ENHANCING THE VISUALIZATION TOOLS OF A CONCEPT GENERATOR

A Thesis in
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by
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ABSTRACT

The thesis work consists of improving the visualization capabilities of an automated concept generator, which generates conceptual solutions from a repository of existing design data related to product design. The repository is currently maintained by researchers at Oregon State University and populated by students at many universities across the United States. The repository consists of images of components of existing consumer products, for example power tools, function flow charts that define the path of energy, material and signal flow through the tools, brief description about the component, its use in an assembly and the assembly chart. The data in the repository is used as input into the concept generator, which gives a list of possible design solutions from user-input functional requirements. Currently, this output is in the form of text and flow chart, which is difficult to grasp for a novice designer.

The first step in the proposed research is to understand the level of information to be displayed for a specific search in the repository. The idea here is not to crowd the novice with excess information. This also enables research into setting up a framework for more experienced users. The next step is to determine the type of visualization that would help users readily understand the conceptual data on the screen. This aspect of the research is critical to making this tool effective in a design process while avoiding unwanted fixation on the given conceptual design prompts. This portion of the research will be completed with the help of test cases wherein students are provided with various types of visualization data (e.g., rough sketches, photographic data, and CAD models) and the impact on various markers of creativity are measured and assessed. To understand how designers of various levels of expertise interact with the concept generator and to determine the levels of details and types of visualization required with this tool, the research will be coordinated with research in the Department of Organizational Psychology.
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Chapter 1

Introduction

Design in itself is a very lengthy process starting with the initial requirement for a product and concluding with a feasible solution to manufacturing this product with effective cost and time constraints. In general, product development time allotments have shortened considerably, thus a design engineer can benefit from the assistance that computer technology is capable of providing. To this end, a concept generator can be a valuable part of the starting phase of design [1].

The definition of a design engineer will not consider the experience or the background knowledge in a specific field. Thus, a concept generator will have to incorporate as much information as is available to accommodate various levels of expertise and backgrounds. Considerable research has been done to incorporate data into the design repository to support various design tools including concept generation, failure analysis, function analysis etc [3].

The concept generator considered in this study also uses data from the repository. The study considers the output visuals from the concept generator and tests methods to improve the visual display. The improvement cannot be done in a single step, as there are multiple levels of expertise among users. The first step in any improvement project is to consider the drawbacks in the system, in this case the concept generator. The display screens of the concept generator are shown in Figure 1-1.
Figure 1-1. The input and output screens of the concept generator [1]
The input screen requires the functional model text file that defines the functional diagram of the new concept under consideration. Also, the Function Component Matrix (FCM) and the Design Structure Matrix (DSM) have to be defined from the design repository [1]. The most current information from the repository is captured as component functionality and compatibility information in the form of FCM and DSM respectively. Initial training will be provided to the engineer for adapting to this design system. The second screen is the output from the concept generator and gives a list of components that satisfy the requirements defined in the functional model text file. Results are filtered to only include complete solutions which are determined from component compatible data from the repository.

The output screen is the area of interest in this study, as there is a lot of ambiguity in the contents displayed. The drop down menu can be used to select a more or less innovative component, based on the frequency at which the component solves the indicated function. But, the connections between the components and the physical appearance of the components have to be imagined by the user and hence will reduce the effectiveness of the concept generator, especially when presenting results to a novice user.

The feasibility of any improvement to the output screen has to be measured by considering the requirements of the user. The requirements may include pictorial representation of the components or connections between the components or any of the thousands of reasons that may go through the user’s head. Because this would mean looking at how a user feels about the output screen, surveys and tests would be conducted across various levels of user expertise to determine the final output screen.
The first improvement decided was incorporating pictures and CAD models of the component terms displayed on the output screen. The effectiveness of this improvement was tested using a survey developed by the Department of Organizational Psychology. This would also provide the guidelines for further improvements to the output display from the concept generator.

The subsequent chapters will discuss the various methods already researched in the field of concept generation, the advantages of these methods that could be explored in the concept generator with reference to visualization. The various visualization tools provided would be discussed in detail along with a case study to simulate the use of the data. The results section would look into the feedback from the peanut sheller experiment, which would help in understanding the requirements of the novice user. The final chapter would look into the future work that could be incorporated in the concept generator to make it a robust design tool.
Chapter 2

Literature Review

A review of research in the area of concept generation, creativity and design fixation are included in this chapter to assist in exploring the improvements made in these fields, to consider exploration of new areas in the field of interest, and help set the focus for the study presented.

Concept Generator

An automated concept generator is an algorithm used to generate concepts often from a repository of design data. The concept generator [1] used in the study relies on user inputs, which are based on function-based structured design methods [2]. The generator then searches through the design database of over 150 consumer products to produce a list of feasible conceptual designs [3]. The list of concepts was not visually receptive as the results were in a formal text similar to the input. This study will try to improve the output by visually enhancing the output text.

Earlier research in the incorporation of a concept generator in the design process has been in areas ranging from use of artificial intelligence in concept generation to failure analysis of the listed concepts. The color concept generator [4] describes the process of using artificial intelligence in attributing color codes to the products to improve the aesthetics. The process looks into the different colors that could be generated for a particular product and studies the effect of these colors on the customer. Thus, the concepts are limited to concepts with different colors rather than concepts with different components for the same product. But, the advantage of such a
system if adapted to the visual output of our study would be a cost effective model for use by novice designers. The system that would be used in the study would be slightly modified and would use different modes of visualization to determine the effect on the designers. This would be the final goal of the study.

Another important issue with the concept generator is to keep the repository current, that is to have the latest consumer products in the database. Since products are developed all over the world, it becomes difficult for updating the repository from one place. A simple way of updating the repository is to allow users to update the repository with products that they come across. Web-based morphological charts [5] are one such way of utilizing the Internet to allow users to update the repository. The technique could be adapted to allow users access to the repository through the internet to update the repository, with pictures, CAD models or any information regarding a component.

