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INCREASING INNOVATION: PRESENTATION AND EVALUATION OF THE WORDTREE DESIGN-BY-ANALOGY METHOD

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ABSTRACT

Numerous examples of innovation through analogy are found throughout current trade journals, magazines and product offerings. Design-by-analogy is a powerful tool in creative design, but generally relies on unproven, ad-hoc approaches. Although a few notable computational knowledge bases have been created to support analogous design, very few methods provide suitable guidance on how to identify analogies and analogous domains. This paper presents a novel approach, referred to as the WordTree Design-by-Analogy Method, for identifying analogies as part of the ideation process. The WordTree Method derives its effectiveness through a design team's knowledge and readily available information sources but does not require specialized computational knowledge bases. A controlled experiment and an evaluation of the method with redesign projects illustrate the method's influence in assisting engineers in design-by-analogy. Unexpected and unique solutions are identified using the method. The experimental results also highlight potential improvements for the method and areas for future research in engineering design theory.

1. INTRODUCTION

Recently much attention focuses on increasing innovation in engineering design. The National Academy of Engineering, in recent reports, emphasizes the need for engineers with innovation and creativity skills [1,2]. Ingenuity needs to be taught and tools must be available to support it. Analogies are frequently referenced as sources of inspiration for innovative design. This paper presents a new method, founded on prior research, for increasing engineering innovation through design-by-analogy. The method systematically guides the engineer to new linguistic representations for their design problems. This leads to potential analogies and analogous domains. This endeavor begins with a discussion of the empirical evidence highlighting the extensive use of analogy in design and then explores the currently available methods and tools supporting analogous design. Next, the WordTree Design-by-Analogy Method is presented along with the guiding principles derived from experimental evidence. A controlled experiment is then described that measures the effectiveness of the method. Results from implementing the WordTree Method on a series of redesign projects are shown. Finally, conclusions are drawn,

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directions for future work are explored, and possible improvements to the method are given.

2. MOTIVATION AND PRIOR WORK

A few formal design-by-analogy methods exist and are detailed in the following section. Most of these methods provide little guidance in identifying potential analogies. More recently, computational tools that rely on specialized databases have been and are being created. In addition, empirical work on design-by-analogy has solidified its position as an effective approach for design and also highlighted potential approaches to improved techniques.

2.1. Empirical Work on Design-by-Analogy

The empirical evidence supports the use of analogy for design. Professional designers often use analogies [3,4,5]. Unlike biologists who mainly use analogies within their domain, engineers employ cross-domain analogies in their design process [5]. This finding is based on protocol analysis of design team's conversations during conceptual design. Design teams also frequently use close-domain analogies in the form of references to past designs [6]. Eckert, *et al.* found designers use references to previous designs for more than just conceptual design. Designers also use past designs in a number of other phases of the design process including process planning, cost estimation, and evaluation of concepts for a new product.

A few controlled experiments have explored the use of analogy within design. Casakin and Goldschmidt [3] found that visual analogies can improve design problem solving for both novice and expert architects. Visual analogy had a greater impact for novices as compared to experts. Ball, Ormerod, and Morley [7] investigated the spontaneous use of analogy with engineers. They found experts use significantly more analogies than novices do. The type of analogies used by experts was significantly different from the type used by novices. Novices tended to use more case-driven analogies (analogies where a specific concrete example was used to develop a new solution) rather than schema-driven analogies (more general design solution derived from a number of examples). This difference can be explained because novices have more difficulty retrieving relevant information when needed and have more difficulty mapping concepts from disparate domains due to a lack of experience [8].

Other studies on analogical reasoning have focused on easing analogy retrieval from memory and the influence of representation. Prior research in analogical reasoning found the encoded representation of a source analogy can ease retrieval if it is entered into memory in such a way that the key relationships apply in both the source and target problem domains [9,10]. Items that are learned with a more general linguistic description are more easily retrieved from memory and applied to a new situation. This work shows that the internal representations in memory play a key role in retrieval. The analogies and problems used in these experiments were not

specific to any domain of expertise and used fantasy problems relying only on linguistic descriptions.

