to Move on Sheet-Building & Sketching

Record Time(Use the time recording sheet)
Hand over the corresponding participant comments sheet.
Please write down why you decided to end the idea generation session.

Testing the Designs

Add

- Green pen
- 10 pages of paper

Remove

- Blue pen

The next task is to test your designs. Use the stack of paper to test the functionality of your design. Put a star next to the sketches of your designs that if built accurately would meet the design problem requirements. Put an X next to the designs that do not. Again, if new ideas or modifications are thought of, sketch, build and test those ideas as well.
Record Time(Use the time recording sheet)
Hand over the address labels.

When you are finished testing your ideas please attach the corresponding number to them. Please raise your hand when you are finished.
Record Time(Use the time recording sheet)
Help the participant in taping down.
Make sure that the participant has built all the ideas sketched.
(At the end of allotted time) **Please stop the activity**.

Additional Idea Generation and Testing

(if the participant is left out with time)
Remove

- Green pen

Add

- Light blue pen

Continue to generate ideas, build prototypes, and then test them. Most people can continue to generate new ideas even after they think they have run out of ideas.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**.

Sketch examples of Wire paper clips

Remove

- Light blue/Green pen

Add

- pencil

Make sure you have put a star or an "X" next to all of your sketches to indicate if the idea meets the constraints of the design problem.

Please sketch examples of wire paper clips you remember seeing before other than the ones you have drawn already, build them, test them and attach the corresponding number to them.

Please raise your hand when you are finished with both tasks.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**.

Survey

Add

- Survey

This is the final part of the experiment. Please fill out the attached survey.

Wait for participants to finish the survey and pick them up.

Discuss informal survey questions.
This is a pilot experiment so I want to ask a few more questions to help us refine this study.
When you heard the design problem, what was the first thing that came to your mind?

In this study, we are expecting the participants to sketch various types of paper clips. Do you think changing the word "bind" with any of the following words will help in that respect?
Attach, secure, fasten, tie, join, connect.

Do you think the design problem can be made clearer to you in any other ways?

You may take the steel wire and the instruments home and build the ideas you already generated. You will have up to a week time to return them. If you return your ideas built, that will be considered as superior effort and you will be paid a bonus of 10$ or given additional extra credit in your design class. This is fully voluntary.
Thank you for your participation and here is a voucher with payment information/I will make sure that you will receive your extra credit. To receive compensation, follow the directions on the voucher. This concludes your portion of the study. Please remember to not discuss this study with your classmates until after May 1, 2010 since this will bias the data. If you have any questions about this study I can answer them at this time.
Record the questions and answers in case of any.

Experimental Script: Building & Testing

Items required for the experiment

- ☐ Participant consent forms (2 copies)
- ☐ Participant comments sheets
- ☐ Taped down Paper for sketching divided into multiple sections & numbered
- ☐ Taped down problem description
- ☐ Time Recording Sheet
- ☐ Survey
- ☐ Sheet for recording the questions and answers
- ☐ Stop watch utensils
- ☐ Multiple colored writing(black, blue, green, light blue, pencil)
- ☐ Paper
- ☐ Tape
- ☐ Extra paper
- ☐ Stapler
- ☐ Wire cutters
- ☐ Arbor Press
- ☐ Safety goggles
- ☐ String
- ☐ Numbered address labels
- ☐ Payment vouchers
- ☐ Prototype materials
    a. Wire
    b. Pliers (3)
    c. Arbor Press

<u>International Student Protocol</u>

To receive compensation for this study you must be a US citizen or currently on Texas A&M payroll. Does either of these apply to you? If they are international students not on the payroll then they cannot be paid for the experiment.

- ☐ Participant consent forms (2 copies)
- ☐ Blue Pen
- ☐ Box of prototyping materials
- ☐ Taped down paper
- ☐ Covered and taped down design problem instructions
- ☐ 10 sheets of paper

Consent Protocol

6. As soon as participants arrive for the experiment hand out informed consent procedure (2 copies to each person).

7. Read the following statement:

   "You are being asked to participate in a research study on engineering design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.
   You will be asked to complete a series of tasks. You will be asked to generate ideas for a design problem with a short survey at the end of the experiment. The study will require approximately 3 hours. Please let me know if you have any questions about the experiment."

8. Wait until all of the participants have finished reading to proceed with the experiment. Then say**, "If you agree to participate please sign the form and keep the second copy for your records."**

9. Pick up the consent forms. **"Please put away your copy of the consent forms."**

Make sure that the participants are not having their own pens accessible to them during the experiment. Also make sure that they are not monitoring the time using their mobile phones.

Hello and thank you for taking time to participate in this research study today. Please turn off all cell phones.
This experiment has multiple activities and all three hours will be required. Your effort will be compensated with $25 paid out immediately after completion of all activities or with extra credit in your design class. You must agree to not discuss any aspects of the study with other Texas A&M students until after May 1, 2010 since this will bias the results. Your participation is voluntary. Are there any questions before we begin?
Record the questions and answers in case of any.

10. Uncover participant instructions

Make sure every participant has each of the materials

This study is seeking to understand the engineering idea generation process. Today your task will be to generate as many ideas as possible that could help solve the given design problem. There is up to three hours time allotted for this activity, but other activities will fill any remaining time. While generating ideas, be sure to do the following:

- **Generate as many solutions as possible.**
- **Write down everything you can think of even if it does not meet the problem's constraints.**
- **The goal is to generate as many high quality solutions with as great of variety as possible.**
- **Nonconventional, technically infeasible, and far out ideas are also encouraged. This helps to generate unique feasible solutions.**
- **Write down all your ideas even if it cannot be built from the materials provided. Put an "X" next to any of your ideas that cannot be built from the materials provided.**

Sketch and add additional words as needed to describe your ideas. Put one idea in each box on the page in the order of the numbers given in the boxes. There are supplies in front of you that will allow you to make prototypes of your ideas. For each idea, you need to build a prototype of it. If you cannot build a particular idea then just sketch it and put an X next to the sketch. Various colors of pens will be used to keep track of when items are written.
Once you build your idea, use the stack of paper to test the functionality of your design. Put a star next to the sketches of your designs that if built accurately would meet the design problem requirements. Put an X next to the designs that do not.

demo(Use the script for demo)
Please raise your hand if you need additional paper or have questions during the experiment.
The following design problem will be the basis for which you will generate solutions:

> **Design Problem: Design a small object made of only steel wire of maximum 9" length to bind papers together.**
> **Requirement: The object must securely bind 10 pages of paper together.**
> **Constraint: The papers should not be damaged.**

Different geometries are considered to be different ideas.

You may choose when to end the idea generation session and move on to the next task. When you are ready to move on to the next task please raise your hand.
You can use the entire three hours for idea generation.
Are there any questions?
Record the questions and answers in case of any.
You may begin.
Record Time(Use the time recording sheet)
Check whether the participant has sketched all the ideas they build. If not ask them to sketch. Also, check whether they have built all the ideas they have sketched. If not ask them to build it.
(At the end of allotted time) **Please stop the activity**. or

<u>Why Did you decided to Move on Sheet-Building</u>
Record Time(Use the time recording sheet)
Hand over the corresponding participant comments sheet.
Please write down why you decided to end the idea generation session.

<u>Sketching</u>
Remove

- ☐ Box of prototype materials
- ☐ Blue Pen
- ☐ 10 sheets of paper

Add

- ☐ Black Pen

Your second task of the day will be to sketch other ideas you can think of for the same design problem.
Continue to generate ideas. Most people can continue to generate new ideas even after they think they have run out of ideas.
You will have up to the reminder of the three hours to sketch, but other activities will fill any remaining time. Remember while generating ideas; be sure to do the following:

- **Generate as many solutions as possible.**
- **Write down everything you can think of even if it does not meet the problem's constraints.**
- **The goal is to generate as many high quality solutions with as great of variety as possible.**
- **Nonconventional, technically infeasible, and far out ideas are also encouraged. This helps to generate unique feasible solutions.**

Sketch and add additional words as needed to describe your ideas. Put one idea in each box on the sheet of paper in front of you.
Please raise your hand if you need additional paper or have questions during the experiment.
Are there any questions?
Record the questions and answers in case of any.
You may begin sketching.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**. or

<u>Why Did you decided to Move on Sheet-Sketching</u>
Record Time(Use the time recording sheet)
Hand over the corresponding participant comments sheet.
Please write down why you decided to end the idea generation session.

<u>Building the additional ideas</u>
Record Time(Use the time recording sheet)
Add

- Box of prototyping materials
- Maroon Pen

Remove

- Black pen

Please build the additional ideas that you sketched.
********BREAK*********

Testing the Designs

Add

- Green pen
- 10 pages of paper

Remove

- Maroon pen

The next task is to test your new designs. Use the stack of paper to test the functionality of your design. Put a star next to the sketches of your designs that if built accurately would meet the design problem requirements. Put an X next to the designs that do not. Again, if new ideas or modifications are thought of, sketch, build and test those ideas as well.
You may begin now.
Record Time(Use the time recording sheet)
Provide the tape & number sheet.
When you are finished testing your ideas please label them with the corresponding number. Please raise your hand when you are finished.
Record Time(Use the time recording sheet)
Help the participant in taping down.
(At the end of allotted time) **Please stop the activity**.

Additional Idea Generation and Testing

Remove

- Green pen

Add

- Light blue pen

Continue to generate ideas, build prototypes, and then test them. Most people can continue to generate new ideas even after they think they have run out of ideas.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**.

Sketch examples of Wire paper clips

Remove

- Light blue pen

Add

- pencil

Make sure you have put a star or an "X" next to all of your sketches to indicate if the idea meets the constraints of the design problem.

Please sketch examples of wire paper clips you remember seeing before other than the ones you have drawn already, build them, test them and attach the corresponding number to them.

Please raise your hand when you are finished with the task.
Record Time(Use the time recording sheet)
(At the end of allotted time) **Please stop the activity**.

<u>Survey</u>
Add

- Survey

This is the final part of the experiment. Please fill out the attached survey.

Wait for participants to finish the survey and pick them up.
Discuss informal survey questions.
This is a pilot experiment so I want to ask a few more questions to help us refine this study.
When you heard the design problem, what was the first thing that came to your mind?

In this study, we are expecting the participants to sketch various types of paper clips. Do you think changing the word “bind” with any of the following words will help in that respect?
Attach, secure, fasten, tie, join, connect.

Do you think the design problem can be made clearer to you in any other ways?

