DESIGN-BY-ANALOGY USING THE WORDTREE METHOD AND AN AUTOMATED WORDTREE GENERATING TOOL

E. V. Oriakhi[1], J. S. Linsey[1] and X. Peng[2]
(1) Texas A&M University, USA (2) Prairie View A&M University USA

ABSTRACT
The WordTree method systematically leads a designer with a design problem to potential analogous solutions. The solution relationships are based on the design functions. The WordTree method has been shown to be effective in identifying useful analogies, but automating many of the tedious steps would improve its usability. In this paper we present a tool called WordTree Express (WTE) that simplifies the process of generating WordTrees. In a controlled experiment, the WTE tool showed that its implementation positively influenced the opinions of designers using the WordTree Method. Furthermore, the interest level in the method increased when the tool was used as opposed to generating WordTrees manually which can be very tedious and time consuming. Recommendations for further advancement of the WordTree Method are presented in the concluding remarks. The controlled experiment shows that engineering designers are more likely to use the WordTree Method with the automation of WTE than without.

Keywords: Design-by-Analogy, innovation, creative design.

1 INTRODUCTION

In very competitive industries, engineers and designers need to be innovative to succeed. Analogies can trigger breakthrough ideas in new product development [1]. For example, the design of Velcro was inspired by an analogy to burrs. A number of procedures and methods based on analogies exist that assist in the generation of innovative ideas; examples of such methods include synectics [2], TRIZ [3] and biomimetics [1]. Another design method based on analogy is the WordTree Design-by-Analogy Method [4]. Other tools to assist creative design, such as Design Support System Using Analogy (DESSUA) [5] do exist, but the WordTree Method is unique in the fact that it can assist designers in the identification of both analogies and analogous domains for their design problem. Analogous domains are particularly useful because patent databases are organized by domain.

2 BACKGROUND

The WordTree Method was developed to systematically re-represent a design problem, assisting the designer in identifying analogies and analogous domains [4]. The WordTree Method involves the process shown in Figure 1. Key problem descriptors are identified from the design problem and used to create WordTrees that re-represent key functions, leading to more abstract and domain-specific terms resulting in analogies. Analogies and analogous domains are then identified for possible solutions to a design problem. Research of the analogies and a closer look into the identified analogous domains follows with newly created problem statements. Finally, idea and concept generation occurs.

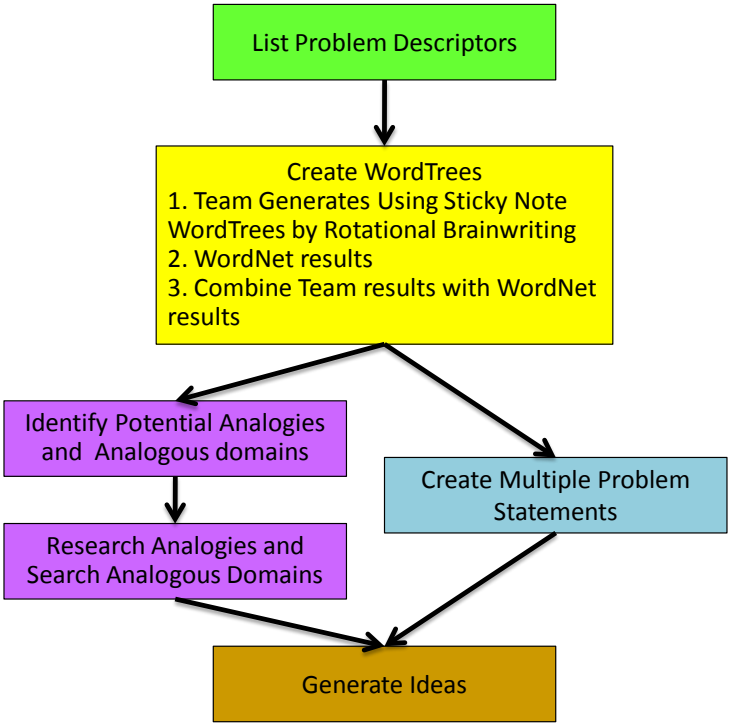

Figure 1. WordTree Design-by-Analogy process

The WordTree Method involves the identification of analogical relationships between keyword functions and other words/phrases in a WordTree diagram. WordTree diagrams are made using an online lexical database called WordNet [6] or in a team idea generation session in which members write down words on sticky notes to create the WordTree. Using the WordTree diagrams, the designers look for analogous relationships between keywords and other words by skimming through all the words on the WordTrees. Sometimes relationships are found domains distant from the original keywords for possible innovative solutions. The solutions from the WordTrees usually come from similar functional relationships between a keyword and other words that represent potential analogies. For example, Figure 2 shows a WordTree for the keyword "shell," used to find solutions to a design problem concerning a novel method for shelling peanuts. The WordTree led the designer to the word "bark," in a distant part of the WordTree, resulting in the identification of potential analogies within the bark stripping domain for the design solution. The existing solutions found for debarking trees inspired design concepts for the peanut shelling problem. (Note: The diagram in Figure 2 was created for descriptive purposes only and does not accurately represent the WordTree used).