Experiments with engineering design problems replicated the results found by Clement, *et al.*, [9,10] and then further investigated the influence of the problem representation [11,12,13]. Linsey, *et al.*, [12,13] found that learning about analogous products with more general linguistic representations that apply across the problem and target domains improves an engineer's ability to use the analogous product at a future time. These prior experimental results show that appropriate linguistic representations (of the design problem and analogous product) have the potential to increase a designer's probability of success by up to 40%. The representation of the design problems has a clear effect on the ability of the designer to retrieve and use an analogy but the representation with the highest probability of success depends on how the analogous product was learned initially.

Other experiments focus on the distance/near domain analogies and on when the analogically similar information is given, prior to the presentation of the design problem or after. The timing of when analogically similar information is presented affects how frequently it is incorporated into an open-ended design problem. If the analogous information is more distantly related to the problem it is more likely to be used to solve the problem if it is presented when there is an open-ended design problem to be solved [14]. This suggests that distant domain analogies are most useful to designers when they are having difficulty solving a design problem.

2.2. Formal Design-by-Analogy Methods

A structured design-by-analogy method would be useful for minimizing the effects of the experiential gap between novices and experts and to further enhance experts' abilities. A few formal methods have been developed to support design-by-analogy such as Synectics [15], French's work on inspiration from nature [16,17], Biomimetic concept generation [18,19] and analogous design through the use of the Function and Flow Basis [20]. Synectics is a group idea generation method that uses four types of analogies to solve problems: personal (be the problem), direct (functional or natural), symbolic and fantasy [15]. Synectics gives little guidance to designers about how to find successful analogies. Other methods also base analogies on the natural world. French [16,17], highlights the powerful examples nature provides for design. Biomimetic concept generation provides a systematic tool to index biological phenomena [18,19,21]. In biomimetic concept generation the functional requirements of the problem and the keywords are first derived. The keywords are then referenced to an introductory college textbook and relevant entries can be found.

Analogous concepts can be also identified by creating abstracted functional models of concepts and comparing the similarities between their functionality. Analogous and non-obvious products can be explored using the functional and flow basis [20]. A case study, using this approach, of a pick-up

winder for an electric guitar is shown in [20]. The analogy to a vegetable peeler leads to an innovative design.

Other database supported computation tools for design-by-analogy have been recently developed. An example of such a tool is the work by Chakrabarti, *et al.* [22,23]. They created an automated tool to provide inspiration to designers as part of idea generation process. Based on the function or behavior of a device, analogies from nature or other devices are provided as potential sources of inspiration to the designer. Chakrabarti, *et al.*, have tested the automation tool and its analogy representations with student participants as part of university design courses.

3. WORDTREE DESIGN-BY-ANALOGY METHOD

There is a lot of anecdotal evidence for the importance of analogy in design, but there is little work on systematic methods for promoting the retrieval and use of analogies to facilitate innovation. The lack of applicable design methods causes the teaching of this influential technique to be limited to little more than interesting examples with accompanying direction to simply “try to find analogies.” Simply trying to “think of” analogies and analogous domains is difficult even for experienced engineers. Yet this ability, based on both anecdotal and empirical evidence, is clearly important and a critical path to innovation.

The WordTree Design-by-Analogy Method systematically re-represents a design problem, assisting the designer in identifying analogies and analogous domains. Figure 1 overviews the method’s steps. For a detailed example illustrating the method see [24]. The method begins by

identifying the “problem descriptors” which are the key functions and customer needs. These are then linguistically re-represented in a diagram know as a WordTree (Figure 2). Next potential analogies and analogous domains are identified. The potential analogies are researched and the analogous domains are used to find solutions in distant domains. New problem statements ranging from very domain specific in multiple domains to very general statements are written. Finally the analogies, patents, analogous domains and new problem statement are implemented in a group idea generation session. This session further refines the method’s results into conceptual solutions to the design problem and provides additional inspiration for the designers.

One of the main principles for enhancing analogical retrieval provided by prior experimental work is the design problems need to be represented in multiple ways ranging from very domain specific to general, thereby providing a variety of related effective retrieval cues. The retrieval cues that will locate useful for analogies stored in memory depend on the representation of the stored information. By creating a variety of related retrieval cues at various levels of abstraction, the chances of finding a relevant analogy are increased. The WordTree method focuses on creating multiple linguistic representations of the design problem through numerous other representations are likely to be effective including functional models. TRIZ, with a different approach, also linguistically re-represents the design problem as the conflict between two generalized engineering parameters [25,26]. Other possible re-representations and other linguistic approaches are possible.