You may take the steel wire and the instruments home and build the ideas you already generated. You will have up to a week time to return them. If you return your ideas built, that will be considered as superior effort and you will be paid a bonus of 10$ or given additional extra credit in your design class. This is fully voluntary.
Thank you for your participation and here is a voucher with payment information/I will make sure that you will receive your extra credit. To receive compensation, follow the directions on the voucher. This concludes your portion of the study. Please remember to not discuss this study with your classmates until

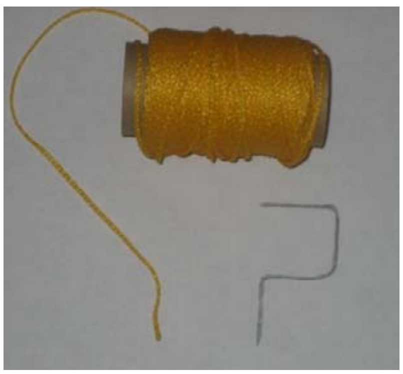
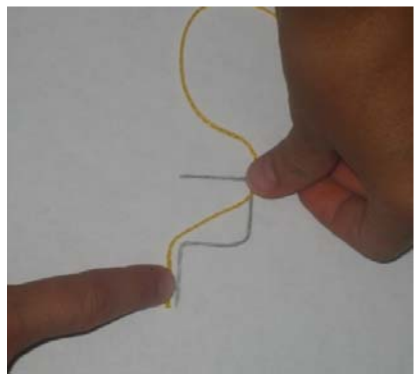
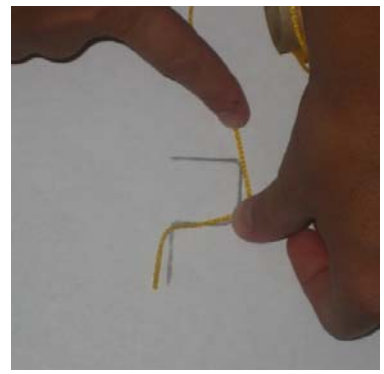
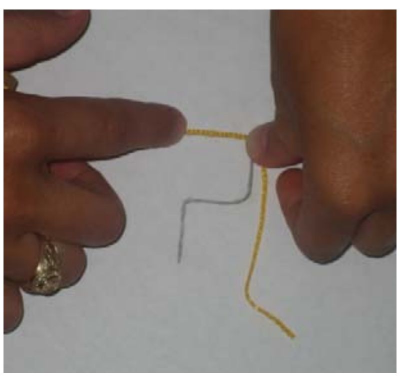
after May 1, 2010 since this will bias the data. If you have any questions about this study I can answer them at this time.
Record the questions and answers in case of any.
Collect the e-mail id of the participant. At the end scan the drawing sheet and send them.

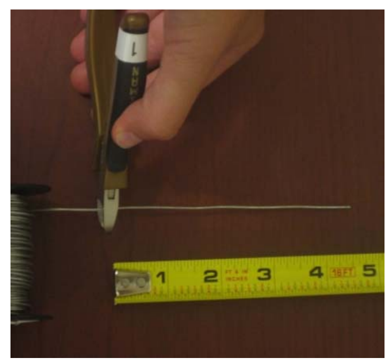
Student Information Sheet - Wire Bending Techniques

Suggested Started Method

Wear your safety goggles

1) Sketch out the desired pattern to scale on paper.
2) Measure the total length of wire needed by tracing the design with the yarn.
3) Lay out the yarn that traced the image, and use the wire cutters (1) to clip the wire at the desired length.

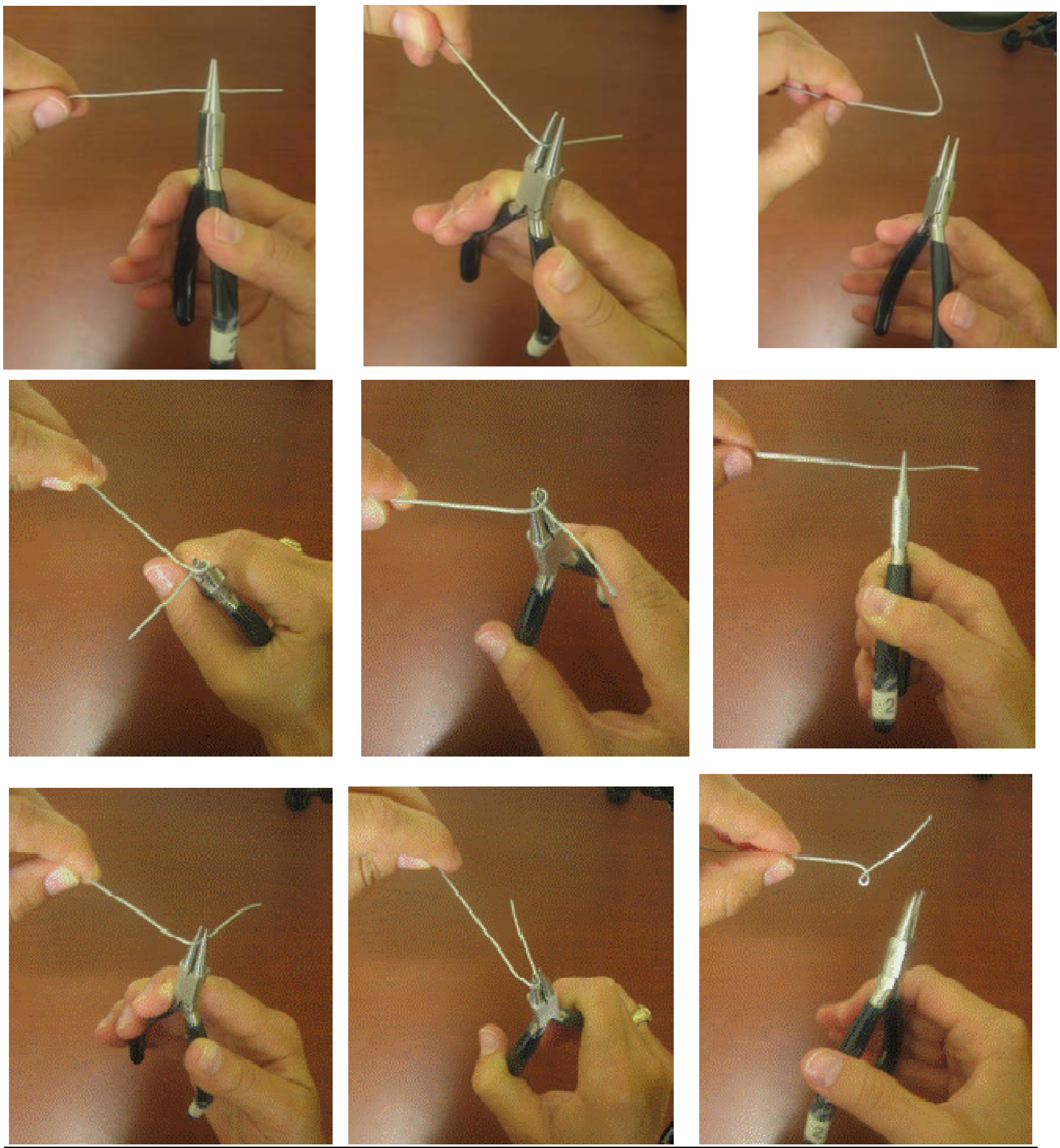





Making rounded edges/curve

- For a **curved edge**, grab the wire with the round nose pliers (2) just before where you want the curve to be and wrap the wire around the pliers with your fingers until 90 degrees (or more/less if desired) is reached. Pull the wire tight so that curve is uniform. Different size curves can be made according to where on the pliers' tip the wire is wound around.

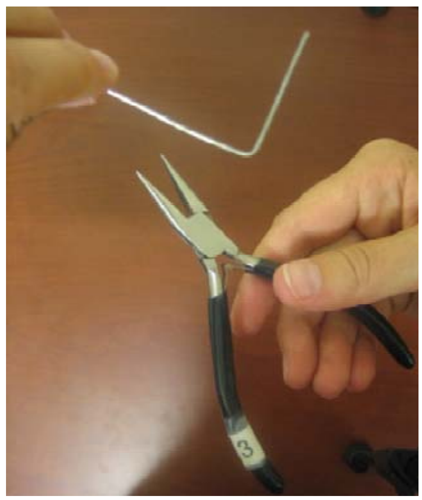
- For a **small loop**, grab the wire with the round nose pliers (2) at the preferred location and twist the pliers in a clockwise/counter-clockwise direction until reaching the desired circumference size. Then slip the pliers out of the loop.



Making a corner

- Grab the wire with the chain nose pliers (3) just before where you want the corner to be and wrap the wire around the pliers with your fingers. Pull the wire tight to make the corner sharp. Clamp the other side of the corner to make the corner sharper.

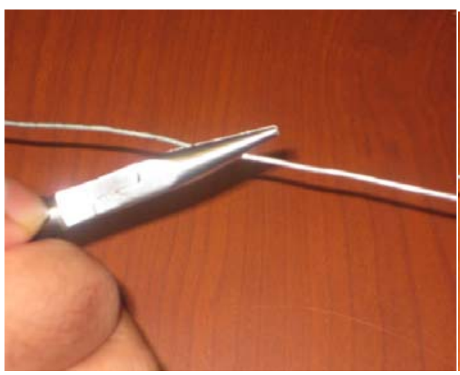
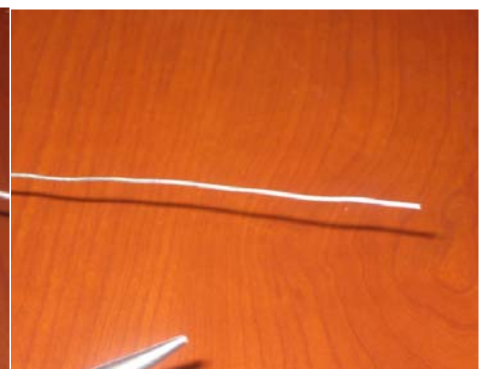


<u>Straightening out the wire</u>

- Using the chain nose pliers (3), start at the section that is in the desired direction. Clamp the square nose pliers at the desired section such that the nose of the pliers will cover maximum length of the wire. Apply force so that the section gets straightened. Repeat multiple times if necessary.



Stiffening the Design

1) Once the design is complete, use the wire cutters (1) to clip off any excess wire.
2) Place the finished design between the bench blocks on the press and press them together. Pressing the wire hard-works it which stiffens the wire. This allows the wire to keep its shape better.



Survey Questions – Sketching only condition

1) During which part of the study did you generate the **most ideas**? If two are equal, please circle both answers.
   a. I. Sketching only
   b. II. Building prototypes and sketching
   c. III. Testing
   d. IV. Continue Generating Ideas, Building& Testing

2) During which part of the study do you feel like you had the **highest quality ideas**? If two are equal, please circle both answers.
   a. I. Sketching only
   b. II. Building prototypes and sketching
   c. III. Testing
   d. IV. Continue Generating Ideas, Building& Testing

3) Which method do you feel helped you to **generate ideas that functioned the best**? If two are equal, please circle both answers.
   a. I. Sketching only
   b. II. Building prototypes and sketching
   c. III. Testing
   d. IV. Continue Generating Ideas, Building& Testing

4) Had you heard about this experiment or 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.

	Strongly Disagree	Disagree	Agree	Strongly Agree
I ran out of **time** before I ran out of ideas.				

Short answer questions.

1) How did being able to sketch affect your ideas?

2) How did being able to build prototypes affect your ideas?

3) How did being able to test your prototypes affect your ideas?

4) Were there any additional materials for building prototypes that would have been useful in the study? If so, what are they?

5) Was the “Wire Bending Techniques” information sheet useful? How might it be improved?

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:

   1^{st} year

   2^{nd} year

   3^{rd}

   4^{th}

   5 or more
6) Country where your undergraduate university is located

   ____

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

Thank you for your time.