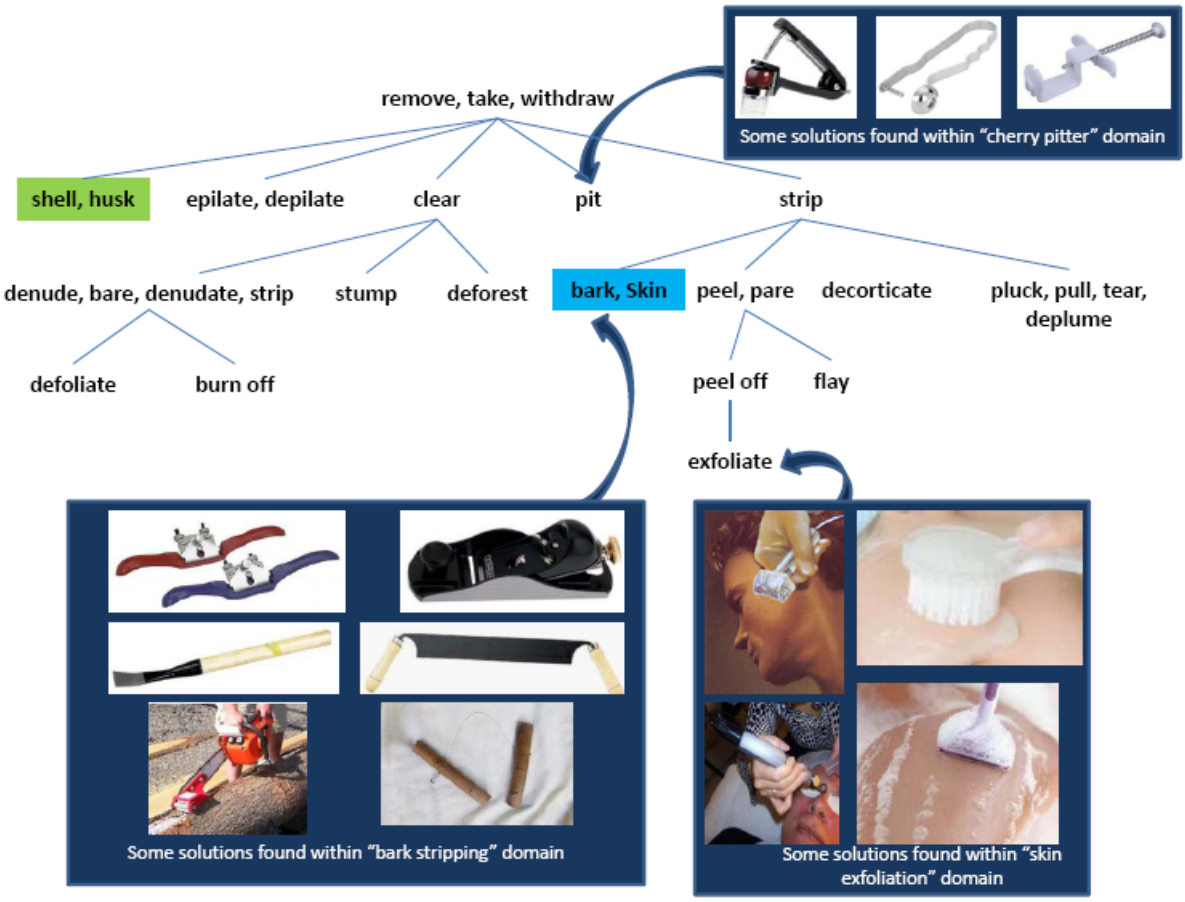

Figure 2. WordTree diagram for the word "shell" and resulting analogs [7-19]

This paper focuses on the WordTree Method because it possesses the capacity to act as an effective tool for the identification of analogies and analogous domains. Although a prior study by Linsey et al., 2008, showed positive results in the method's effectiveness, it also demonstrated that the method requires an easier medium to generate the requisite WordNet-based WordTrees. Simply put, the current method consumes too much time and possesses unnecessary tedium. A major objective of this paper pertains to the improvement of a significant portion of the WordTree generation stage, i.e. the "WordNet results" shown in the yellow block of Figure 1, by developing an automated tool for generating the WordNet-based WordTrees. The said tool, "WordTree Express" (WTE), works in combination with two other programs, Graphviz [20] and Inkscape [21], to accomplish the creation of WordTrees. A simple comparison test shows that a WordTree with 30-40 words takes about 12 minutes to develop manually. Conversely, it takes about 15 seconds to generate an equivalent WordTree using the Express tool. Another objective of this paper was to test the effectiveness of the WTE tool on the user by performing a controlled study and comparing the results with the Linsey et al., 2008 study.