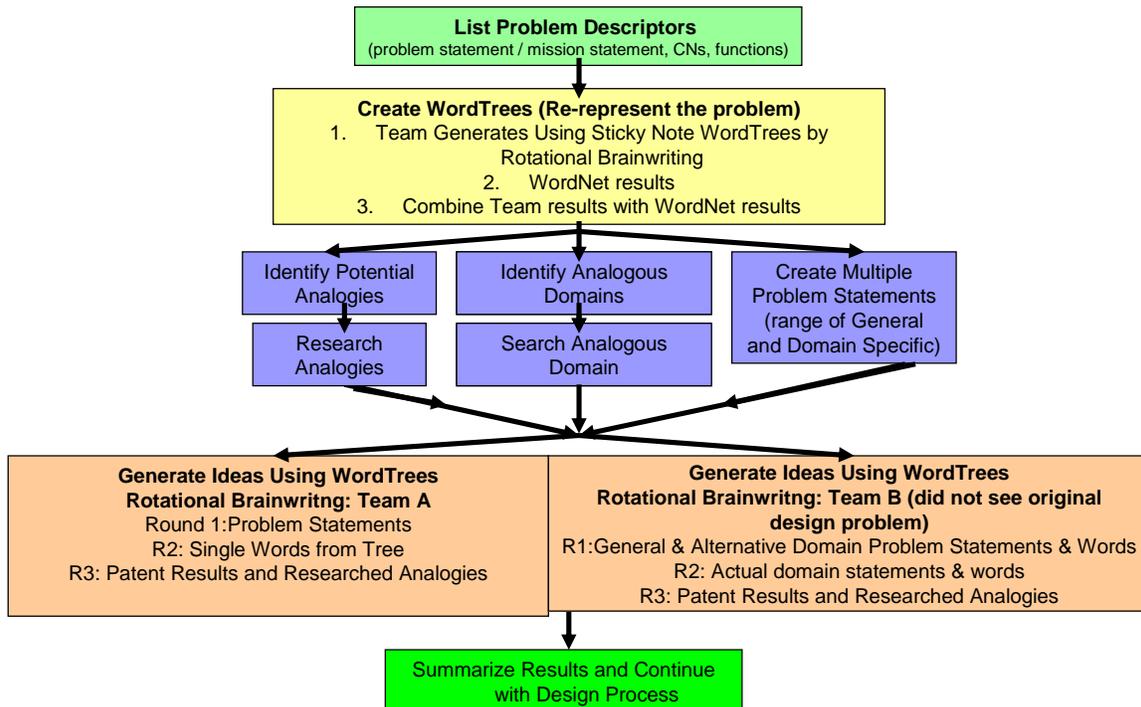


Figure 1: Overview of the WordTree Design-by-Analogy Method

This WordTree method begins by defining the *Key Problem Descriptors*. The key problem descriptors are *single word action verbs* derived from the functions and customer needs for the design problem. Prior research found that transitive verb, which are action verbs, are more effective stimulus for idea generation [27]. The Key Problem Descriptors are defined from the customer needs, mission statement, function structure and black box model. Key Problem Descriptors fall into a few categories. One set describes the overall function of the device with a single word. The next category is the critical or difficult functions to solve, and the final category is the important customer needs transformed into single action verbs. Normally the customer needs are a combination of an adjective and a noun. To be used in the WordTree Method, they must be converted to equivalent verbs. For example, the verb form of the customer need of “easy to repair” is “repair”.

The next step is to re-represent the key problem descriptors using WordTrees. This step facilitates the identification of analogies and analogous domains. The first, the design team uses rotational brainstorming to create sticky note WordTrees. Rotational brainstorming is very similar to 6-3-5 except that each team member receives three separate sheets of paper and develops one WordTree on each sheet. A rotational brainwriting method was chosen since a prior group idea generation experiment showed this type of approach results in a greater number of ideas [28].

After potential analogies and analogous domain have been identified, the analogies are researched along with searching for solutions in analogous domains. Google Image© is an effective and efficient tool for finding information about a potential analogy. Patents in analogous domains should be

searched for also. Design fixation is a potential risk anytime a solution is presented to a designer. The search results have the potential to cause fixation but prior experimental results suggest it is unlikely for this method. Searching for analogies and patents in analogous domains can be completed prior to the teams attempting idea generation because it has been shown that uncommon solution, which is the type of solutions analogies should provide, tend to increase the number of ideas generated and not cause fixation [29,30]. Common solutions were defined as the solutions designers think of most frequently for a given problem.