Survey Questions – Building Condition

1) During which part of the study did you generate the **most ideas**? If two are equal, please circle both answers.
   a. I. Sketching & Building Prototypes
   b. III. Testing
   c. IV. Continue Generating Ideas, Building& Testing

2) During which part of the study do you feel like you had the **highest quality ideas**? If two are equal, please circle both answers.
   a. I. Sketching & Building Prototypes
   b. III. Testing
   c. IV. Continue Generating Ideas, Building& Testing

3) Which method do you feel helped you to **generate ideas that functioned the best**? If two are equal, please circle both answers.
   a. I. Sketching & Building Prototypes
   b. III. Testing
   c. IV. Continue Generating Ideas, Building& Testing

4) Had you heard about this experiment or 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.

	Strongly Disagree	Disagree	Agree	Strongly Agree
I ran out of **time** before I ran out of ideas.				

Short answer questions.

6) How did being able to sketch affect your ideas?

7) How did being able to build prototypes affect your ideas?

8) How did being able to test your prototypes affect your ideas?

9) Were there any additional materials for building prototypes that would have been useful in the study? If so, what are they?

10) Was the “Wire Bending Techniques” information sheet useful? How might it be improved?

7) What is your sex?
   c. Female
   d. Male

8) What is your age?_______________

9) Overall GPA ________________

10) GPA in Major ________________
11) Year in School
    Undergraduate:
        Freshman
        Sophomore
        Junior
        Senior
    Graduate:
        1st year
        2nd year
        3rd
        4th
        5 or more
12) Country where your undergraduate university is located

    ____

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

Thank you for your time.

Survey Questions – Building & testing condition

5) During which part of the study did you generate the **most ideas**? If two are equal, please circle both answers.
   a. I. Building prototypes and testing
   b. II. Sketching only
   c. III. Testing
   d. IV. Continue Generating Ideas, Building& Testing

6) During which part of the study do you feel like you had the **highest quality ideas**? If two are equal, please circle both answers.
   a. I. Building prototypes and testing
   b. II. Sketching only
   c. III. Testing
   d. IV. Continue Generating Ideas, Building& Testing

7) Which method do you feel helped you to **generate ideas that functioned the best**? If two are equal, please circle both answers.
   a. I. Building prototypes and testing
   b. II. Sketching only
   c. III. Testing
   d. IV. Continue Generating Ideas, Building& Testing

8) Had you heard about this experiment or 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.

	Strongly Disagree	Disagree	Agree	Strongly Agree
I ran out of **time** before I ran out of ideas.				

Short answer questions.

11) How did being able to build prototypes affect your ideas?

12) How did being able to sketch affect your ideas?

13) How did being able to test your prototypes affect your ideas?

14) Were there any additional materials for building prototypes that would have been useful in the study? If so, what are they?

15) Was the “Wire Bending Techniques” information sheet useful? How might it be improved?

13) What is your sex?
   e. Female
   f. Male

14) What is your age?_______________

15) Overall GPA ________________

16) GPA in Major ________________
17) Year in School
   Undergraduate:
      Freshman
      Sophomore
      Junior
      Senior
   Graduate:
      1st year
      2nd year
      3rd
      4th
      5 or more
18) Country where your undergraduate university is located
   ____

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

Thank you for your time.

Script 1 - Time Break up

Sl No	Activity	Time period(min)	Total time
1	Consent Protocol	10	10
2	Participent instructions and questions	3	13
3	Design problem (explain & questions)	3	16
4	Sketching	45	1:01
5	******Break*******	5	1:06
6	Continue Sketching	40	1:46
7	******Break*******	5	1:51
8	Buliding instructions	4	1:55
9	Demo of instruments	10	2:05
10	Building	15	2:20
11	Testing of designs	10	2:30
12	Sketching examples of paper clips seen	10	2:40
13	Survey & final instructions	10	2:50

<u>Script 1 - Time Recording Sheet</u>

Activity	Pen Colour	Start Time	End Time	Max Time
Sketching	Black			1:01 - Break 1
Continue sketching	Blue			1:46 - Break2
Building	Blue			2:20
Testing	Green			2:30
Sketching wire paper clips seen	Pencil			2:40

Break 1: Please take a 5 min break. Get up and walk around. Rest rooms are out the room, down the hall to the right

Break2 : Please take a 5 min break

<u>Script 2 - Time Recording Sheet</u>

Activity	Pen Colour	Start Time	End Time	Max Time
Sketching & Building	Blue			1:05 - Break 1
Sketching & Building	blue			2:00 - Break2
Sketching & Building	blue			2:20
Testing	Green			2:30
Sketching wire paper clips seen	Pencil			2:40

Script 3- Time Break up

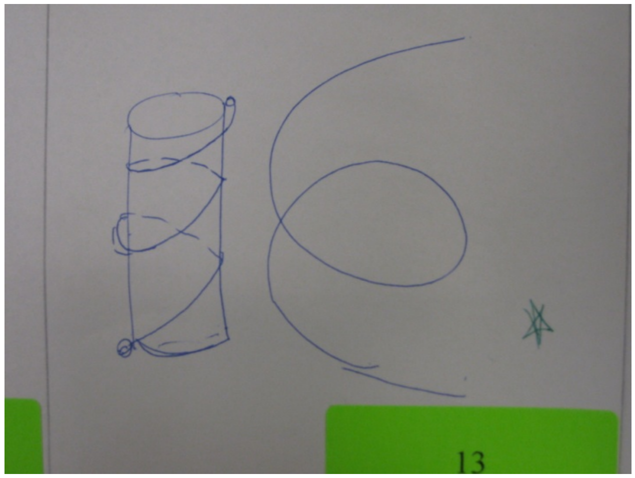
Sl No	Activity	Time period(min)	Total time
1	Consent Protocol	10	10
2	Participent instructions and questions	3	13
3	Design problem (explain & questions)	3	16
4	Demo of instruments	10	26
5	Building & Testing	34	1:00
6	******Break*******	5	1:05
7	Continue building & testing	30	1:35
8	Sketching instructions	5	1:40
9	Sketching	15	1:55
10	******Break*******	5	2:00
11	Continue sketching	15	2:15
12	Building additional ideas sketched	10	2:25
13	Testing of new designs	5	2:30
14	Sketching examples of paper clips seen	10	2:40
15	Survey & final instructions	10	2:50

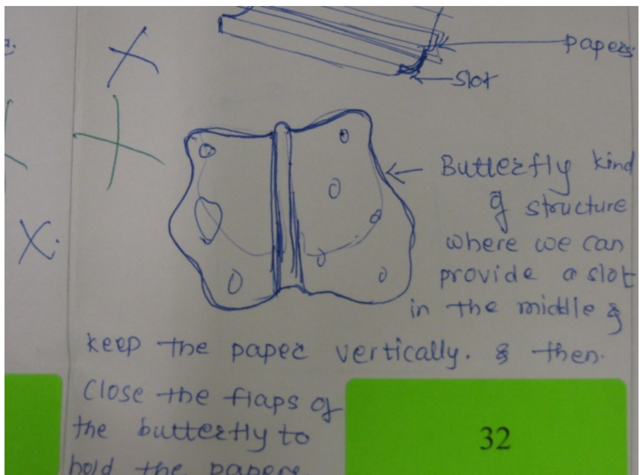
Script 3 - Time Recording Sheet

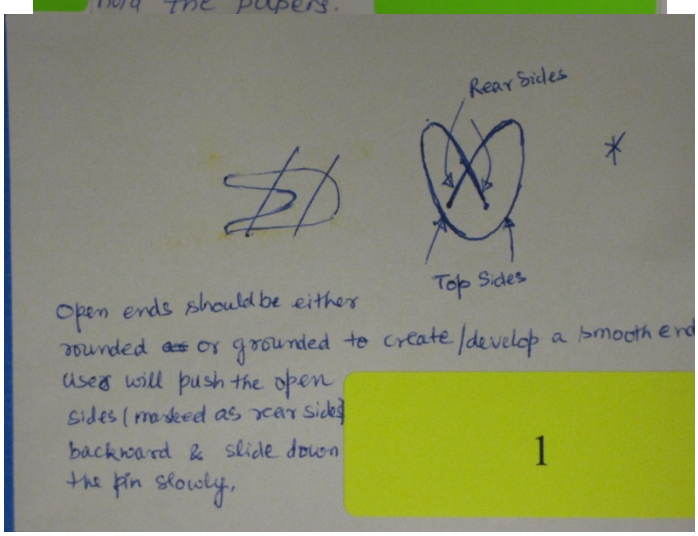
Activity	Pen Colour	Start Time	End Time	Max Time
Building & testing	Blue			1:00 - Break 1
continue building & testing	Blue			1:35
Sketching	Black			1:55 - Break2
continue sketching	Black			2:15
Building additional ideas	Maroon			2:25
Testing	Green			2:30
sketching paper clips seen	pencil			2:40