The WordTree Design Method was developed to assist engineers and designers in the idea generation stage of a Design-by-Analogy approach to design problems. A study by Linsey et al., 2008 on the effects of memory representation on analogy use supports the assertion that the form of concept representation plays an important role in the cognitive analogy formation process [22]. This study acted as one of the drivers for the development of the WordTree Method. Furthermore, a controlled study of the WordTree Method shows that the method assists engineers in identifying more analogies and alters their database search patterns, resulting in cross-domain solution generation [4]. The study also shows that the method needs to provide a better support for the mapping of identified analogies into solutions [4]. In the controlled study of the WordTree Method, participants tended to identify large numbers of analogies, with a high percentage not inspiring conceptual solutions [4]. In surveys,

participants ranked the WordTree Method among the least valuable methods for future generation of innovative solutions to design problems. Of the 13 total methods, the WordTree Method ranked comparable to the TIPS/TRIZ, morph matrix and 6-3-5, among the lowest scorers, with the other 9 methods ranking higher. It is also important to note that TIPS/TRIZ is a highly valued method in industry.

The method's developer suggests that a possible reason for such an outcome concerns the methods presentation to the participants. In other words, the use more powerful examples could strongly highlight the purpose of the method. The method's developer suggests another reason might be because some of the participants' lack of experience with the method or skill with Design-by-Analogy. This paper suggests that an automated WordTree generation tool could simplify part of the method's application (i.e. creating WordTrees), thereby simplifying the teaching of the method and positively affecting users' opinions about the method.

3 WORD TREE EXPRESS TOOL

The WordTree Express tool shown in Figure 3 was developed using Visual Basics (VB). It uses the WordNet database [6] to generate WordTrees by reading the database and creating text files that are formatted in a way that a second program, Graphviz (Figure 4), can read and interpret them, subsequently generating a graphical display. A third program, Inkscape (Figure 5), is used to display large WordTrees since Graphviz possesses a size limitation. The Graphviz program can convert text files to different file formats; for the Inkscape program, the ideal format to store the WordTrees in was scalar vector graphics (SVG).

To use the WordTree Express tool, the user inputs a keyword function (i.e. a verb) into the textbox and clicks the search button to generate the different senses of the entered keyword. The user then selects the sense that best suits the design problem he or she needs to solve. Next, they click the "Create File and Start Graphgviz" button to generate the WordTree file. Graphviz opens the created file, either displaying the WordTree or converting it into another file format to display with other programs such as Inkscape.