Finally the teams use the results to generate more ideas. Two separate teams of designers are recommended to base their idea generation sessions on the results from the WordTree Method. The first team is the original team who generated the WordTree and knows the details of the design problem. The second team is unfamiliar with the problem and is given the general and alternative domain problem statements along with general and alternative domain words. When using analogies, individuals tend to focus too much on the surface and unimportant features of the problem rather than the causal structure [31,32]. It is believed, the second team will be less likely to focus on unimportant features of the original design problem since they will be shown a series of analogous problems which will tend to focus them on the deep structure and not the surface information. After team idea generation, the results are summarized using any number of methods such as morph matrixes or mind maps. The team then continues with the design process and moves to idea selection.

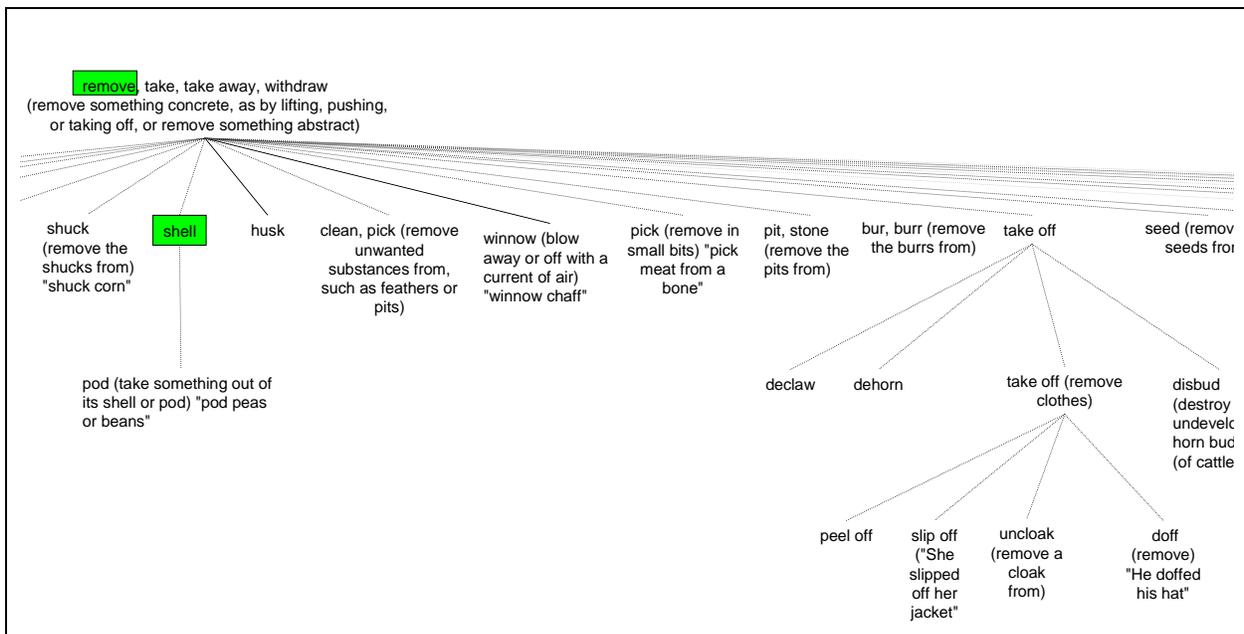


Figure 2: Part of the WordNet© WordTree provided to the participants.

4. RESEARCH QUESTIONS REGARDING THE WORDTREE METHOD

The WordTree Method is founded on prior experimental results and theory. This basis does not guarantee an effective design approach. A series of evaluations is used to understand the outcomes of the WordTree Method and provide guidance for further refinement. This endeavor is focused through a set of research questions as follows:

- Question 1: Does the WordTree Method increase the number of analogies identified? Does the WordTree Method produce unexpected, useful analogies?
- Question 2: Does the WordTree Method change how designers search for solutions using databases?
- Question 3: What are some avenues for improvements to the WordTree Method?

The WordTree method was evaluated using a controlled experiment and with teams working on the redesign of commercial products. The teams working on the redesign of commercial products provided a more realistic design setting but afforded less control. The experiment facilitated good control but also limited the time that could be spent on the design problem.