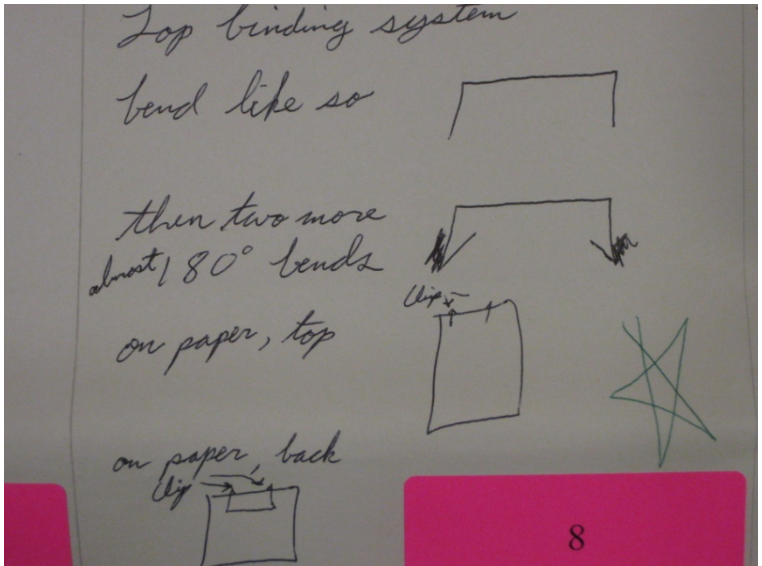
APPENDIX B

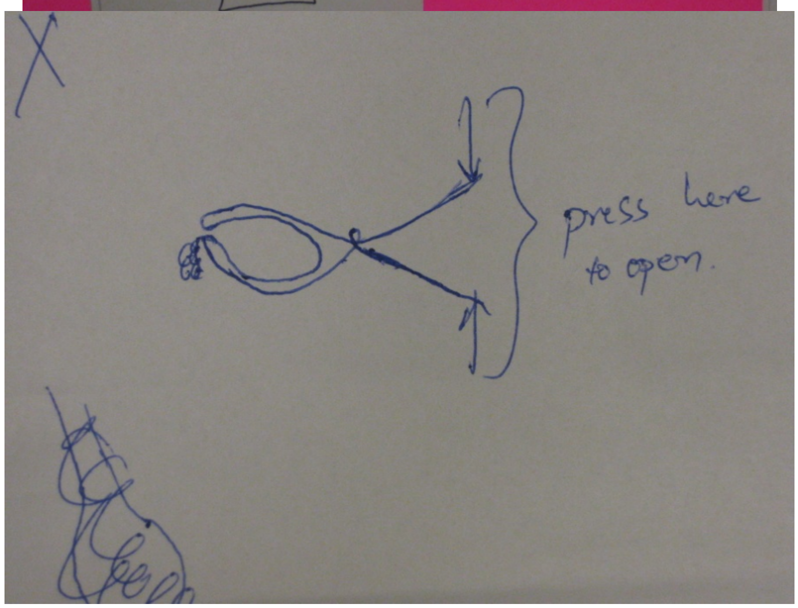
EXAMPLE SOLUTIONS FROM EXPERIMENT 1

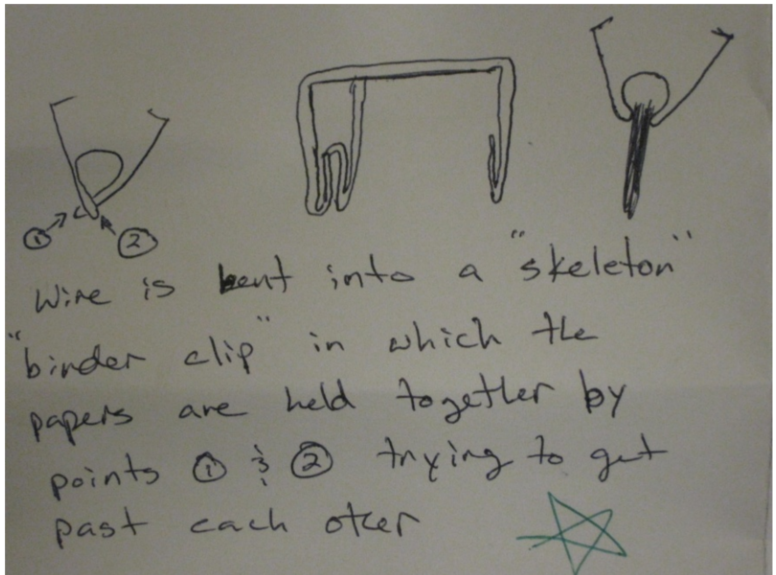

13

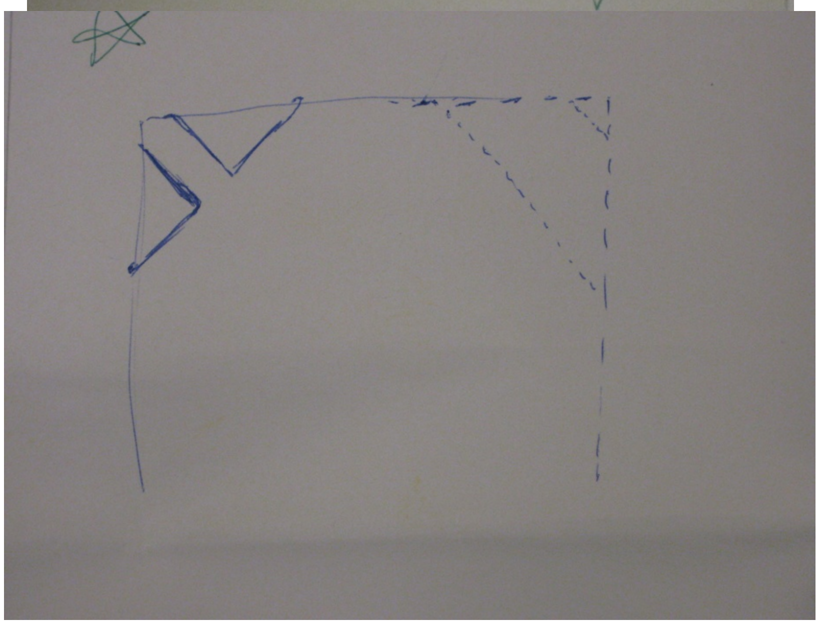

papers
Slot
Butterfly kind of structure where we can provide a slot in the middle & keep the paper vertically. & then. Close the flaps of the butterfly to hold the papers.
32


Rear Sides
Top Sides
Open ends should be either rounded or grounded to create/develop a smooth end
user will push the open sides (marked as rear sides) backward & slide down the pin slowly.
1


Top binding system
bend like so
then two more
almost 180° bends
clip
on paper, top
on paper, back
clip
8


press here
to open.


1
2
Wire is bent into a "skeleton"
"binder clip" in which the
papers are held together by
points 1 & 2 trying to get
past each otcer



APPENDIX C

MATERIALS USED FOR EXPERIMENT 2

Visualize IT – Experimenter Script - Control

Checklist

	PC 1
Computer running	o
Projector	o
Mouse	o
Keyboard	o
Logged in	o
Training lecture is ready	o

- O 5 Mini-Quizzes with identificators, put upside down on blank paper, match each quiz to the PC– 2009-mm-dd_EX_PC1-4!
- O Sketch paper at each workplace (8.5 x 11)
- O Extra paper at hand
- O 6 Pens each
  - o blue (creation) – **one at each workplace**
  - o green (creation)
  - o black (creation)
  - o red (creation)
  - o purple (creation)
  - o pink (creation)
- O Stopwatch
- O 10 consent forms
- O 5 pens for signatures on the round table
- O Stapler
- O 5 Water Lifting Problem descriptions & 5 Water Lifting functional model printouts – place on left top corner, upside down
- O 5 Peanut Sheller Problem descriptions & 5 Peanut Sheller functional model printouts – AFTER BREAK place on left top corner, upside down
- O 5 Questionnaires

Prior to experiment

Run a random number generator to predict which participant, based on the order they will enter the experiment room, will sit at which workplace. (Www.randomizer.org. Number of participants out of 5.) Enter PC numbers in list above. Save random assignment in the shared experiment folder. Create an experiment specific subfolder: year-month-day_NumberOfExperiment, e.g. 2009-06-03_E4, which will contain all data from that specific experiment.
PC assignment (based on the order of the participants entering the room, write characteristic (red shirt, blue glasses, …) on line, so you know whom to send where):

- P1 -> WP ______________________________
- P2 -> WP ______________________________
- P3 -> WP ______________________________
- P4 -> WP ______________________________

Consent

As soon as each participant arrives: **“Please sit down at the round table. You can put your backpack close to the wall. Please turn off or silence your cell phones. We are waiting for x more participants before we begin./ We are ready to begin.”**

As everybody has arrived and taken their seats, hand out consent forms, two per participant. Have pens ready on the table. Read the following statement:

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

You will be asked to complete a series of tasks. You will be asked to generate ideas and concepts for a given design problem, to complete a questionnaire and participate in a short interview at the end of the experiment. The study will require approximately three hours. Please let me know if you have any questions about the study.”

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, **“Do you have any questions?** (Answer.) **If you agree to participate please sign the consent form and keep the copy for your records.**”

“I have on request before we begin: Please do not discuss the experiment with anybody in the Mechanical Engineering Department at TAMU until after December 31, 2010. The reason is that it will bias the results if a participant knows what the design problem is or what the tasks are.”

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

Training

Lecture

"Now you will relocate to your workplace." [Instruct who should sit where]. Wait until all participants have sat down. **"Please sit so that you can see the projection."**
"The experiment today is based on function structures. To help refresh your memory you will now attend a recorded mini-lecture. It will take 10 minutes and will be followed by a quiz. The quiz will concentrate on the information presented in the mini-lecture. I will start the lecture now."
After the end of the lecture, <u>hand out blue pens,</u> one for each participant.
"Please turn around to the table. You have 3 minutes to complete the quiz. It is right in front of you. Please turn the quiz over now and start."
<u>Shut down Computer and Projector.</u>
"The time is up. Please hand me the quiz."
Collect quizzes.

Training Problem

"In the experiment, you will be creating solutions for a design problem assisted by its function structure.
For the training, the design problem is called water lifting device. You have a printout of the water lifting problem and its functional model in the left top corner of your desk. Please take these sheets now. I will read the problem description to you, please follow along.
Water lifting device. For people living in rural areas in developing countries there is often the necessity to deliver the daily water supply for their own daily needs, their animals and their crop. Often all water needs to be lifted from a well, as rain may be scarce. This is a strenuous and time intensive task that sometimes puts restrictions on the size of the crops. Therefore a water-lifting device that eases the process of unearthing water is needed.
Goals:

- Low cost.
- Easy to maintain.
- Well depth about 10m/ 30feet

Do you have questions regarding the design problem?
Then, you have 20 minutes to sketch concepts to solve the water lifting design problem. I will give you a 3 minute warning before the time is up. You have blank sheets of paper in front of you and a pen to sketch. Do you remember the slide with the functional model, the component layout, the

picture and the hand sketch of the toothbrush? [Wait for answer] **Because, we expect you to sketch concepts, just as the conceptual sketch you saw in the middle of the slide. Your conceptual sketches do not need to be pretty, and they do not need to be complete. And you can annotate your sketches if you like. Try to generate as many conceptual sketches as possible. Use a new page for each concept.**
I will start the time now."
Start time.
"You have 3 minutes to finish you concept generation."
"The time is up. Please put the pens down. You'll have a five minute break now. Afterwards the main part of the experiment will start. The restrooms are right there (point in direction)**, and a water fountain is around the corner from them. Please be back on time."**

Concept Generation

- Collect and staple generated concepts.
- Collect water lifting problem descriptions and function structures.
- Refill blank paper.
- Place Peanut Sheller problem description and functional model upside down in upper left corner of desk.

“Welcome back. Please sit at the same workplace as before the break.”
Wait until all participants are back.
“You will now start the main part of the experiment. It is the same task as you worked on just before the break: You will be given a problem description and a function structure, and you are asked to sketch concepts solving the design problem based on the function structure. Do you have any questions regarding the general task?
You will have 55 minutes total to generate concepts. I will exchange your pen each 10 minutes - after 10, 20, 30, 40 and 50 minutes have passed. I will give you a five minute warning before the time is up.
You have a paper copy of the problem description and of the functional model in the upper left corner of your desk, please take those sheets now.
I will now read the design problem to you and afterwards start the time. Please follow along.
Peanut Sheller: 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 of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.
Goals:

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

Are there any questions?
I will start the time now. You have 55 minutes for the concept generation. I will give you a 5 minute warning before the time is up. Try to generate as many concepts as possible.”

Start time.
"10 minutes are over, I'll exchange your pen."
Collect pens and give GREEN pens to participants.
"20 minutes are over, I'll exchange your pen."
Collect pens and give BLACK pens to participants.
"30 minutes are over, I'll exchange your pen."
Collect pens and give RED pens to participants.
"40 minutes are over, I'll exchange your pen."
Collect pens and give PURPLE pens to participants.
"50 minutes are over, you have 5 minutes left to finish you concept generation and I'll exchange your pen one last time."
Collect pens and give PINK pens to participants.
"The time is up. Please put the pens down. The main part of the experiment is now over, the experiment will conclude with a short questionnaire."

Questionnaire (Pilots and Experiments)

"I'll hand you the questionnaire now. You will have 5 minutes to fill it in. When you are done, please turn it upside down and put it on the table in front of you. "
Hand out one questionnaire to each participant (at the round table in the pilots / at their workplaces in the real experiment). Wait until all participants have completed the questionnaire.