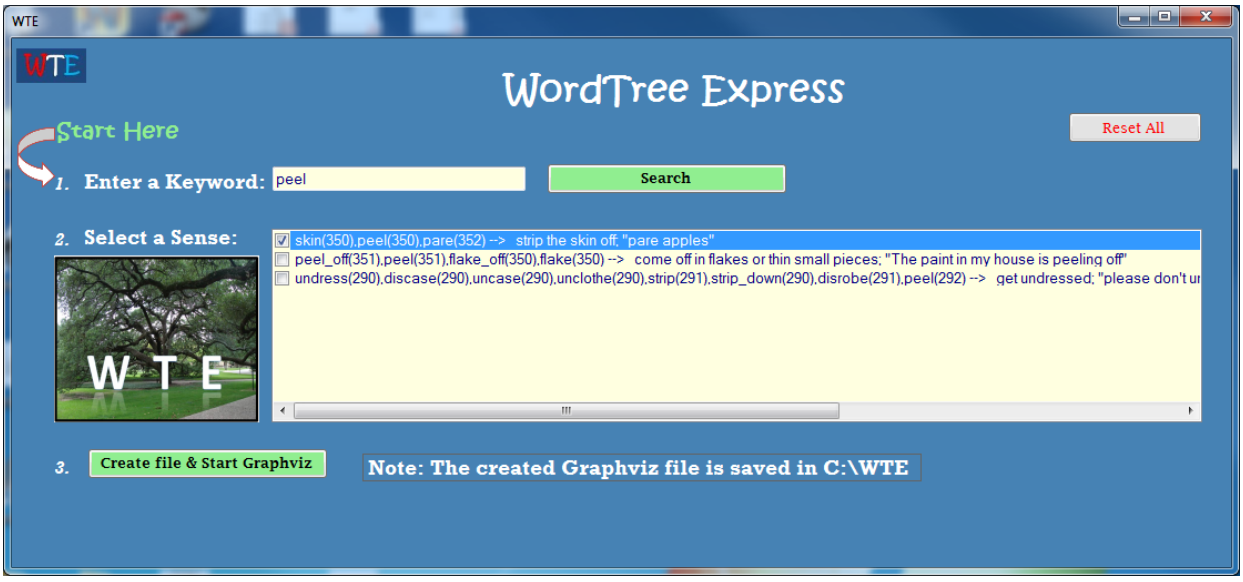

Figure 3. WordTree Express User Interface

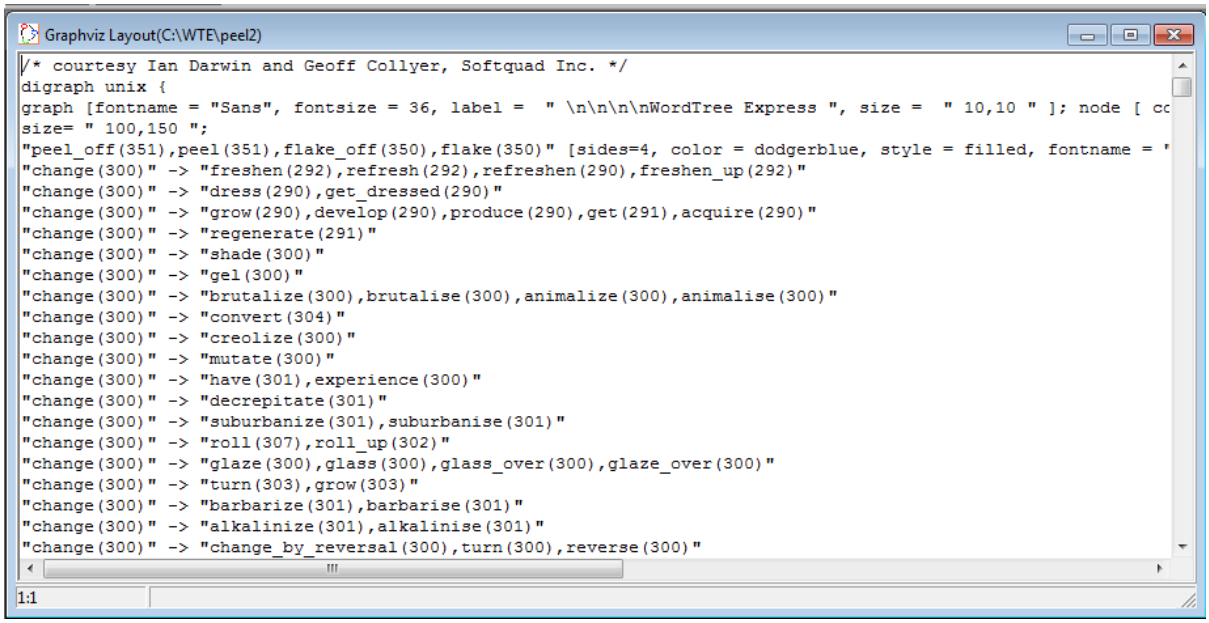

Figure 4. Graphviz visualization software (output text file)