Improving the visual tools in the concept generator would also assist the design engineer with checking the compatibility of the chosen component in an assembly, and allow the design engineer to check whether the component is the best fit for the given product. Since the repository will have the data related to the failure modes of a component, the concept generator output including this data will be useful to the design engineer while choosing the component that is optimal for the assembly. The Function-Failure Design Method (FFDM) of Stone et. al., [6] is one such method that looks at the failure analysis of the components in a design.

The research efforts so far have focused on the inclusion of a concept generator in the design process, but not on the quality of the final output in terms of visual appeal. The study will make an effort to include a visual tool for making the output data more user-friendly.
Design Fixation

Since visual data is provided to support the output of the concept generator, one important issue to consider in the study is design fixation. Design fixation happens when the design engineer in his/her enthusiasm reproduces either a part of or the complete design from previous projects [7]. This could be counter-productive to the design as there could be issues of plagiarism or carrying the flaws of the previous design to the new design. Design fixation could also be seen as a creative road block, which prevents the exploration of novel designs.

Since design fixation cannot be quantified using a scale, it becomes difficult in any study to state accurately the extent of design fixation. Research has shown that fixation can occur whether the visual output is a line drawing or a picture [8]. So, the study will be conducted with pictures and CAD models of the components rather than the assembly, and checked to see whether there is less effect of fixation in the final product.

The visual data will assist users in creating concepts that may or may not be similar to already existing products. Users generally draw sketches of the concepts that they think are the required outcome of the design process. Then, the user will try to increase the number of concepts based on the sketches as the interpretation becomes more coherent [9]. The study will also look at how many new concepts were generated based on the sketches drawn using the output from the concept generator. This will give an idea into the creative thinking of the user and help in the final phase of the study, wherein the user is allowed to enter data into the repository.

Although commonly viewed as a detriment to creativity, design fixation should not necessarily be considered a clog in the design process. There are certain benefits of design
fixation such as design reuse [10], which assists in reducing the cost of manufacturing, maintaining quality and increasing customization. Consider the example of the first automobile engine developed in 1769 by Nicolas J Cugnot [11]. Even though there has been tremendous development in the field of automobile engines, certain factors like the combustion cycle and crank system have been more or less similar to the earlier design. Thus, the designers should not be completely restricted from reusing the earlier designs, but design reuse should not affect the development of new and improved design ideas.

**Creativity in Design**

Creativity in design is as old as design itself. Creativity is a part of every individual and evolves with new experiences. For example, consider a teacher, an engineer and a carpenter. All three have different types and levels of creativity and are based on their education, surroundings and requisites of their jobs. Thus, creativity in design would depend on the designers mind set and experience and hence could be improved by providing proper training.

Research suggests that there are two types of creativity [12]. Individual creativity stems from personal experience and insights [13]. This type of creativity has led to many exceptional discoveries such as *Theory of Relativity* by Einstein and *Gravitational Law* by Newton. But, such examples where an individual’s creativity is exemplary are limited, as one individual can only think in a particular direction and may not be able to comprehend the other features that may be incorporated in the design, due to constraints in the available technology or due to limitations in the designer’s abilities. Thus the term *team work*, which reflects on social creativity [14]. There are multiple benefits of such creativity, such as reduction of work load, brain storming and
encouragement through appreciation. Thus, the study has tried to inculcate the social creativity through creation of student groups and the effect on concept generation was studied.

There are multiple algorithms aimed at maximizing the effect of creativity. One such framework is the GENEX framework [15], which aims at providing technological and peer support within a particular field of interest. This framework would assist in not only encouraging social creativity, but also helps in motivating individual creativity. Thus, individual and social creativity could be accomplished to accelerate advancement in the design process.

**Visualization in Concept Design**

Since there are many types of visualization such as pictures, CAD models, natural landscapes and there are some visualizations that are memory induced, studies have to done to check how these visualizations affects the quality of the concepts generated. Research suggests that imagination-based visualization wherein the designer thinks from the end user point of view gives better design and has been more successful in the market [16]. The tools used in this study and their importance are briefly described below.

**Pictures as Visual Tools**

“A picture is worth a thousand words”, the phrase itself suggests the importance of having a picture to describe an object rather than use words. This phrase becomes even more relevant in a cross cultural setting where language could be a barrier. For example, consider the bicycle as shown in Figure 2-1, which is referred to as ‘bike’ in the US and as ‘cycle’ in India. A ‘bike’ in India refers to a motorcycle.
Thus, a simple term like ‘bike’ could cause some confusion. Use the picture however, and the problem is solved. This does not necessarily mean that a picture always helps in understanding a term. Consider the scenario where a presentation is given to the client on the use of bio-gas as fuel for a car. Just showing the picture of a farm where bio-gas is being produced without describing the process is not going to impress the client.

Studies have shown that the human brain can process the information better if there is a combination of pictures and words. This is termed *multimedia learning* [18]. Research has also shown that students can learn more with a multimedia presentation rather than a verbal-only message. One explanation is that humans use two senses, which are hearing and seeing, to process the information. Most of the information processed by the hearing is lost due to limitations in an individual’s processing capabilities, but the information seen is better retained due to the brain’s ability to process visual information faster [18].
The question now is how to use this information in helping designers using the concept generator optimally. It becomes insurmountably difficult to provide pictures for all of the components that are uploaded from different universities across the United States. In addition, the concept generator employs a method of grouping similar components under a component term in a rigorously defined component taxonomy [4]. Thus, an algorithm should be in place that would be able to provide pictures for terms that are added in the context of a component. There are systems that have been developed such as IAM-eMMa and EVIDII [19], that provide visual images to support the design process. The two systems are basically search engines that search across millions of pictures uploaded on the internet and provide suitable returns to the keywords entered. Similar systems could be developed and will be very useful to the design engineer using the concept generator, which may not have all the pictures to describe the component basis terms [4]. Component basis terms is the terminology used to describe the various components in the repository.