Disbursement

"Thank you very much for your participation in the experiment. You will receive extra credit in your design class as disbursement."
EXTRA CREDIT: Write name and class affiliation down. Do not write date or experiment number down. **"OK, I wrote down that you'd like the extra credit. Once your classmates who volunteered have done the experiment, too, I will send one email to your professor to let him know who should receive the extra credit. Do you have any questions?**

First, Last Name	**Class Affiliation**

"Then, thank you again for your participation. Please do not talk about the experiment to anybody at TAMU until after December 31, 2010, as it will bias the results. Have a good afternoon/ evening."

Clean-up

- Gather each participant’s papers. At the participants workplace:
    - Separate blank paper.
- Clip each participant’s concepts together
- Write identificator on the top sheet year-month-day_numberOfExperiment_PCnumber (e.g. 2009-06-03_E4_P1_PS or _WL)
- Detach the chapter 9 Disbursement page, and store securely, but separate from the consent forms.
- Gather material and prepare room for next experiment

Visualize IT – Experimenter Script - Software Checklist

O Workplaces are set-up	PC 1	PC2	PC3	PC4	PC5
Computer running	1	2	3	4	5
Monitor	1	2	3	4	
Projector					5
Logged in	1	2	3	4	5
Mouse	1	2	3	4	5
Visualize IT software is running	1	2	3	4	
Camtasia is ready	1	2	3	4	
Keyboard moved out of the way	1	2	3	4	

- O 5 Mini-Quizzes with identificators, put upside down on blank paper, match each quiz to the PC– 2009-mm-dd_E#_PC1-4!
- O Sketch paper at each workplace (8.5 x 11)
- O Extra paper at hand
- O 5 Pens each
  - blue (creation) – **one at each workplace**
  - green (creation)
  - black (creation)
  - red (creation)
  - purple (creation)
  - pink (creation)
- O Stopwatch
- O 10 consent forms
- O 5 pens for signatures on the round table
- O Stapler
- O 5 Questionnaires
- O 5 Water Lifting Problem descriptions & 5 Water Lifting functional model printouts – place on left top corner, upside down
- O 5 Peanut Sheller Problem descriptions & 5 Peanut Sheller functional model printouts – AFTER BREAK place on left top corner, upside down

Prior to experiment

Run a random number generator to predict which participant, based on the order they will enter the experiment room, will sit at which workplace. (Www.randomizer.org. Number of participants out of 5.) Enter PC numbers in list above. Save random assignment in the shared experiment folder. Create an experiment specific subfolder: year-month-day_NumberOfExperiment, e.g. 2009-06-03_E4, which will contain all data from that specific experiment.
PC assignment (based on the order of the participants entering the room, write characteristic (red shirt, blue glasses, …) on line, so you know whom to send where):

- P1 -> PC ________________________________
- P2 -> PC ________________________________
- P3 -> PC ________________________________
- P4 -> PC ________________________________

Consent

As soon as each participant arrives: **"Please sit down at the round table. You can put your backpack close to the wall. Please turn off or silence your cell phones. We are waiting for x more participants before we begin./ We are ready to begin."**
As everybody has arrived and taken their seats, hand out consent forms, two per participant. Have pens ready on the table. Read the following statement:
"**You are being asked to participate in a research study on engineering education and design. Please read the consent form. You are not required to participate in this study and may end your participation at any time.**
You will be asked to complete a series of tasks. You will be asked to generate ideas and concepts for a given design problem, to complete a questionnaire and participate in a short interview at the end of the experiment. The study will require approximately three hours. Please let me know if you have any questions about the study."
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, **"Do you have any questions?** (Answer.) **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 Mechanical Engineering Department at TAMU until after December 31, 2010. The reason is that it will bias the results if a participant knows what the design problem is or what the tasks are."
Sign the consent forms and take them. If wished, sign copies for records.

Training

Start Camtasia recording when participants relocate to workplace.

Lecture

"Now you will relocate to your workplace." [Instruct who should sit where]. Wait until all participants have sat down. **"Please sit so that you can see the projection."**
"The experiment today is based on function structures. To help refresh your memory you will now attend a recorded mini-lecture. It will take 10 minutes and will be followed by a quiz. The quiz will concentrate on the information presented in the mini-lecture. I will start the lecture now."
Wait for end of lecture. (hand out blue pens if you forgot to put them on the tables…)
"Please turn around to the table. You have 3 minutes to complete the quiz. It is right in front of you. Please turn the quiz over now and start."
Shut down Computer and Projector.
"The time is up. Please hand me the quiz."
Collect quizzes.

Software Training

"In the experiment, you will be using a software program called Visualize IT. The Visualize IT explorer will show you component layouts, as they were presented in the mini-lecture. Your task is to read the component layouts and to sketch concepts inspired by them.
To make the actual experiment easier, you will first do a training problem in the program. Please click on the Firefox minimized in your task bar. Please note that you are not allowed to visit any other pages besides the Visualize IT software.
For the training, the design problem is called water lifting device. Please click on water lifting device in the upper left corner of your screen. Now, you see the problem description. You have a printout of it and of the functional model in the upper left corner of your desk. Please take those two sheets. I will now read the problem description to you, please follow along.
Water lifting device. For people living in rural areas in developing countries there is often the necessity to deliver the daily water supply for their own daily needs, their animals and their crop. Often all water needs to be lifted from a well, as rain may be scarce. This is a strenuous and time intensive task that sometimes puts restrictions on the size of the crops. Therefore a water-lifting device that eases the process of unearthing water is needed.
Goals:

- Low cost.

- Easy to maintain.
- Well depth about 10m/ 30feet

Do you have questions regarding the design problem?
OK, back to the Visualize IT software. Please click on functional model. Now you see the functional model of the water lifting design problem. Please use the mouse wheel or scroll bar at the right side of the page to look at all elements. You also have a printout of the functional model. Do you have any questions so far? (Answer.)
On the left, underneath Select candidate cluster, please click on PCA Water Lifting clusters. The list of candidates opens up. There are 7 clusters, named A trough G. Each cluster contains 7 component layouts, called candidates, for a total of 49 component layouts. Please click on candidate 1, which is the first one in the list of cluster A. Do you see the component layout of candidate 1? (check screens, wait for answers)
Sometimes, as you can see in candidate 1, not all functions can be replaced with a corresponding component by the software. You will see dark grey boxes showing the functions which have not been replaced by a component. For example, the functions import, export, supply and convert were not replaced with corresponding components. In these cases you need to think about what you might use to fulfill the functional requirement. This is the main reason why the candidates are rather suggestions and an inspiration for concepts than solutions by themselves. Also, sometimes flows will be missing. In candidate 1 there is one flow missing between the shaft n5 and the agitator n5. It is represented by a red arrow, and besides it the words No Flow Information are shown.
There are two different representations available: A word based and a picture based representation of the candidates. On the top of the screen, please click on graph with component images. Now, you see the picture based representation of the component layout. There is a problem with this graph, besides the unknown components and the unknown flow identified earlier: the hydraulic coupler picture was not found and there is an empty space. But, there will always be the component name next to the empty space.
To see the whole candidate, please use the mouse wheel or the scroll bar at the right edge of the screen.
Do you have any questions so far? (Answer.)
Then, you have 20 minutes to sketch concepts to the water lifting design problem based on the component layouts and your own ideas. You have blank sheets of paper in front of you and a pen to sketch. So, please look at the different component layouts, and try to develop solutions to the design problem based on them. Do you remember the slide with the

functional model, the component layout, the picture and the hand sketch of the toothbrush? [Wait for answer] **Because, we expect you to sketch concepts, just as the conceptual sketch you saw in the middle of the slide. Your conceptual sketches do not need to be pretty, and they do not need to be complete. And you can annotate your sketches if you like. Try to generate as many conceptual sketches as possible. Use a new sketch for each concept.**

When you sketch a concept, please write the candidate number that inspired it in the space in the upper right corner of the paper. I will give you a 3 minute warning before the 20 minutes are up. Do you have any questions?

I am starting the time now."

<u>Start time.</u>

"You have 3 minutes to finish you concept generation."

"The time is up. Please put the pens down. You'll have a five minute break now. Afterwards the main part of the experiment will start. The restrooms are right there (point in direction)**, and a water fountain is around the corner from them. Please be back on time."**

Concept Generation

- Minimize Visualize IT software to task bar
- Collect and staple generated concepts.
- Collect water lifting problem descriptions and function structures.
- Collect pens.
- Refill blank paper.
- Place Peanut Sheller problem description and functional model upside down in upper left corner of desk.

"Welcome back. Please sit at the same workplace as before the break."
Wait until all participants are back.
"You will now start the main part of the experiment. It is the same task as you worked on just before the break: You will be given a problem description, a function structure, and component layouts, and you are asked to sketch concepts solving the design problem. Try to use the component layouts as inspiration. When you create a concept inspired by one or multiple component layouts, please put the component layout numbers in the right upper corner of the paper. Do you have any questions regarding the general task?
You will have a total of 1 hour 5 minutes. The first 10 minutes you will look at the different component layouts to find out how they are similar and different. Then, you will have 55 minutes to generate your concepts. I will hand you pens after the first 10 minutes are up. Then, I will exchange your pen each ten minutes, after 10, 20, 30, 40 and 50 minutes have passed. I will give you a five minute warning before the time is up.
Please maximize the Firefox window from the task bar. Click on Peanut Sheller in the upper left corner. Do you see the Peanut Sheller problem description on the screen? (Check screens!) **You have a paper copy of the problem description and of the functional model in the upper left corner of your desk, you may take those sheets now.**
I will now read the design problem to you. Please follow along, either on the screen or on the paper copy.
Peanut Sheller: 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 of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.
Goals:

- Must remove the shell with minimal damage to the peanuts.

- Electrical outlets are not available as a power source.

- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Please click on the functional model. Can you see the functional model of the Peanut Sheller?
Then, click on PCA Peanut Sheller Cluster. Now you should be able to access the different candidates. You have ten minutes to compare and contrast the different component layouts and to think how they solve the design problem. I will give you a 1 minute warning before the time is up. Do you have any questions? (Answer.) **I will start the time now.**
<u>Start time.</u>
You have one minute left.
The time is up. I will now hand you a pen. You can go ahead and sketch concepts to solve the Peanut Sheller design problem based on the component layouts and your own ideas. Try to sketch as many concepts as possible. Please remember to write down the component layout number in the box on the paper if it inspired a concept. You have 55 minutes for the concept generation. I will give you a 5 minute warning before the time is up. Let me know if you have any questions. I am starting the time now."
<u>Start time.</u>
<u>Hand out BLUE pens.</u>
"10 minutes are over, I'll exchange your pen."
<u>Collect pens and give GREEN pens to participants.</u>
"20 minutes are over, I'll exchange your pen."
<u>Collect pens and give BLACK pens to participants.</u>
"30 minutes are over, I'll exchange your pen."
<u>Collect pens and give RED pens to participants.</u>
"40 minutes are over, I'll exchange your pen."
<u>Collect pens and give PURPLE pens to participants.</u>
"50 minutes are over, you have 5 minutes left to finish you concept generation and I'll exchange your pen one last time."
<u>Collect pens and give PINK pens to participants.</u>
"The time is up. Please put the pens down. The main part of the experiment is now over, the experiment will conclude with a short questionnaire."