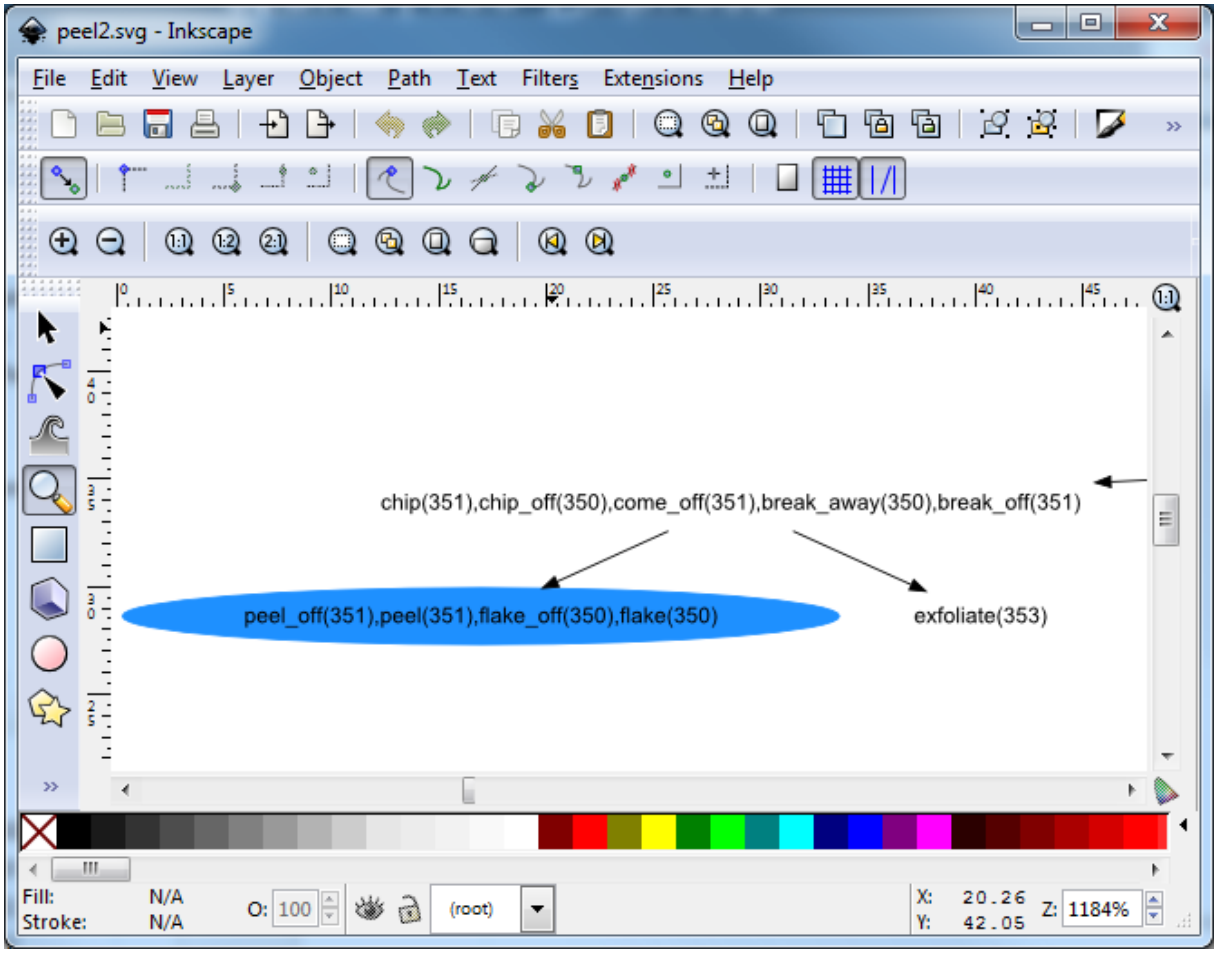

Figure 5. Inkscape visualization software

4 EXPERIMENT

The research question of interest is as follows:
Does the WordTree Express program affect engineering designers' opinions of the WordTree Method?
Does simplifying the process of generating WordNet-based WordTrees have a positive effect on the opinions of engineers when asked to rate the value of the WordTree Method against other design methods for each of the following?

1. A typical engineering design problem.
2. How likely they would be to use the method in the future.

To investigate this research question the following hypothesis was proposed:

> *Hypothesis: WTE, by simplifying the process of generating WordNet-based WordTrees, will increase designers' opinions of the WordTree Method.*

This paper investigates the research question by performing a repeated measures study of the participants. This was accomplished by surveying the participants who were taught different design methods, including the WordTree Method, without the use of WTE, and then surveying the participants after they use the automated WordTree generation tool (WTE). Furthermore, the study replicates the Linsey et al., 2008 WordTree Method control study with some minor modifications while also comparing both results. Table 1 summarizes the minor differences between the Linsey et al., 2008 WordTree control study and the study in this paper.

Table 1. Difference between Linsey et al., 2008 study and the current study

Linsey et al., 2008 WordTree Control Study	**Current Study**
Participants were undergrad students.	Participants were graduate Students.
Method was taught in a senior capstone course during one 50 minute lecture	Method was taught in a 60 minute graduate design course
Method included re-writing problem statements	Method did not include re-writing problem statements
Participant did not have to generate WordNet-based WordTrees, they were provided with them	Participants were asked to generate their WordNet-based WordTrees using WTE

Although the training on how to use WTE increased the total training time for the WordTree Method, the effect on the outcome was not expected to be significant. Also, during the experimental procedure it proved necessary to remind the participants about the WordTree Method and how to apply it. The designed reminder was the same as the one used in the 2008 study. A video tutorial was made to teach the participants how to use the WTE tool; the quality of the tutorial and the learning ability of each of the participants could have had a considerable effect on the outcome of the study. This approach was chosen as opposed to running two different studies because the number of qualified participants for the study was limited.

4.1 Participants

The participants were graduate Mechanical Engineering students at Texas A&M University. All the participants were recruited from a graduate design class and were compensated for their participation in the experiment with extra credit in said class.

4.2 Procedure

The WordTree Method was taught in a graduate design course during a 60 minute lecture. Participants were recruited from the graduate design course after they demonstrated an understanding of the method based upon the results of a class assignment concerning the WordTree Method. The participants received extra credit for their participation and were told the amount of extra credit depended upon their efforts and results. A total of 15 participants took part in the study. One of the participants was not an engineer, but a psychology graduate student taking the design course. Most of the participants were PhD level students.