5. CONTROLLED EXPERIMENTAL METHOD

The controlled experiment compared the WordTree Method to having participants generate ideas without the method. Both groups were familiar with design-by-analogy and had been exposed to a few different idea generation techniques as a part of their mechanical engineering Senior Design Methods Class.

5.1. Procedure

The WordTree Method was taught to the Senior Design Projects Class during one 50 minute lecture. This version of the method did not include idea generation with a design team that had not seen the original design problem (this aspect of the method was not evaluated). The limited experimental time did not allow for this aspect of the method to be tested. The reduced method explored in this experiment is shown in Figure 3.

Participants were recruited from the Senior Design Projects Class prior to the lecture on the WordTree Method. They were given extra credit for their participation and were told the amount of extra credit would depend on their effort and results. The control group session occurred pre-lecture and the WordTree conditions occurred post-lecture. To reduce biases due to when participants chose to sign-up for sessions, half of the participants were randomly email sessions that occurred as control groups prior to lecture and the other half received session times after the WordTree lecture. Participants who missed their first session time or signed up later were assigned

to available time slots. Two participants were assigned to the WordTree group sessions but did not attend the WordTree lecture so they were run in the control condition but their data was not included in the results. Participants knew this was a new method being evaluated.

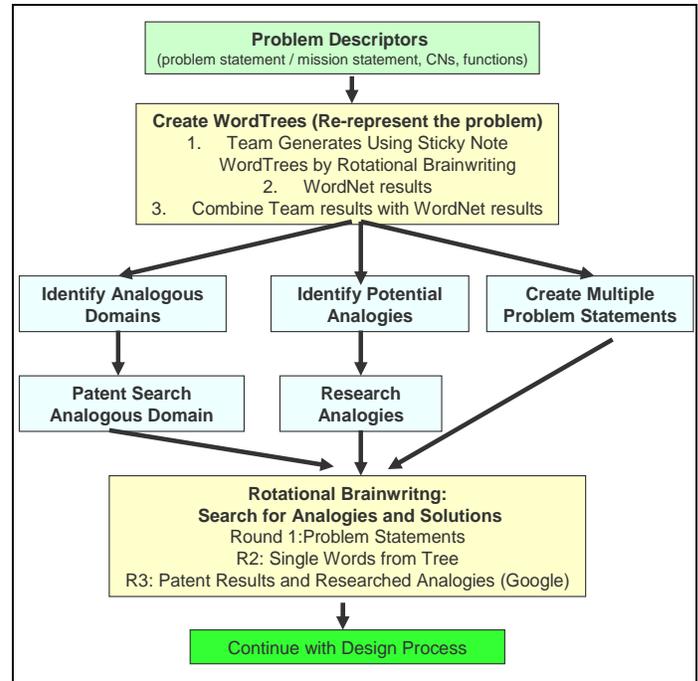


Figure 3: WordTree Method used for the controlled evaluation.

The design problem was to develop a device to shell peanut for use in third world countries, and had been used in previous experiments [28]. Participants in both conditions were guided by the experimenter using scripted instructions. They were told they could end idea generation at any time, moving on to the next task or they could spend the entire time generating ideas. They were also reminded their amount of extra credit depended on effort and results. After 45 minutes participants were also allowed to use a computer to search for ideas and solutions. If they found a useful idea they were asked to reference it. At the end of the session, participants were asked to record their search strategy including what terms they searched for and which search engines they used. If participants left the web browser open on the computer, the webpage history was recorded to provide further insights into their search approach.

When participants decided to end idea generation, the time was recorded and they were given a sheet asking them why they decided to end the sessions and then a second sheet stating that most people could generate ideas after they thought they had run out of ideas. It was hoped that this could give a measure of time on task and the influence of other participants' actions would be minimal. Instead, the other participants' actions had a large influence on when participants decided to

end the idea generation session. One to five participants worked individually in the same room. They were given a five minute break after 60 minutes. This first session lasted about two hours.

Participants in the control group were told to generate ideas and analogies using any method they learned in the design methods class. The control group had a total of ninety minutes for idea generation. Throughout the entire session for both groups, the color of pens being used was switched every fifteen minutes so that the time an idea occurred could be documented.