Questionnaire (Pilots and Experiments)

“I’ll hand you the questionnaire now. You will have 5 minutes to fill it in. When you are done, please turn it upside down and put it on the table in front of you. “

Hand out one questionnaire to each participant (at the round table in the pilots / at their workplaces in the real experiment). Wait until all participants have completed the questionnaire.

Disbursement

"Thank you very much for your participation in the experiment. You will receive extra credit in your design class as disbursement."
EXTRA CREDIT: Write name and class affiliation down. Do not write date or experiment number down. **"OK, I wrote down that you'd like the extra credit. Once your classmates who volunteered have done the experiment, too, I will send one email to your professor to let him know who should receive the extra credit. Do you have any questions?**

First, Last Name	**Class Affiliation**

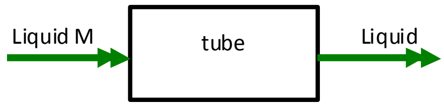
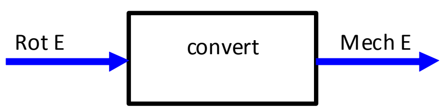
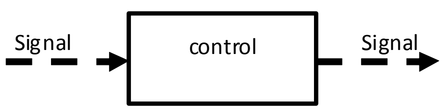
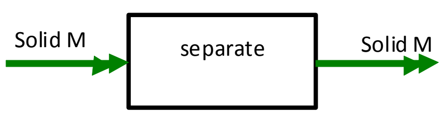
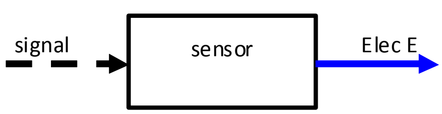
"Then, thank you again for your participation. Please do not talk about the experiment to anybody in the Mechanical Engineering Department at TAMU until after December 31, 2010, as it will bias the results. Have a good afternoon/ evening."

Clean-up

- Gather each participant’s papers. At the participants workplace:
  - Separate blank paper.
- Staple each participant’s concepts together.
- Write identificator on the top sheet year-month-day_numberOfExperiment_PCnumber (e.g. 2009-06-03_Enumber_PC1_PS or _WL)
- Save the Camtasia recording to the documents folder to the desktop of the used PC. Naming convention: year-month-day_numberOfExperiment_PCnumber (e.g. 2009-06-03_Enumber_PC1_PS or _WL)
- Transfer the Camtasia recording files into a folder on IDREEM1. Shared experiment folder, create a folder named year-month-day_numberOfExperiment (e.g. 2009-06-03_E4)
- After the transfer was successful, move file from desktop to document folder of the computer (under the login used).
- Detach the chapter 7 Disbursement page, and store securely, but separate from the consent forms.
- Gather material and prepare room for next experiment

Visualize IT – Function Quiz

Are the following functions or components? Please **mark the appropriate column** for each example

	Function	Component
	Function	Component
	Function	Component
	Function	Component
	Function	Component
	Function	Component
	Function	Component

Is each one of the following statements correct? **Mark True or False** in the appropriate column.

Functions are solution neutral.	TRUE	FALSE
Each function can only be fulfilled by exactly one component.	TRUE	FALSE
A Black Box model shows all functions of a device in detail.	TRUE	FALSE
Functions can have multiple inputs and outputs.	TRUE	FALSE
A component layout represents a possible product configuration.	TRUE	FALSE
Human, Gas, Solid and Liquid are types of material flows.	TRUE	FALSE
Electrical, Mechanical, Human, and Acoustic are types of Energy flow.	TRUE	FALSE
There are four types of input and output flows.	TRUE	FALSE

Visualize IT Questionnaire - Control

Question	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
How to mark your answer: Please circle your answer.	1	2	(3)	4	5
The mini-lecture was helpful to understand the relation between component layouts and functional models.	1	2	3	4	5
The mini-lecture was sufficiently detailed to understand the new concepts.	1	2	3	4	5
The mini-lecture was too long.	1	2	3	4	5
A more detailed and longer lecture is needed.	1	2	3	4	5
The exercise was a good preparation for the experiment.	1	2	3	4	5
The exercise was too long.	1	2	3	4	5
I liked the water lifting design problem.	1	2	3	4	5
I liked the peanut sheller design problem.	1	2	3	4	5
I knew what I was supposed to do during the experiment.	1	2	3	4	5
It was clear to me that I was supposed to sketch concepts solving the design problem.	1	2	3	4	5
The functional model helped me generate ideas.	1	2	3	4	5

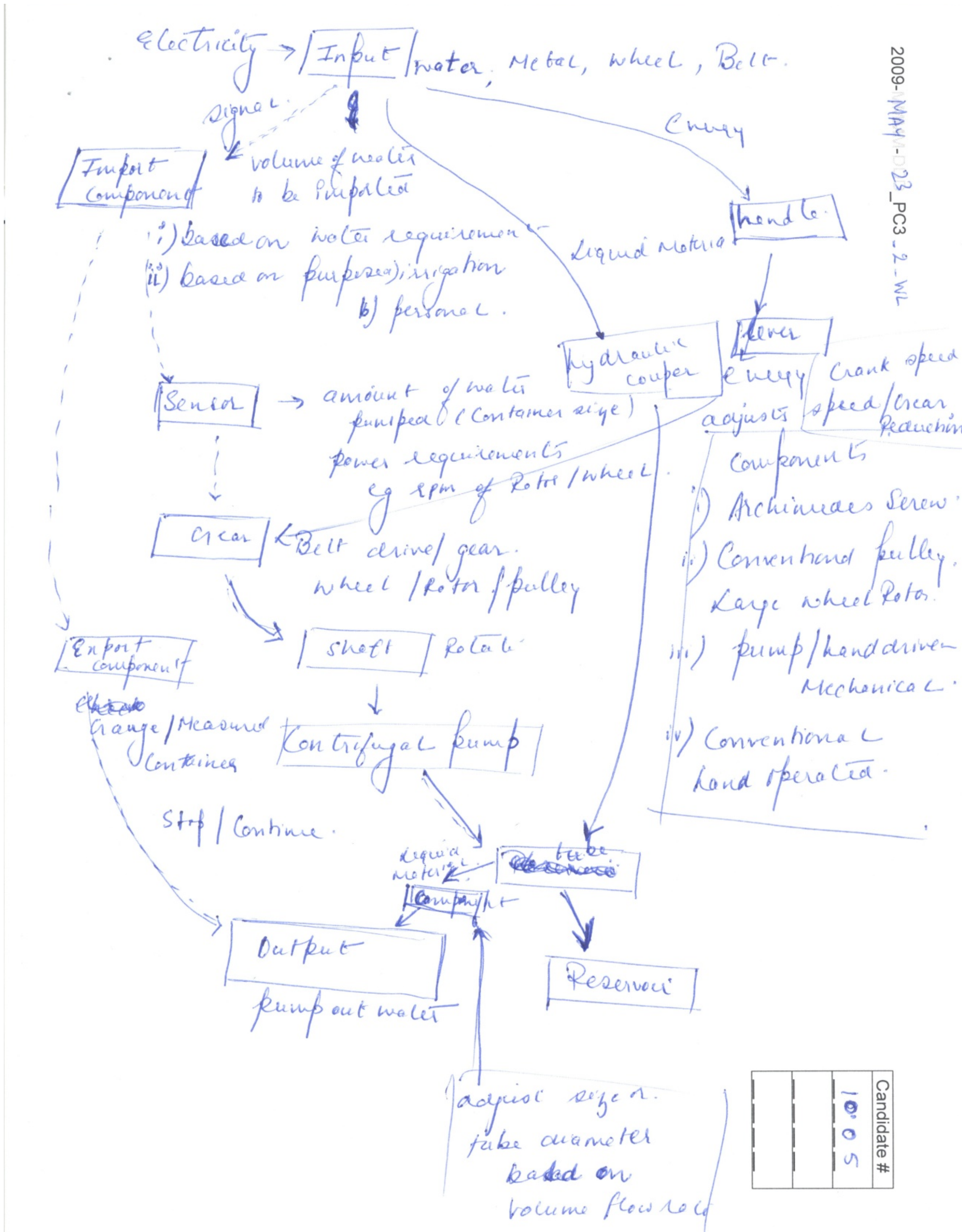
Question					
How to mark your answer: Please cross your choice.			**O option 1**	**⊗ option 2**	**O option 3**
Do you have prior experience in sketching designs?				O Yes	O No
Have you seen the water lifting design problem before (e.g. in another experiment)?				O Yes	O No
Have you seen the peanut sheller design problem before (e.g. in another experiment)?				O Yes	O No
What mechanical engineering design class are you currently enrolled in (summer 2009)?	O MEEN 401	O MEEN 402	O MEEN 404		O None
What mechanical engineering design classes have you already taken at TAMU?	O MEEN 401	O MEEN 402	O MEEN 404	O MEEN 601 (Advanced. Machine Design)	O None
How old are you? ->>			___________YEARS		
What is your sex?- ->>				O female	O male
Please add any additional comments on the back.					

Visualize IT Questionnaire – Software

Question	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree
How to mark your answer: Please circle your answer.	1	2	3	4	5
The mini-lecture was helpful to understand the relation between component layouts and functional models.	1	2	3	4	5
The mini-lecture was sufficiently detailed to understand the new concepts.	1	2	3	4	5
The mini-lecture was too long.	1	2	3	4	5
A more detailed and longer lecture is needed.	1	2	3	4	5
The exercise using the Visualize IT software was a good preparation for the experiment.	1	2	3	4	5
The exercise was too long.	1	2	3	4	5
I liked the water lifting design problem.	1	2	3	4	5
I liked the peanut sheller design problem.	1	2	3	4	5
The component layouts were helpful for developing concepts.	1	2	3	4	5
The word based component layout representation (the candidates under the graph tab) helped me generate ideas.	1	2	3	4	5
The picture based component layout representation (the candidates under the graph with component images tab) helped me generate ideas.	1	2	3	4	5
The component layouts did not resemble each other.	1	2	3	4	5
It was easy to see the difference between component layouts.	1	2	3	4	5
The functional model helped me generate ideas.	1	2	3	4	5
The Visualize IT software is easy to use.	1	2	3	4	5
The Visualize IT software is helpful for concept generation.	1	2	3	4	5
I knew what I was supposed to do during the experiment.	1	2	3	4	5
It was clear to me that I was supposed to sketch concepts solving the design problem.	1	2	3	4	5
Please continue on the back.					