As a coin has two faces, any argument with reference to having pictures for assisting design engineers will have its own disadvantages. Studies have suggested that if too many pictures are provided, then design engineers may have the tendency to depend on the pictures rather than going by the component term and imagining it [20]. There has to be a fine balance between the visualization and the textual descriptions for each component term. But, probing the boundaries of this fine balance would require extensive study and is out of scope for the research in hand.
Use of CAD Tools for Design

In nearly any design process these days, some type of CAD software is used to generate the detailed model before the manufacturing process is planned. This process not only provides the designer with input into the feasibility of the design, but also allows the designer to look for potential defects in the design. The cost savings can be huge when such a method is utilized as the manufacturing will only be done after all the defects are rectified in the design.

Thus, it becomes extremely important for students to learn the CAD packages so that they can be seamlessly integrated into the design team in the industry. Studies in the United Kingdom [21] have indicated the importance of teaching CAD tools to students as this increases the ability of the student to better describe the concepts that he or she has in mind and also to analyze the feasibility of the design by visually inspecting it.

Because CAD tools allow design engineers to visualize the product before manufacturing, the study will also look into the feasibility of introducing the CAD tools in the first stage of design, such as developing the initial concepts as CAD models, rather than sketches. The study will check whether this step would help in accelerating the design process. Currently, CAD is really used after the decision has been made on the design selection. Use of CAD models also allows all the concepts to be documented and accessed by all members of the design team.

Importance of Sketches for Idea Generation in Design

Sketches are one of the first steps in any design process for the designer. When a client describes a new product, the designer tends to visualize the product by creating a sketch and then
comparing it with the requirements of the client. Also, sketches allow the designer to make a rough copy of the ideas which can be stored for later use.

There are two modes of drawing in any design, drafting and sketching. The difference between the two is drafting involves creating a drawing of the product with exact dimensions and is usually the last step of the design process and sketching is creating a rough drawing of the concepts that seem to satisfy the customer needs. A sketch is just a concept and may not even be the product that the customer wants, but rather a visual description of a general operating theory. Sketching is a convenient way for the designer to put his thoughts on paper, and this leads to generation of different concepts and, ultimately, the final design. Studies have shown that drawing is an essential part of the design process [22] and has led to improvement in the overall design of the product.

Students will be asked to generate concepts based on the output from the concept generator and the visual outputs provided. The concepts so generated would be checked to see whether the initial sketches drawn led to the creation of the final concept or if the two were completely different. This process will also assist in determining the natural intelligence of the designer [23], and would help in differentiating between designers and good designers. The procedure would be continued for different levels of designer experience, so that the level of visual data that has to be provided can be optimized.
Chapter 3
Visualization Data for the Experiment

Introduction

The output from the concept generator [1] is shown in Figure 1-1. The functional model for the desired product is drawn by hand and the function connectivity information is provided as the input text file. Based on the key words in the text file, the component solutions are displayed for each function in the functional model. The number in the parenthesis next to each component indicates the frequency of a particular component being ideal for the sub-function required in the functional model. This number is based on the components’ use in the database of existing products and it is up to the designer to verify the feasibility for the current product design.

The various visualization tools provided for the experimental setup are briefly discussed and the pictures, CAD models and textual information for some of the component basis terms have been cataloged in Appendix B.

The selected components displayed may be changed by using the pull down menus, and compatibility between the components is dynamically updated based on the user’s selections. For the concept generator under consideration, the components in the pull down menu are grouped together under the Component Basis Terms [24]. Currently 111 terms are defined and have been cataloged using a Wiki web interface, as shown in Figure 3-1.
Since the output will consist of these component terms, the first set of visual data provided would be related to these terms. For instance, if the component basis term ‘Mechanical Transformer’ is selected, then a comprehensive description of the term is provided. Pictures that describe the physical applications of the ‘Mechanical Transformer’ are shown in Figure 3-2. Images are followed by the input energy flow information. Relevant external website links are also provided if more information is desired. For the computer savvy, a CAD model of one example application is also provided. General design consideration related to the mechanical properties, failure conditions, etc., are also provided. This data has been provided for all 111 component basis terms. Thus the user will have an increased amount of design-related information to help decide on a particular component. Multiple examples are provided for each term to help reduce the effect of design fixation.
Figure 3-2. The pictures and CAD model provided for the component basis term ‘Mechanical Transformer’ [26, 27, 28, 29]
The information on the Wiki page would consist of different types of visualizations as well as textual information. An example shown below will illustrate the various details provided.

**Wiki page**

Any website would require the information to be provided in an ordered fashion, so that the aesthetics as well as ease of use are improved and users will want to use the page again. So, it was decided that the Wiki page would consist of,

- Contents
- Descriptions
- Images
- Design considerations
- CAD models

A simple example would be the component basis term ‘Abrasive’ as shown in Figure 3-3. Abrasive refers to any device or material that uses texture on a surface to remove any portion of a firm (non-fluid) material. The page starts with a definition and an image to allow the user to understand the term. Then, all the other information is provided in an ordered fashion.
Figure 3-3. Basic definition and image of the term ‘Abrasive’

Contents

The contents would describe the order of the information provided on the Wiki page as shown in Figure 3-4. This becomes very important when there is a lot of information and the user is searching for a specific term or application.

Figure 3-4. Contents list for the term ‘Abrasive’
Descriptions

The description section would consist of information regarding the applications of the device, the function flows that the device can provide and brief explanations of the uses of the device in the market. References are provided if the user wants to explore other information on the Internet. Figure 3-5 shows a sample descriptions column. The flow would suggest about the type of interaction that would take place between the abrasive and the material being shaped.