A series of slides with a script guided the participants through the WordTree Method. Each step in the process had a time limit as follows:

- Create sticky note WordTree for the following Key Problem Descriptors (20 minutes):
 - Shell
 - Remove
 - Separate
 - Import energy
- Combine sticky not WordTree with WordNet WordTree (5 minutes)
- Identify and list potential analogies and analogies domains (10 minutes)
- Write new problem statements (10 minutes)
- Generate ideas (45 minutes)
- Generate ideas using database support if desired (15 minutes)

The sticky note WordTrees were recorded prior to combination with the provided WordNet WordTree. Two WordNet WordTrees for “shell” and “separate” were created by the experimenter and provided in finished form. Part of the “shell” WordTree is shown in Figure 2. The WordTrees are filtered versions of the words provided by WordNet and were chosen as a combination of words possibly relevant and miscellaneous words.

During a second session hour-long session, participants documented the analogies they had generated, put all of their ideas into a morph matrix and filled out a post-session survey. The matrix contained some common pre-defined functions for the peanut shelling machine but participants were encouraged to add additional functions as needed. Participants also filled out a post-session survey. The participants’ documentation facilitated measurement. When participants finished the list of analogies, morph matrix, and the survey, they were told to spend any remanding time generating ideas. This step prevented participants from rushing through these final steps.

5.2. Measures

The controlled experimental set-up allowed for quantitative and qualitative measures to be made. All metrics were scored by one of the authors and the condition information was removed as much as possible during

evaluation. The number of analogies was calculated with two approaches. The first was based on all analogies the participants listed during the second session. It was noticed that many of the participants in the WordTree condition did not list the potential analogies and analogous domains they had identified during the first session. A second measure was made of the number of non-redundant analogies listed in either the first or second session.

The search strategy used by the participants was scored for containing words outside the domain of peanut shelling or not. Not all of the participants chose to use databases to assist them and a few of the participants’ search strategies could not be determined based on the information they provided. The two participants who missed the lecture on the WordTree Method were included in the search strategy data but not for the rest of the measures. The number of ideas generated was based on the number of boxes filled in for the morph matrix.

5.3. Controlled Experiment Results and Discussion

The number of analogies identified by the participants and the number of ideas is shown in Table 1 and Table 2. Participants in the WordTree condition found significantly more analogies than the control group. A t-test shows this difference to be statistically significant ($p < 0.01$). Based on the participants’ scores, the number of ideas did not vary between the two groups. All results shown are calculated for the first 60 minutes of idea generation. The control group had a total of 90 minutes for idea generation whereas the WordTree group had only 60 minutes.

Table 3 shows the percentage of the analogies identified by the WordTree group that were implemented in solutions. Participants are not using the potential analogies to find solutions to the design problem.

Table 1: Number of analogies as scored by the participants and the evaluator.

	Evaluator Scores (S. E.)	Raw Participant Scores (S.E.)	N
Mean Control	7.6 (4.8)	7.6 (4.8)	10
Mean WordTree	25.0 (16.1)*	15.6 (13.2)	10

*statistically significant difference $p < 0.01$

Table 2: Mean number of ideas per person as indicated by the participants.

Condition	Number of Ideas (S.E.)
Mean Control	16.2 (7.1)
Mean WordTree	16.0 (8.6)

Table 3: The participants implemented only a small fraction of the analogies that they identified.

	Percentage of identified analogies that were used to find solutions
Mean Usage	42%
Min. Usage	15%
Max. Usage	64%

Novelty, variety and quality were not measured. A coarse review of the results indicated a difference in novelty, variety or quality was not likely between the two conditions. Therefore, a more robust quantitative assessment was not undertaken. In addition, the participants appear to not be using their listed analogies to support their concept generation which further supports the conclusion that the two conditions are likely to show similar levels of novelty, variety and quality.

5.3.1. Results from Database Searches

Table 4 summarizes the number of participants in each condition who searched outside the domain of peanut shelling and those who only searched within the domain. Examples of the search results from both conditions are shown in Figures 5-7. The WordTree Method supports participants in finding novel cross-domain analogies and substantially modified their search strategy. Examples of terms within the domain of peanut shelling included shell, nut, peanut and crack. Terms that were

considered outside the domain were peel, panning and winnowing. These are not obvious analogies for peanut shelling. Participants in the control conditions did find useful information for the peanut shelling problem but the information they found was all closely related to peanut shelling. They located the current solution for this problem which is Malian peanut shelling machine (Figure 7) and industrial large-scale solutions for peanut shelling.