APPENDIX D

EXAMPLE SOLUTIONS FROM EXPERIMENT 2

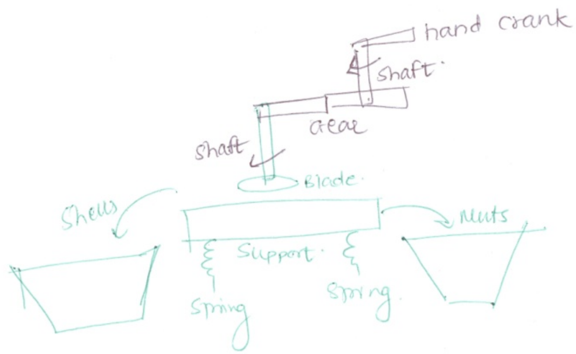


2009-MAY-D23_PC3_2_WL

Candidate # 1005

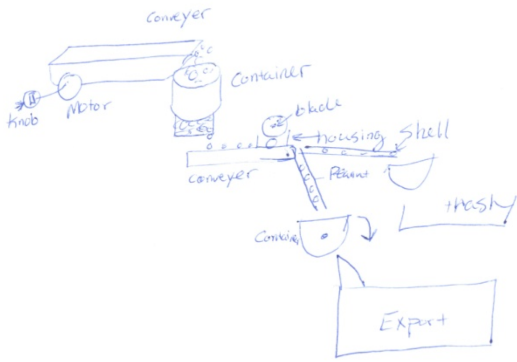
2009-May-28_PC3_ E6 – RS

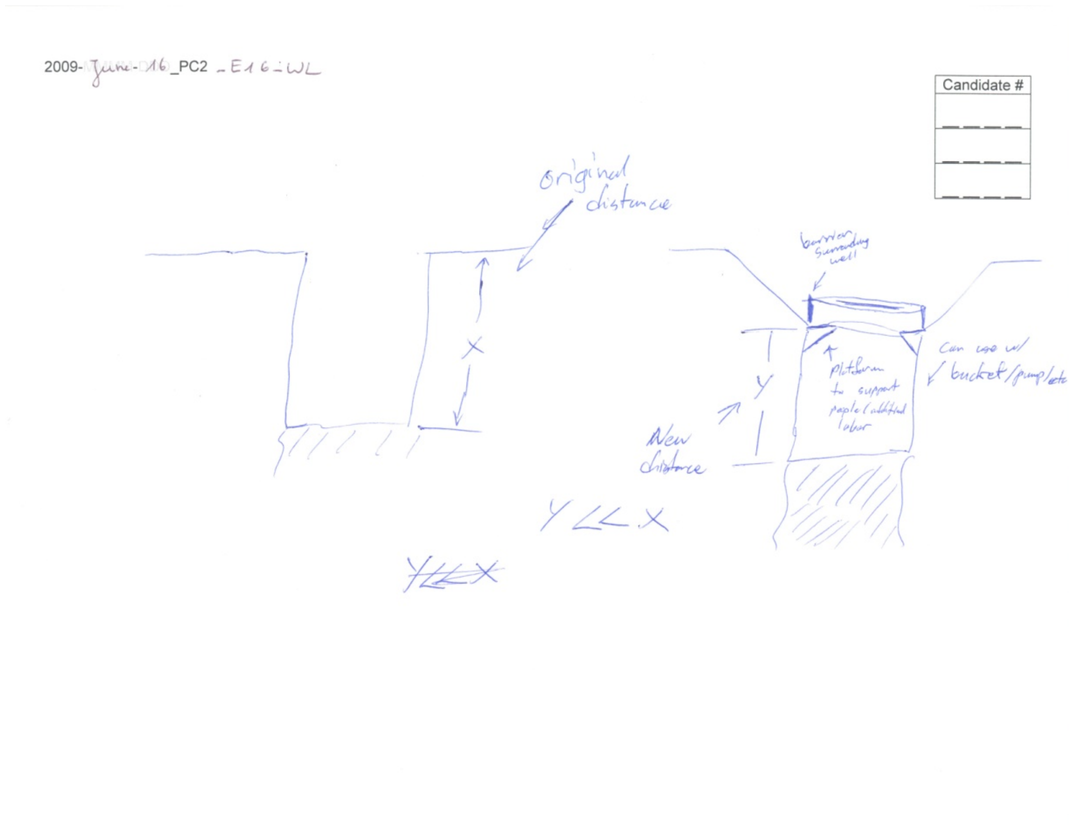
Candidate #
663



2009-June-19_PC2 - E18 - ps

Candidate #
2




2009-June-16_PC2 _E16_WL
Candidate #
original distance
X
barrier surrounding well
Can use w/ bucket/pump/etc
platform to support people/additional labor
Y
New distance
Y << X

APPENDIX E

MATERIALS USED FOR EXPERIMENT 3

VISUALIZE IT – CLUSTERING EXPERIMENT - SCRIPT

Check List

- Two copies of consent forms
- Pen
- Problem description
- Printouts of the mixture of clusters (stapled)
- Blank sheets to sketch
- Print outs of PCA clusters
- Print outs of K-Means clusters
- Opinion sheets (3 numbers)
- Print outs of clusters with 1, 3, 5 displayed at a time
- Print outs of clusters – one shown side by side and the other stapled together
- Survey

Consent

On the table

- Two copies of consent forms
- Pen

As soon as the participant arrives: **Hello and welcome to the experiment. Please take your seat. You can put your back packs close to the wall. Please switch off or silence your cell phones.**

As the participant sits down:

Start the stop watch.

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

You will be asked to complete a series of tasks. You will be asked to generate ideas for a given design problem based on different component layouts, followed by some surveys. This study will require approximately two hours. Please let me know if you have any questions.

Wait until the participant finishes reading the consent form. Answer all questions the participants ask. Wait until all participants have finished reading before proceeding. **Do you have any questions?**

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

I have one request before we begin: Please do not discuss the experiment with anybody at in Mechanical Engineering at TAMU until after December 31, 2010, since it will bias the results.

Remove

Signed consent forms

Component Layout Lecture

Now please relocate to your workplaces.
Show workplace. **Please adjust your chairs so that you can see the projection. For refreshing your memory, I will show you a mini lecture about component layouts. It will take approximately 10 min. Please look into the projection.**
*** Lecture***
Do you have any questions?

Idea Generation

Add

- Problem description
- Printouts of the mixture of clusters (stapled)
- Blank sheets to sketch

Please turn back your chairs towards the work table.
------------------------- If happens after the control experiment ---
(For clustering experiments after control condition)

- **Keep the computer ready and VIT window minimized.**

Visualize IT is a software tool to help designers in idea generation. It presents component layouts which act as an inspiration for designers in the generation of ideas. I will give you a brief overview of this software. Then you will solve the Peanut Sheller design problem with the help of this software.
Please maximize the Firefox on your desktop. Please note that you are not allowed to visit any other pages besides the Visualize IT software.
Please click on the Peanut Sheller on the left top corner of your screen. Now you will see the problem description. It is the same as what you did earlier. A print out of the same is available on the top left corner of your table. I will read out the design problem once again for you. Please follow along.
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 of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

- **The customer requirements are:**
- **Must remove the shell with minimal damage to the peanuts.**
- **Electrical outlets are not available as a power source.**
- **A large quantity of peanuts must be quickly shelled.**
- **Low cost.**
- **Easy to manufacture.**

OK, back to the Visualize IT software. Please click on functional model. Now you see the functional model of the water lifting design problem. You also have a printout of it. Do you have any questions so far? (Answer.)
On the left, underneath Select candidate cluster, please click on PCA Peanut Sheller clusters. The list of candidates opens up. There are 7 clusters, named A trough G. Each cluster contains 7 component layouts, called candidates, for a total of 49 component layouts. Please click on candidate 12, which is the fifth one in the list of cluster B. Do you see the component layout of candidate 12? (check screens, wait for answers)
Sometimes, as you can see in candidate 12, not all functions can be replaced with a corresponding component by the software. You will see black boxes showing the functions which have not been replaced by a component. For example, the functions distribute and convert was not replaced with corresponding components. In these cases you need to think about what you might use to fulfill the functional requirement. This is the main reason why the candidates are rather suggestions and an inspiration for concepts than solutions by themselves.
Also, sometimes flows will be missing. In candidate 12 there is one flow missing between the two gears. It is represented by a red arrow, and besides it the words No Flow Information are shown.
There are two different representations available: A word based and a picture based representation of the candidates. On the top of the screen, please click on graph with component images. Now, you see the picture based representation of the component layout. There is a problem with this graph, besides the unknown components and the unknown flow identified earlier: some pictures may not be found and there will be an empty space. But, there will always be the component name next to the empty space.
To see the whole candidate, please use the mouse wheel or the scroll bar at the right edge of the screen.
Do you have any questions so far? (Answer.)
Then, you have 15 minutes to sketch concepts to the Peanut Sheller design problem based on the component layouts and your own ideas. You have blank sheets of paper in front of you and a pen to sketch. So, please look at the different component layouts, and try to develop solutions to the design problem based on them. Do you remember the slide with the functional model, the component layout, the picture and the hand sketch of the toothbrush? [Wait for answer] **Because, we expect you to sketch concepts, just as the conceptual sketch you saw in the middle of the slide. Your conceptual sketches do not need to be pretty, and they do not need to be complete. And you can annotate your sketches if you like. Try to generate as many conceptual sketches as possible. Use a new sketch for each concept.**
When you sketch a concept, please write the candidate number that inspired it in the space in the upper right corner of the paper. I will give you a 2 minute warning before the 15 minutes are up. Do you have any questions?
I am starting the time now."

(For full clustering experiments)

In this part of the experiment, you will be generating solutions for the given design problem assisted by the component layouts provided to you. Component layouts show the flow of energy, material and signals between the various possible components of the arrangement that solve the given design problem. You have 15 minutes for this activity. Try to generate as many solutions as possible. I will give you a 3 min warning before the time is up. Please do not mark anything on the component layouts.

I will read out the design problem for which you will generate solution. A printout of the same is available on the table in front of you. Please 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 of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

The customer requirements are:

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

Are there any questions before we begin?

Wait for questions and answer them, if any.

You may start now.

Note down the start time in the time sheet.

(After 12 min) **There are 2 minutes remaining for the idea generation.**

(After 3 min) **Your time is up. Please put down the pen. Please stack the sheets together and hand over them to me.**

Remove

- Problem description
- Printouts of the mixture of clusters (stapled)
- Sketches

---------------------------------- start here if happens after the software experiment ----------------------------------

<u>Clustering Approach</u>

Add

- Print outs of PCA clusters
- Print outs of K-Means clusters
- Sheet to mark the opinions

In the next part of the experiment, you are going to evaluate which of the given component layouts are most useful for you to generate solutions for the Peanut Sheller design problem. You have the various clusters of component layouts in front of you. Please arrange them in the order of usefulness and enter them in the sheet provided to you. You can enter the identification number at the top right corner of the cluster sheets to represent them in the opinion sheet. Please do not mark anything on the cluster sheets provided to you. You have 15 min to complete this task. Are there any questions?

Ok, you may start now.

Collect the sheet and clusters back once the participant finishes sorting and entering in the opinion sheet.

Please hand over the sheets to me.

Remove

- Print outs of PCA clusters
- Print outs of K-Means clusters
- Opinion sheet

Display Method

Add

- Print outs of clusters – one shown side by side and the other stapled together
- Sheet to mark the opinions

Today, your next task is to arrange the given sheets of component layout in your order of preference. These are two different possible representations of the same component layouts. Imagine that you are seeing them on a computer screen. In the first case, you have 5 component layouts displayed side by side in a single browser window and in the other case you can view them one by one using different tabs on your browser. The print outs in front of you represent these two cases. Please choose the one you prefer to see on a computer screen and record that in the opinion sheet provided to you. Please note that you are not supposed to remove the stapler pin or mark anything on the cluster sheets. You have 5 min to complete this task.