<table>
<thead>
<tr>
<th>Application</th>
<th>Acts on Flow(s) of</th>
<th>Brief Description(s) of Usage</th>
<th>Relevant Link(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandpaper</td>
<td>Solid Material</td>
<td>Used to remove surface imperfections and create a smoother or polished finish.</td>
<td>[1]</td>
</tr>
<tr>
<td>Pumice stone/dust</td>
<td>Human Material</td>
<td>Often used wet to remove rough skin and calluses from human feet.</td>
<td>[2]</td>
</tr>
<tr>
<td></td>
<td>Solid Material</td>
<td>May also be used to remove mineral deposits from porcelain surfaces (e.g., toilets)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Powder used in toothpaste to help remove plaque and bacteria.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Removes fabric and dye to produce &quot;stone-washed&quot; jeans.</td>
<td></td>
</tr>
</tbody>
</table>

References


Figure 3-5. The description for the component basis term ‘Abrasive’

Images

The images would consist of pictures of the various applications of the device which would be similar to the descriptions, but would convey more meaning as the user will be able to comprehend the information better. Figure 3-6 shows a sample set of images.
Design considerations

Any device on the market will have properties such as physical, mechanical, electrical etc., which define the application and the useful life span of the device. The design considerations would address the properties so that the user would have the choice of choosing the components based on the properties (in case of two components meeting a certain criteria). Figure 3-7 shows a sample set of design considerations.
Figure 3-7. Design considerations for the term ‘Abrasive’

**CAD models**

The images would be good to look at but for design engineers, especially mechanical engineers who are proficient with CAD tools would be more interested if they have models that they can manipulate. Thus, a CAD model is also provided as shown in Figure 3-8. The other use of the CAD model is the user would be able to create a final assembly with all the models.

Figure 3-8. CAD model for the term ‘Abrasive’

The same syntax is followed while providing information for all the 111 component basis terms. The Wiki page is updated frequently to keep it current with the information. This is
done using feedback from the users. The visual data is never complete without the feedback from the user and the study tries to incorporate the same to check for additional improvements that could be added to this visual data. A survey included questions regarding the quality of the visual data provided.

The users would be instructed about the various visualization tools available at their disposal and feedback would suggest any improvements to be made to the visual data. A case study describing the procedure to use the concept generator and the usefulness of the visual data has also been discussed in the next chapter.

**Improvements in the Visual Data**

The results from the survey show that the inclusion of visual data such as pictures and CAD models was a great idea, but since the assignment consisted of designing a peanut sheller as described in Chapter 5, the students were not able to fully utilize the data. The use of the Internet for finding similar products also hindered proper appreciation for the visual enhancements. Thus, more tests have to be conducted with different products to understand the deficiencies in the visual data.

One important point that was noted from the surveys was the need for sketches as aid for the output. The reasons for such a requirement by the students may be due to the fact that they have been more comfortable using sketches whenever they have been asked to design products in their class projects. The use of CAD tools is not compulsory and thus many may have not used
the software. Getting senior students to use the concept generator with the visual aid could provide more insight into this issue.

The feasibility of providing sketches as visual aid was discussed and since software that support creating sketches were available, the software SketchUp™ was used to develop sketches for all the 111 component basis terms in the repository. Sketches were generated from the 3-D models developed in SketchUp. As discussed earlier, the term ‘Mechanical Transformer’ has the following sketches added to the visual data.

![Sketches for 'Mechanical Transformer'](image)

Figure 3-9. The sketches for the ‘Mechanical Transformer’ (gear, pulley and sprocket)
SketchUp™

SketchUp is a 3-D modeling program developed to assist architects, civil engineers and people in similar professions to develop designs without having to be experts in CAD softwares. It is designed to easier to use than most 3-D CAD tools [34].

The decision to use SketchUp were the various advantages that it provides for a novice design engineer such as,

- It is free to use, and does not require a powerful computer to work.
- There are many tutorial videos available to help students to learn the software.
- There are online forums where all kinds of models are uploaded and are free to download.
- Different styles are available, which allow users to develop images of products that look like those shown in Figure 3-9.
- The quality of the models generated is as good as those of the other CAD tools.

The only disadvantage is its inability to create models that can be easily exported to other CAD tools. The advantages of this software are too many to ignore and thus it was decided that the sketches would be developed and then included in the visual data for future tests and surveys.
Chapter 4

Case Study

A case study has been presented to show how the visualization tools would work when a new product has to be designed; an old product has to be re-designed or new concepts have to be generated to solve a design problem in the product. The case study would not give an optimum solution for the problem defined, but would show how the visualization tools could be utilized to get an idea about the product and then think about solutions.

Problem Statement

Consider a problem wherein a machine shop has a small punching machine operation, and now would like to expand the setup so that long blocks of metal could be accommodated. Thus, there needs to be an assembly that has to be setup in between the block and the punching machine to feed the metal at the required rate along a path.

Functional Model

The first step to be followed is to create the functional model that defines the energy, material and signal flows in the entire operation. One important thing to remember is the functional model could be abstract or very detailed depending on the experience of the user. An abstract functional model would give many components that could match the required component
list. A very detailed functional model would narrow the list of components and would be easier for the user to pick the components. A sample functional model would be as shown in Figure 4-1.

Figure 4-1. Sample functional model for the given problem

The functional model and the links to the FCM and DSM are loaded in the input screen of the concept generator and the list of feasible components would be generated. Consider a sample set of terms to be,

- Electric Distributor
- Electric Cord
- Mechanical Transformer Pulley
- Electric Motor
- Conveyor
- Hydraulic Piston
• Punch
• Support

Sketch

After considering the terms generated by the concept generator, rough sketches are created by hand to meaningfully assemble the parts to get the final product. The sketches are evaluated and then a sketch is selected. A sample sketch is shown in Figure 4-2.