The experiment procedure was as follows and was consistent with the Linsey, et al., 2008 study:
1. Participants were provided with a pre-experiment survey which asked for their opinions about the WordTree Method and other design methods.

2. Examples of analogies were shown to the participants using PowerPoint slides.
3. The participants were provided with the design problem shown in Figure 6, told that the design problem was real and from the website thinkcycle.org and that their solutions could be given to a design team working on the problem.
4. The participants were then asked to create sticky note WordTrees for 20 minutes, concerning the problem descriptors: shell, remove, separate, and import energy. A printout reminder of the WordTree Method was also given to the participants for reference. The method shown on the WordTree Method reminder was slightly modified and geared towards an individual rather than a team.
5. The participants were asked to watch a recorded tutorial for the WordTree Express tool and to use it to generated two WordTrees, one for the keyword "shell" and the other for the keyword "separate". These were the same two WordTrees presented to the participants in the Linsey et al., 2008 controlled study. The participants were asked to circle all the words of interest on each WordTree that might lead to potential analogies. The participants had 30 minutes for this step which included the 9 minute tutorial video.
6. Participants were then asked to generate ideas for the design problem by sketching and providing short descriptions to illustrate their ideas.

Device to shell peanuts

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 is to build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the peanut farmers. The target throughput is approximately 50Kg (110lbs) per hour.

Customer Needs:

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

Functions:

- Import energy to the system.
- Break peanut shell.
- Separate peanut shell from the nut.

Figure 6. Design problem presented to the participants

7. After 45 minutes of idea generation, the participants were told that they could use the internet in idea generation. They were instructed it could be used to research the potential analogies they identified and to search for patents in the analogous domains. Web searches were optional and lasted for 15 minutes.
8. In the final step of the experiment, the participants were provided with a post-experiment survey nearly identical to the first except for the inclusion of questions specific to the WordTree Express program and a set of interview questions.

4.3 Metrics

Quantitative and qualitative measures were accomplished in the same manner as was used in the prior study. The metric of interest for this paper involved: *The opinions of the participants concerning the WordTree Method*. Metrics were scored by the experimenter. The data was collected and analyzed with the set of surveys given to the participants.

5 RESULTS AND DISCUSSION

Figure 7 shows the results of the participant surveys on the value of different methods for a typical engineering design problem. The change in the pre-experiment and post-experiment scores across all methods was insignificant except for the WordTree Method. A statistical difference exists between the non-automated WordTree Method and the WordTree Method using WTE.

A t-test shows statistical significance (t= -1.9, p= 0.07) for an increased opinion of the Method. This result suggests that the opinions of the participants on the value of the WordTree Method changed in a positive direction following the use of the WordTree Express program.

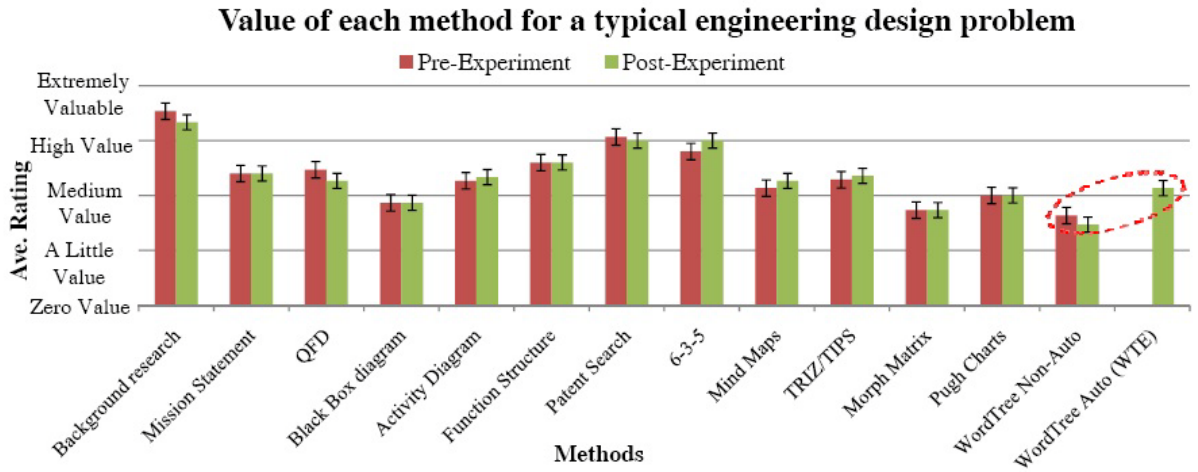

Figure 7. Participants were asked how valuable each method was for a typical engineering design problem. Error bars are +/- one standard error.