Are there any questions?

You may begin now.

Collect the sheet and clusters back once the participant finishes sorting and entering in the opinion sheet.

Please hand over the sheets to me.

Remove

- Print outs of clusters – one shown side by side and the other stapled together

- Opinion sheet

Number of concepts per cluster

Add

- Print outs of clusters with 1, 3, 5 displayed at a time
- Sheet to mark the opinions

The software we are researching has created 1000's of component layouts for the design problem, each component layout being a possible solution of the design problem. The software will create as many component layouts for any other design problem. Lots of the component layouts are very similar to each other; therefore these are grouped into so-called clusters. A cluster usually contains between 20 to 30 of very similar component layouts.

Now, our question for you is: How many component layouts would you like to see from each cluster to represent the cluster? Each sheet you are given represents a cluster. One cluster is represented by one component layout; another cluster is represented by 3 of its component layouts and a third one by 5 of its component layouts. As these clusters would be part of a computer program, you could click on them and see all component layouts of a cluster if you liked.

Please don't mark anything on the component layout printouts. You have around 5 min to complete the task. Please record on the opinion sheet how many component layouts you would like to see from each cluster to represent it.

Are there any questions?

You may begin now.

Collect the sheet and clusters back once the participant finishes sorting and entering in the opinion sheet.

Please hand over the sheets to me.

Remove

- Print outs of clusters with 1, 3, 5 displayed at a time
- Opinion sheet

Survey

Add

- Survey

This is the last part of the experiment. Please fill out the survey.

Wait until the participants finish the survey. Collect once they are done.

------------------------ If after software experiment, go to the interview part from here ------------------------------

Disbursement

Thank you very much for your participation in the experiment. What would you like for disbursement? Your options are a gift card, cash or extra credit in your design class.

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, I wrote down that you'd like the extra credit. Once your classmates who volunteered also have done the experiment, I will send one email to your professor to let them know who should receive the extra credit. Do you have any questions?**

First, Last Name	**Class Affiliation**

Then, thank you again for your participation. Please do not talk about the experiment to anybody in Mechanical Engineering at TAMU until after December 31, 2010, as it will bias the results. Have a good afternoon/ evening.

Participant Opinion Sheets

Sort the cluster sheets given in the order of usefulness for generating ideas

Rank (based on usefulness)	**Cluster Number**
1. Best	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	
11.	
12. Worst	

In general, which were the most useful component layouts for idea generation?

Red Box	**Green Box**	**Blue Box**	**All Equal**

How many component layouts per cluster should be displayed at a time?

1	**3**	**5**

- Do you think displaying more than 5 component layouts at a time would be helpful?

- Yes
- No
- No answer

Which representation of clusters is more useful for generating ideas?

Side-by-Side	**One above the other**

Survey (TAMU)

19) What is your sex?
    g. Female
    h. Male

20) What is your age? _______________

21) Overall GPA ________________

22) What engineering design class (es) are you currently (Summer 2009) enrolled in at TAMU?

    - MEEN 401
    - MEEN 402
    - MEEN 404
    - None of the above

23) What engineering design class (es) have you already taken at TAMU?
    - MEEN 401
    - MEEN 402
    - MEEN 404
    - MEEN 601 (Advanced Machine Design)
    - None of the above

24) Are there any additional comments about this experiment?

Survey (UT)

25) What is your sex?

i. Female
j. Male

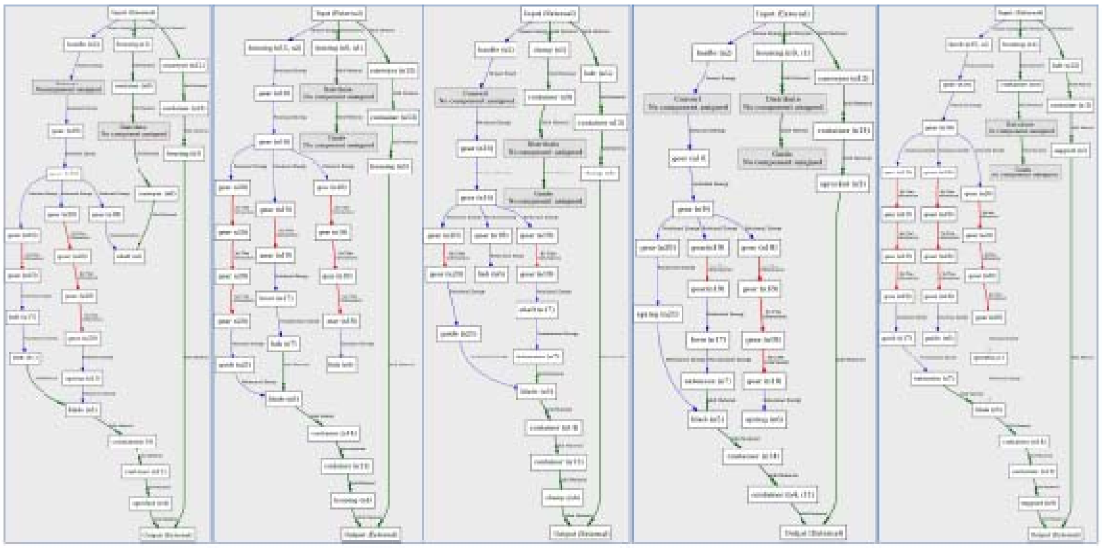
26) What is your age? _______________

27) Overall GPA ________________

28) Are there any additional comments about this experiment?

Cluster sheets provided to the participants

5



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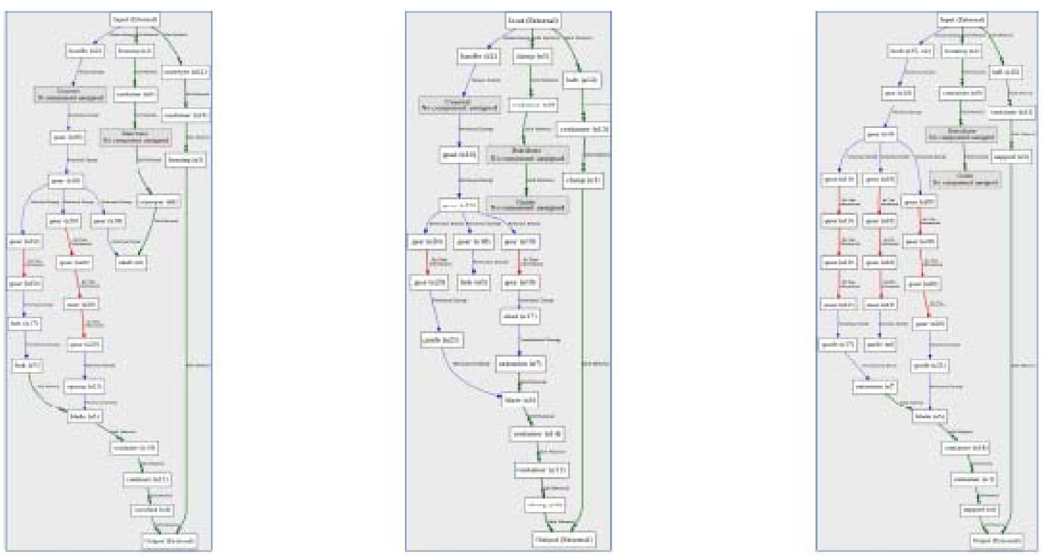

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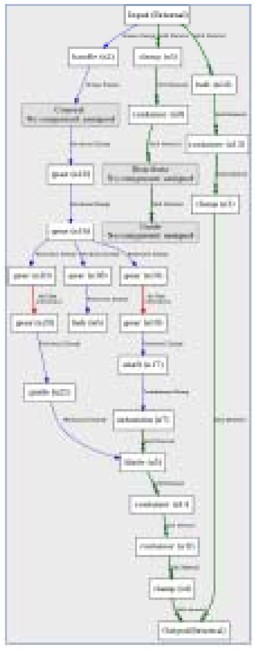

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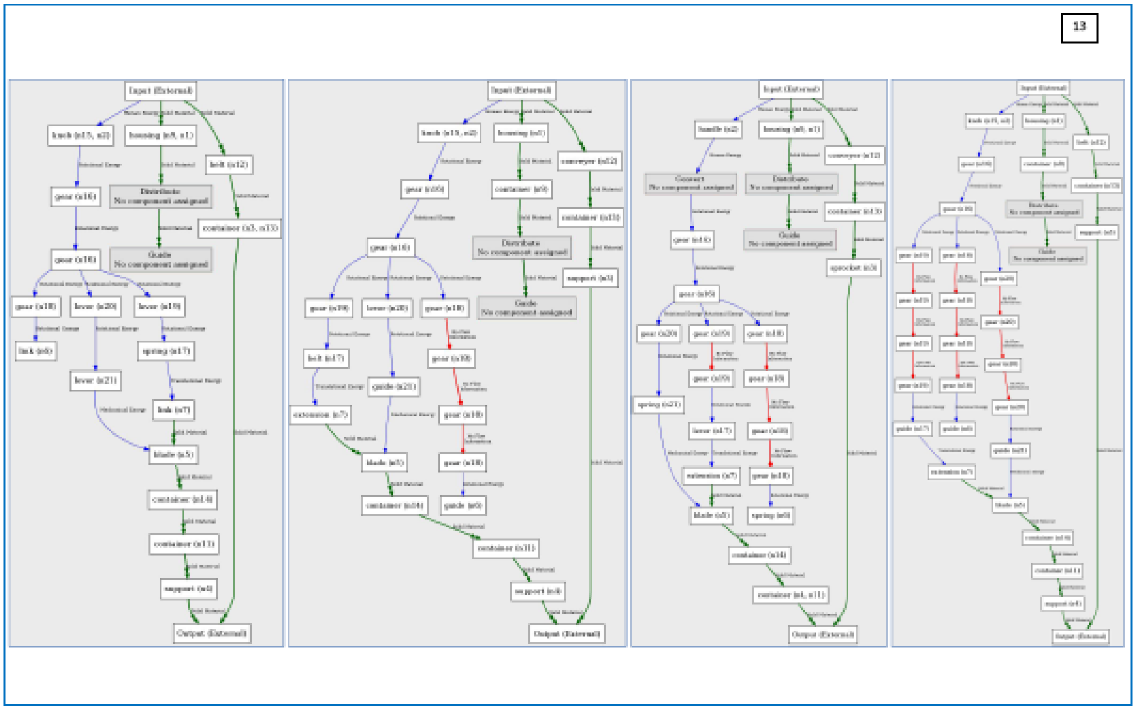

VITA

Vimal Kumar Cherickal Viswanathan obtained his Bachelor of Technology degree in mechanical engineering from National Institute of Technology, Calicut, India in June 2005. He worked as a structural design engineer for offshore platforms in Larsen and Toubro Limited, Surat, India from August 2005 to June 2008. He pursued his graduate studies at Texas A&M University in mechanical engineering from August 2008 and received his Master of Science degree in December 2010. His research interests include effects of various representations on engineering idea generation process.

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Email: vimkucv@gmail.com