Figure 4-2. A sample sketch for the given problem
CAD Model

After a sketch has been selected, an assembly could be generated using the CAD models as shown in Figure 4-3. The assembly would help the user in visualizing the entire setup and to find any inconsistencies in the design.

Figure 4-3. The CAD assembly for the sketch shown in figure 4-2
As can be observed from Figure 4-3, the user will be able to understand the working of the product as well as make it more meaningful to the other people in the team or the client. Images and sketches could also be used depending on the user’s preference.

The assembly shown in Figure 4-3 is just one of the many other designs that could be made with the given components. Depending on the functional model, the component list generated by the concept generator and the creativity of the user, similar ideas could be developed by the user.
Chapter 5

Peanut Sheller-Experimental Setup and Results

An experiment was conducted to analyze the feasibility of the visualization tools provided for the concept generator and also the limitations that could be improved.

Description of the Peanut Sheller

The peanut sheller to be designed would be used in places such as Haiti and certain West African countries where peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, or by inefficient and labor-intensive process. The idea is to create a low cost, easy to manufacture peanut sheller targeted at individuals and small cooperative societies. The student groups would have to concentrate on the following customer needs [30].

- Low cost
- Easy to manufacture and with domestic materials
- Self-powered
- Quantity of peanuts shelled should be high and rate should be quick
- Damage to the peanut should be minimum
The idea of giving the customer needs is make the students think about the concepts and make a product that is marketable. Thus, students will not make up concepts that may not be practical or of no use for the problem at hand.

A common peanut sheller available in the market is shown in Figure 5-1.

![Figure 5-1](image)

Figure 5-1. The operation and the cross sectional view of a peanut sheller [31, 32]

The operation of such a device is simple and practical. It is hand operated and works on the principle of centrifugal force. This peanut sheller was chosen to check whether the students will try to make a similar product by looking up peanut shellers on the Internet.

**Inputs to the Concept Generator**

The inputs to be provided to the concept generator are the team-generated functional model, the Function Component Matrix (FCM) and the Design Structure Matrix (DSM). The functional model will have to be developed with the customer needs in mind, but the FCM and DSM are related to the repository and hence will not need to be changed by the user. When there
are updates in the product list in the repository, the FSM and DSM are automatically updated. A sample functional model will be drawn as shown in Figure 5-2.

![Figure 5-2](image)

Figure 5-2. The functional model used to abstractly define the device to shell peanuts

Once these inputs are provided, the student will have to click on ‘create concepts’ to get the compatible components. It then depends on the intelligence and creativity of the students to create the concepts and make sure that the customer needs are taken into account. The students will have sixty minutes to come up with as many concepts as they could.

The experimental setup will be allowed to use the computers for accessing the concept generator. The students will also be allowed to use the Internet to access the Wiki web-pages that contain information about the various visualization tools provided. The students will be allowed to form teams of four members each. Once the components are displayed on the output screen of the concept generator, the students will have to use the visualization tools and come up with as many concepts as possible. The concepts will then be graded using metrics and feedback will be considered to improve the visualization tools.
Results

The results considered two aspects of the concept generator, the assistance the visual data provided in creating the concepts and the feedback pertaining to the usability of the concept generator and the visual data. These results would help in making improvements to the concept generator so that experienced users in design would adapt to this system and also help in looking into other types of visual data that can be incorporated into the software.

Quality of the Concepts

The students were divided into four groups as it has been seen that social creativity would be better than individual creativity for such an assignment. Another reason is the time constraint for completing this assignment. The student groups were given the peanut sheller assignment and were allowed thirty minutes to come up with as many concepts as possible. They were able to come up with a total of thirty designs, which is very impressive considering their experience with design and the concept generator.

It is not possible to measure the quality of the concepts by just using an expert in the field to look at the concepts and decide if there were any good designs. To quantify the results, it was decided to use metrics such as Completeness [24], Novelty and Variety [33]. Completeness refers to the concepts being complete considering the customer needs, novelty refers to the innovative aspect of the design and variety refers to the different concepts generated for the same product. Since, this experiment has more to do with the improvement of the concept generator and its assistance in the design process, and not the overall quality of the concepts, a single expert in the design field was asked to gauge the quality of the concept with reference to the metrics.
Group 1 came up with ten concepts, Group 2 had sex concepts, Group 3 had eight concepts and Group 4 had six concepts [Appendix A].

The metrics were measured for each concept and then were checked for creativity and design fixation using the metrics and weights. The concepts can be measured for completeness if concepts satisfy all customer needs. If being measured for novelty or variety, then it may not be expected that all customer needs are satisfied. This is because an innovative design may not be a low cost solution, but may have a longer life compared to a cheaper design. Thus, it depends on weights given to the metrics depending on the requirement. A Likert scale of 1 (low) to 5 (high) was used.

If completeness is considered, then weights of 70% could be given to completeness, 20% to novelty and 10% to variety. The weights cannot be just assigned randomly but in this case since the idea is to check whether the visual data has been useful and not the overall quality of the concepts, it has been assigned this way. A designer would consider such weights when complete designs are to be considered and are usually for new products.

If novelty is considered, when, for example creating the new generation iPhone or iPod, then weights could be in the ratio 60:30:10 for novelty, completeness and variety respectively.

Thus, two scenarios of different weights would give an idea of how the students think and use the visual data provided. Based on these weights, ranking could be done for the different concepts and the best among them could be chosen. The four groups then had the following scores as shown in Table 5-1.
Table 5-1. Scores for completeness and novelty in the concepts

<table>
<thead>
<tr>
<th>Groups</th>
<th>Completeness</th>
<th>Novelty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.99</td>
<td>3.19</td>
</tr>
<tr>
<td>2</td>
<td>2.93</td>
<td>3.20</td>
</tr>
<tr>
<td>3</td>
<td>3.00</td>
<td>3.10</td>
</tr>
<tr>
<td>4</td>
<td>3.30</td>
<td>3.20</td>
</tr>
</tbody>
</table>

This score does not necessarily mean that the group with the highest score had the best design. For the given conditions and the assumptions in the weights, the best score and thus the best design is chosen.