Figure 8 shows the results from the participant surveys asking them how likely they were to use each method in the future. A t-test for change in the pre-experiment and post-experiment scores was significant ($p<0.1$) for the black box diagram and patent search ($t=-1.9$, $p=0.08$; $t=2.6$, $p=0.02$ respectively). The change in the WordTree Method (non-automated) and the WordTree Method (using the WTE) were also statistically significant ($p<0.1$) based upon the t-test ($t=-1.9$, $p=0.08$; $t=-4.2$, $p=0.001$ respectively). The change found in the use of the black box was not expected, but the change in patent search could have resulted from the use of a patent search during the WordTree Method (as a step). The change found between the pre-experiment and post-experiment for the non-automated WordTree Method suggests that the participants are more willing to apply the method, even manually, in the future. A possible explanation for this result pertains to the fact that the use of the WordTree Express tool influence their perception or understanding of the WordTree Method, instigating their willingness to use the non-automated method in the future.

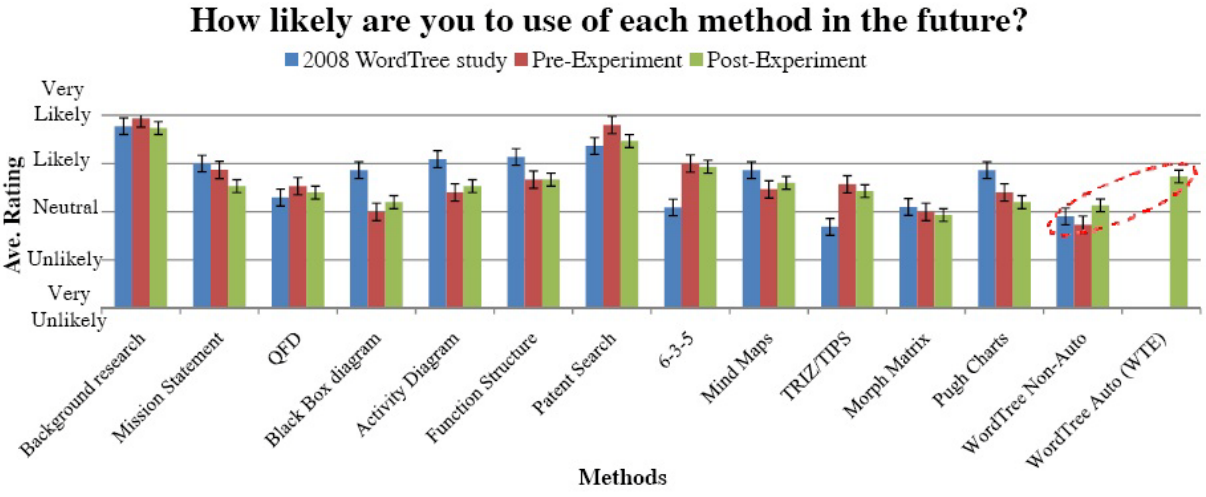

Figure 8. Participants were asked how likely they were to use each method in the future. Error bars are +/- one standard error.

In comparing the Linsey et al., 2008 study with the WTE study, statistical differences in the black box diagram, activity diagrams, function structure, 6-3-5 and TIPS/TRIZ exist. These results could be attributable to the graduate versus undergraduate discrepancy in understanding each method's value or in how the methods were taught.

5.1 Addressing the Research Question

Question: Does the WordTree Express program affect engineering designers' opinions of the WordTree Method?

The WordTree Express program positively affected the opinions of the designers. The study shows a significant rise in value scores for the WordTree Method in two of the three measures taken, the question concerning: the value of the WordTree Method for a typical engineering design problem and how likely they would be to use the Method in the future. The results from Figures 7 and 8 support the hypothesis that WTE, by simplifying the process of generating WordNet-based WordTrees, will increase designers' opinions of the WordTree Method. Although the positive results seem to point to the use of the WordTree Express tool, another factor which might have contributed to the results concerns the fact that participants knew at the time of the post experiment survey what they were being tested for. Such a fact might have biased their response.

6. CONCLUSION

The WordTree Method not only presents a way to lead engineers and designers to useful analogies in nature, but also to other existing and useful non-natural analogies. This paper investigates the WordTree Method's potential in an effort to foster the advancement of the state of the method to increase its ease of use for engineers and designers. The first step to achieving this involves changing designers' negative opinion of the method through automation of the WordTree generation process. The WordTree Express (WTE) was developed and demonstrates the capacity, by experiment, to significantly improve the opinions of engineers regarding the WordTree Method. The results from the experiment show that the participants' opinions of the WordTree Method positively change across most of the survey questions. The results from each participant regarding the use of the WordTree Method in the future either increase or remain the same. This was the desired outcome of the study. Design by analogy is a powerful tool for innovation and many methods can enhance it. Recommendations for future work include: Investigate other potentially useful databases in combination with the WordNet database; improve the user interface by making it a single, rather than multiple, interface; and, combine words with images to potentially assist in the analogy retrieval process.