The best designs based on completeness and novelty are as shown in Figure 5-3 and Figure 5-4 respectively.
Figure 5-3. Best concept based on completeness

Figure 5-4. Best concept based on novelty
As can be seen from the Figures, many ideas have been considered based on the visual data provided during the experiment.

Now, the concepts were also checked for design fixation and the metric *variety* was considered to see whether there were any differences between the concepts generated. The scores suggested that, when the groups were not able to get more concepts, they tended to look at the previous designs either on the sketches drawn, or the images generated by the search on the Internet. Groups 1 and 3 had many ideas, but Groups 2 and 4 had one or two good ideas and the rest were minor changes made to the main idea. Figure 5-5 shows how fixation could affect the conceptual phase.

![Figure 5-5. Concept looks similar to the actual peanut sheller](image)

Thus all three metrics assist in accessing the quality of the concepts from different viewpoints and more importantly, look into how the designer thinks.
The study showed firsthand how the designers use the visual data to generate concepts, but still the effectiveness of the concept generator and the visual data can only be assessed by asking the students groups about their experience with it. Thus a survey was conducted to check whether the use of pictures and CAD models was the right step in enhancing the visual output of the concept generator.

**Concept Generator Visual Output**

The survey has been done considering the individual rather than the team, as sometimes a feedback of one member could be lost due to collective assertiveness of the team to a question. The results from the survey were categorized into four different intentions of using the concept generator.

**Intention of Usage**

The intention of using the concept generator in future design projects by students was perceived at a mean of 2.69/5 and standard deviation of 1.13 for a total of eighteen participants. This suggests many of the users are willing to use the concept generator in the future as seen from Table 5-2. It should be noted that this was after the visual data was provided.
Table 5-2. Intention of usage

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>For future work I would use the concept generator.</td>
<td>1</td>
<td>5</td>
<td>2.89</td>
<td>1.28</td>
</tr>
<tr>
<td>I intend to increase my use of the concept generator on future assignments.</td>
<td>1</td>
<td>4</td>
<td>2.50</td>
<td>1.04</td>
</tr>
</tbody>
</table>

Unless otherwise indicated, all questions are on a 5-point Likert Scale, with scale anchors, 1 = “Strongly disagree” to 5 = “Strongly agree”.

**Perceived Compatibility with Work Style**

The compatibility of using a concept generator at the front end of the design process was high, as the students suggest that such software would be well suited for the conceptual phase of design.

Table 5-3. Perceived compatibility with work style

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using the concept generator would be compatible with all aspects of my work.</td>
<td>1</td>
<td>5</td>
<td>2.67</td>
<td>0.97</td>
</tr>
<tr>
<td>I think that using the concept generator would fit well with the way I like to work.</td>
<td>1</td>
<td>5</td>
<td>2.89</td>
<td>1.18</td>
</tr>
<tr>
<td>Using the concept generator would fit into my work style.</td>
<td>1</td>
<td>4</td>
<td>3.00</td>
<td>1.14</td>
</tr>
</tbody>
</table>
Perceived Ease of Use

The ease of use of the concept generator defines the ease with which the user can use the software. The ease of use considers the training provided to the students, and even then most students believe the software is tough to use. Thus, the visual interface needs to be made more user-friendly and self-help manuals are also helpful. It should be noted that the scale has been increased to 7 to allow for higher degree of expression from the users.

Table 5-4. Perceived ease of use

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>I find the concept generator cumbersome to use.</td>
<td>4</td>
<td>6</td>
<td>5.22</td>
<td>0.81</td>
</tr>
<tr>
<td>Learning to operate the concept generator is easy for me.</td>
<td>2</td>
<td>5</td>
<td>3.78</td>
<td>0.81</td>
</tr>
<tr>
<td>Interacting with the concept generator is often frustrating.</td>
<td>3</td>
<td>6</td>
<td>5.22</td>
<td>1.11</td>
</tr>
<tr>
<td>I find it easy to get the concept generator to do what I want it to do.</td>
<td>1</td>
<td>5</td>
<td>3.39</td>
<td>0.98</td>
</tr>
<tr>
<td>The concept generator is rigid and inflexible to interact with.</td>
<td>3</td>
<td>6</td>
<td>5.28</td>
<td>0.89</td>
</tr>
<tr>
<td>It is easy for me to remember how to perform tasks using the concept generator.</td>
<td>2</td>
<td>5</td>
<td>3.67</td>
<td>0.76</td>
</tr>
<tr>
<td>Interacting with the concept generator requires a lot of mental effort.</td>
<td>4</td>
<td>7</td>
<td>5.66</td>
<td>0.68</td>
</tr>
<tr>
<td>My interaction with the concept generator is clear and understandable.</td>
<td>2</td>
<td>5</td>
<td>3.56</td>
<td>0.92</td>
</tr>
<tr>
<td>I find it takes a lot of effort to become skillful at using the concept generator.</td>
<td>3</td>
<td>7</td>
<td>5.38</td>
<td>0.98</td>
</tr>
<tr>
<td>Overall, I find the concept generator to be easy to use.</td>
<td>2</td>
<td>5</td>
<td>3.61</td>
<td>0.97</td>
</tr>
</tbody>
</table>
Perceived Usefulness

Users think that the concept generator could be accommodated during the design process of their projects. This correlates with the earlier assessment of the users willing to use the concept generator in the future work. The users have also noted that the interface has to be made more user-friendly to increase the usage in the design process.

Table 5-5. Perceived usefulness

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Using the concept generator improves the quality of the work I do.</td>
<td>1</td>
<td>4</td>
<td>2.94</td>
<td>0.94</td>
</tr>
<tr>
<td>Using the concept generator gives me greater control over my work.</td>
<td>1</td>
<td>4</td>
<td>2.78</td>
<td>0.81</td>
</tr>
<tr>
<td>The concept generator enables me to accomplish tasks more quickly.</td>
<td>1</td>
<td>4</td>
<td>2.89</td>
<td>0.96</td>
</tr>
<tr>
<td>The concept generator supports critical aspects of my work.</td>
<td>1</td>
<td>4</td>
<td>3.11</td>
<td>0.90</td>
</tr>
<tr>
<td>Using the concept generator increases my productivity.</td>
<td>2</td>
<td>5</td>
<td>3.00</td>
<td>0.97</td>
</tr>
<tr>
<td>Using the concept generator improves my class performance.</td>
<td>2</td>
<td>5</td>
<td>3.33</td>
<td>1.03</td>
</tr>
<tr>
<td>Using the concept generator allows me to accomplish more work than would otherwise be possible.</td>
<td>2</td>
<td>5</td>
<td>2.83</td>
<td>0.92</td>
</tr>
<tr>
<td>Using the concept generator enhances my effectiveness on assignments.</td>
<td>2</td>
<td>4</td>
<td>3.06</td>
<td>0.87</td>
</tr>
<tr>
<td>Using the concept generator makes it easier to complete my assignments.</td>
<td>2</td>
<td>5</td>
<td>3.17</td>
<td>1.04</td>
</tr>
<tr>
<td>Overall, I find the concept generator system useful in my assignments.</td>
<td>1</td>
<td>5</td>
<td>3.00</td>
<td>1.14</td>
</tr>
</tbody>
</table>
From the tables, it can be seen that the idea of having a concept generator to generate concepts for a given product seems appealing and would be used more by the users if the visual interface was more user-friendly.

The inclusion of the pictures and CAD models seems to have made the concept generator more user-friendly, but for the current problem of designing a peanut sheller did not seem to have made much difference based on the following survey results shown in Table 5-6 and Figure 5-6.

1. When using the concept generator, how difficult has it been to envision your design without the software providing supplementary visual aids?

(1 = “Very Difficult” to 5 = “Very Easy”)

Table 5-6. Statistical summary for the question

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.28</td>
</tr>
<tr>
<td>Variance</td>
<td>1.27</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>1.13</td>
</tr>
<tr>
<td>Total Responses</td>
<td>18</td>
</tr>
</tbody>
</table>

Figure 5-6. Difficulty in using concept generator without supplemental visual aids
This result might be due to two reasons, one being the users were allowed to use the Internet to assist in understanding the components, and as such would have come across many other examples for the same component basis terms. Another reason might be that the supplemental visual aids provided may not have had components which were useful in the peanut sheller design. Thus, more examples and an assignment which makes use of most components in the repository might give better understanding regarding the above question.

The above reasons were verified by the other question in the survey as shown in Table 5-7 and Figure 5-7.

2. If you were to use the concept generator in the future, how helpful do you think the following visualization components would be?

(1 = “Not at all Helpful” 3 = “Somewhat Helpful” 5 = “Very Helpful”)

Table 5-7. Statistical summary for the question

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Diagrams of design elements</th>
<th>Photographic examples of design elements</th>
<th>CAD models of design elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.89</td>
<td>4.17</td>
<td>3.94</td>
</tr>
<tr>
<td>Variance</td>
<td>0.69</td>
<td>0.50</td>
<td>0.76</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.83</td>
<td>0.71</td>
<td>0.87</td>
</tr>
</tbody>
</table>
Figure 5-7. Use of visualization components

Thus, the visual data of pictures and CAD models have to be increased and a relevant product has to be assigned in the next assignment to study the usefulness of the visualization data and compare the results with the above results to check for the feasibility of incorporating the visual data in the concept generator.

The reason for asking for diagrams of design elements might be to use the same when drawing sketches. This may also suggest that the students are not able to convert the visual data provided in three-dimensions (3D) to a sketch and may find it difficult to visualize the final product in 3D. The future studies would look into this issue to check whether providing two-dimensional (2D) sketches would be better than the pictures and CAD models.
Chapter 6

Discussion and Future Work

Discussion

An automated concept generator [1] has been developed to assist the design engineer in developing concepts for a new product from a web-based repository consisting of over 150 consumer products.

The current study looks into enhancing the visual output that of the concept generator, as currently the output is in the form of text and a design engineer not well versed in the terminology used, will find the concept generator cumbersome to use.

Students were provided with pictures and CAD models corresponding to the 111 component basis terms and a survey was conducted to check the feasibility of the visual data provided.

The results suggest that the students would be interested in using the concept generator in the design process, and also suggest that training and self-help manuals would be useful to make the concept generator more user-friendly. Also, the visual data provided seems to be helpful for the understanding of the component basis terms. But, for the current assignment, the visual data seems to be inadequate and hence further testing needs to be done with different products to check whether more types of visual data needs to be included in the Wiki web pages.
Future work on this topic would be to test the concept generator with experienced users (design experts) and comparing the results with the above results to check for similarities or discrepancies. This result would assist in predicting the level of detail to be displayed for optimum use of the visual data for any product to be conceptualized. Future work would also look into enhancing the input screen of the concept generator to simplify the creation of the functional model for the product under consideration. This has been discussed in detail in the future work section.

**Future Work**

The first survey consisted of students who were freshmen and their opinions on the concept generator with and without the visual aid was encouraging. But, any opinion which is not scrutinized may lead to premature decisions. Thus, it has been decided that the surveys would be done for at least five more groups of students (freshmen and sophomore), before any more improvements need to be made to the concept generator and the visual data provided. Also, there was criticism for the approach that the student had to take to get the concepts in the first place. He or she had to develop functional models and then put the FCM and DSM as input before getting only the components that are most likely to be used in the product under consideration. Thus, the input screen would have to be improved to make it more user-friendly.
Input Screen

The current input screen looks as shown in Figure 6-1. Many improvements have been thought out to improve the screen so as to make it more appealing for the user to want to use the concept generator.