ACKNOWLEDGEMENTS

This work was supported by the Pathways to the Doctorate Fellowship at Texas A&M University.

REFERENCES

[1] Schild, K., Herstatt, C., & Lüthje, C. (2004). *How to Use Analogies for Breakthrough Innovations*. Hamburg, Germany: Technical University of Hamburg, 63: 495-508.

[2] Weaver, W., & Prince, G. (1990). Synectics: Its potential for education. *Phi Delta Kappan, 71(5),* 378-388.

[3] Altshuller, G. (1999). The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity, Worchester, MA. Technical Innovation Center.

[4] Linsey, J.S. (2007). *Design-by-Analogy and Representation in Innovative Engineering Concept Generation*. Ph.D. The University of Teaxas at Austin.

[5] Qian L. and J. S. Gero (1996), Function-Behavior-Structure Paths and Their Role in Analogy-Based Design, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, **10**(4):289-312.

[6] Princeton University (2010). About WordNet. *WordNet*. Princeton University. http://wordnet.princeton.edu

[7] Harbor Freight Tools, available from: http://www.harborfreight.com [4/29/2009]

[8] Amazon.com, available from: http://www.amazon.com/Columbus-McKinnon-Draw-Shave-13in/dp/B0000DI84S/ref=sr_1_2?ie=UTF8&s=hi&qid=1279442115&sr=8-2 [4/29/2009]
[9] Amazon.com, available from: http://www.amazon.com/Northern-Industrial-Bark-Spud-2-Ft/dp/B000OEXMXY/ref=sr_1_1?ie=UTF8&s=hi&qid=1279442115&sr=8-1 [4/29/2009]
[10] Amazon.com, available from: http://www.amazon.com/Stanley-12-220-Block-Plane/dp/B00002X1Z8/ref=sr_1_3?ie=UTF8&s=hi&qid=1279442371&sr=8-3 [4/29/2009]
[11] Hud-Son Forest equipment for the work you do, available from: http://www.hud-son.com/hand_tools_access.htm [4/29/2009]
[12] Paleo tube, available from: http://paleoplanet69529.yuku.com/topic/23268 [4/29/2009]
[13] Loma Linda University, available from: http://www.llu.edu/medicine/plastics/patient_info/dermabrasion.page [4/29/2009]
[14] Anti Aging Treatments, available from: http://antiagingtreatments.blogspot.com/2008/06/exfoliating-key-part-of-anti-aging-skin.html [4/29/2009]
[15] Beaut.ie: The Irish beauty blog, available from: http://beaut.ie/blog/wp-content/uploads/2008/07/shave-legs.jpg [4/29/2009]
[16] Hamptons.com, available from: http://www.hamptons.com/gallery/article/1417b.jpg [4/29/2009]
[17] Amazon.com, available from: http://www.amazon.com/Oxo-Good-Grips-Cherry-Pitter/dp/B000NQ925K/ref=sr_1_1?ie=UTF8&s=home-garden&qid=1279441292&sr=8-1 [4/29/2009]
[18] Amazon.com, available from: http://www.amazon.com/MIU-Polished-Stainless-Steel-Cherry-Stoner/dp/B000VWDQQ2/ref=sr_1_8?ie=UTF8&s=home-garden&qid=1279441292&sr=8-8 [4/29/2009]
[19] ACE, available from: http://www.acehardware.com/product/index.jsp?productId=1386346&CAWELAID=109362493 [4/29/2009]
[20] Ellson, J., Gansner, E., Hu, Y., & Bilgin, A. (2010). *Graphviz - Graph Visualization Software*. http://www.graphviz.org
[21] INKSCAPE. (2010), *Open Source Scalable Vector Graphics Editor*, http://www.inkscape.org.
[22] Linsey, J., Wood, K., & Markman, A. (2008). Modality and representation in analogy, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing 22(2)*, 85-100.

Contact: Julie Linsey
Texas A&M University
Department of Mechanical Engineering
3123 TAMU
College Station, Texas 77843
USA
Tel: Int +1 979 845 1531
Fax: Int +1 979 845 3081
Email: jlinsey@tamu.edu
URL: http://www1.mengr.tamu.edu/i-dreem

Julie S. Linsey is an assistant professor at Texas A&M University in the Mechanical Engineering Department. She earned a PhD and MS in mechanical engineering from The University of Texas at Austin and a BS in mechanical engineering from the University of Michigan. She teaches the mechanical engineering undergraduate capstone design courses and the mechanical engineering graduate course, Advanced Product Design. Her research focus is on systematic methods and tools for innovative design with a particular focus on concept generation and design-by-analogy. She has co-authored over twenty technical publications including two book chapters and she holds two patents.