Figure 6-1. The input screen of the concept generator

The only actual input required is the functional model and the FCM and DSM are already available and just need to be loaded. Thus, a simple solution would be to preload the two data sets so that the user will have to only concentrate on the functional model. This simple step will make the concept generator more user friendly without any need to tweak the algorithm.

The generation of the functional model is difficult for a first time user and he or she has to be tutored about the procedure. One more addition that could be done is to develop an algorithm that could be used to generate the functional model. The algorithm will assist the user with selecting the functions that are to be performed by the product under consideration and then specify the input and output connections in terms in terms of energy, component and material flow in the system. This improvement in the concept generator will make it much more user friendly and fun to use.
The next issue to be looked into is the concept generator screen. As seen in Figure 6-1, the screen is not appealing and looks a bit dull. This could be improved by adding pictures of a few products that are there in the repository and enhance the visual image on the screen.

**Output Screen**

The output screen from the concept generator currently provides the component terms that have been used in similar products in the repository. So, it is very difficult for a novice designer to start looking at connections between the various components and then make an assembly. Thus, an improvement could be made in the algorithm to order the components (like a top down approach in assembly), so that the user can built the assembly by putting one component on top of the other. Consider the simple example of a laptop computer. In layman terms, it has a bottom cover, then the motherboard, the keyboard, the screen and then the top cover, as shown in Figure 6-2.
The above is an example wherein the component terms could be displayed in an order wherein the user would easily make the connections and then try to generate concepts that are either different or similar to the already existing products.

Another improvement in the output screen would be to provide visual data corresponding to the terms displayed. Currently, there is a wiki website that displays details such as definitions of the component basis terms, examples in terms of usage of that component in various applications, visual data such as pictures, CAD models and sketches. The next step is to integrate this information in the output screen of the concept generator so that the user will have all the information in one place.
Apple iPhone® Application

Apple iPhone is a smart phone released by Apple Inc. and combines the functionalities of the phone, web and the camera. It is one of the most popular mobile phones and has thousands of applications. Last year, more than two billion apps were downloaded [36]. Thus, the suggestion to develop an app for the concept generator does not seem far-fetched. Also, statistics suggest that the majority of users are below thirty years of age.

A recent survey entitled ‘The Apple iPhone: Successes and Challenges for the Mobile Industry’ looked at the profile of iPhone users [37]. They found that:

- The iPhone user base consists mainly of young early adopters about three quarters of whom are previous Apple customers.
- 50 percent of iPhone users are under thirty, and fifteen percent are students.
- Half of the iPhone users replaced conventional mobile phones (commonly the Motorola Razr) while 40 percent replaced other smartphones (such as Blackberrys and Windows Mobile devices).
- Email is the most commonly used feature — 70 percent of users check email on the iPhone at least once a day
- 60 percent of users browse the internet at least once per day
- Three quarters of users do more web surfing on the iPhone than on their previous device

Thus, an app developed for the concept generator will allow users to use it with their iPhones and thus make it more user friendly. The repository is currently populated across different universities and the only way of doing it is through the Internet using computers. Thus,
an iPhone app will allow users to upload images of the components or sketches as and when they create it and would lead to a improved and current database in the repository.

As specified earlier, none of the above improvements would make sense without feedback from the user and the only way is to conduct tests and surveys while using the available data. Further tests would ask the users to generate concepts for different products and then the surveys would answer questions that would allow for the above mentioned improvements.
Appendix A

Score from the Design Expert to all Concepts and the Rankings

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completeness</td>
<td>Novelty</td>
<td>Variety</td>
<td>Based on</td>
</tr>
<tr>
<td>Completeness (70%)</td>
<td>Novelty (60%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4.7</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>5</td>
<td>3.6</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>2</td>
<td>3.3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
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Appendix B

Sample Set of Pictures, CAD models and Sketches for the Component Basis Terms

Agitator

Airfoil


Ammeter


Auditory Indicator (Recorder)


Brush

Clamp

Condenser

Container
**Conveyor**


**Crank**


**Door**

Electric Distributor


Electromagnet


Extender

Fan


Flywheel


Friction Enhancer

http://en.wikipedia.org/wiki/Brake_pad
**Inductor**


**Heat Exchanger**


**Housing**

More Info: In Google search, type “define:enclosure”
Punch

http://en.wikipedia.org/wiki/Punching

Signal Filter


Speaker

Thermostat

Valve

Visual Indicator (Digital)


[28]’double-pulley-system.jpg (JPEG Image, 550x384 pixels)’, 02/10/2010,

[29] ‘sprocket.gif (GIF Image, 458x423 pixels)’, 02/10/2010,
“http://desertwar.files.wordpress.com/2008/04/sprocket.gif”


[31] ‘Peanut_sheller.png (PNG Image, 381x500 pixels)’, 02/10/2010,
“http://upload.wikimedia.org/wikipedia/commons/archive/7/74/20090926072812!Peanut_sheller.png”

[32] ‘x5434e1g.gif (GIF Image, 332x376 pixels), 02/10/2010,
“http://www.fao.org/wairdocs/X5434E/x5434e1g.gif”


[35] ‘eeepchack – main.jpf (JPG Image, 485x430 pixels)’, 02/10/2010,
[36] ‘Unbelievable iPhone App Store Statistics | The iPhone FAQ’, 02/10/2010,
“http://www.iphonefaq.org/archives/97682”

[37] ‘Profile of an iPhone User: Interesting Statistics About Yourself’, 02/10/2010