All available data were included in this analysis for the entire time participants spent searching databases. This means that the WordTree group had a maximum of 15 minutes to find solutions whereas the control group had up to 45 minutes with most participants in the control group having at least 30 minutes. Not all participants chose to use the assistance of databases. Web history information was also used to evaluate the search strategy. Web histories were available for six of the participants.

Table 4: Number of participants who searched outside the domain of peanut shelling.

	Outside Peanut Shelling Domain	Only Within Domain of Peanut Shelling
Control	0	4
WordTree	6	2

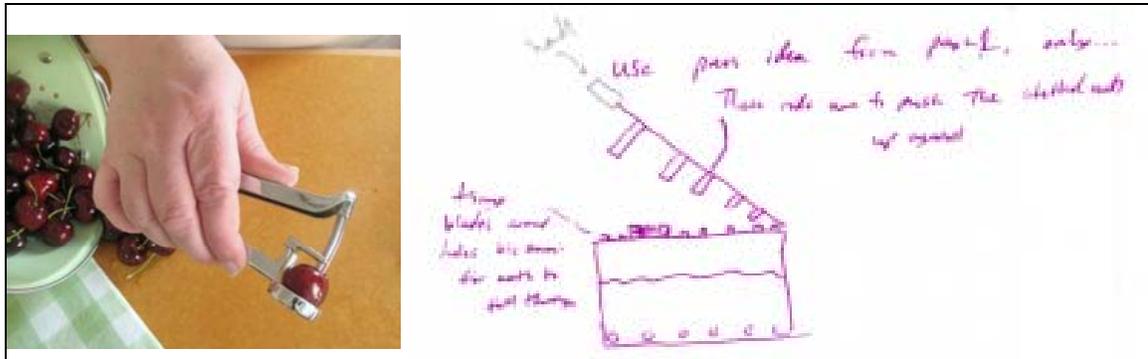


Figure 4: Another analogy identified and implemented by a participant in the WordTree group was a cherry pitting device (image source: “How to Pit Cherries”, 2007).

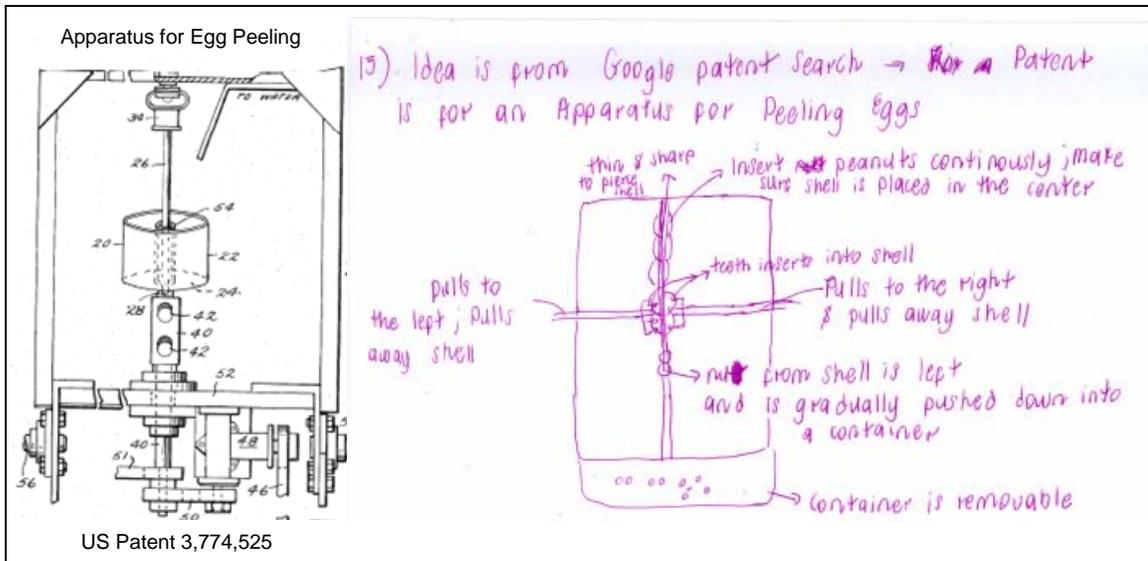


Figure 5: An analogous solution found by a participant in the WordTree group. The egg peeling device was used as an analogy to find a solution to the peanut shelling problem.

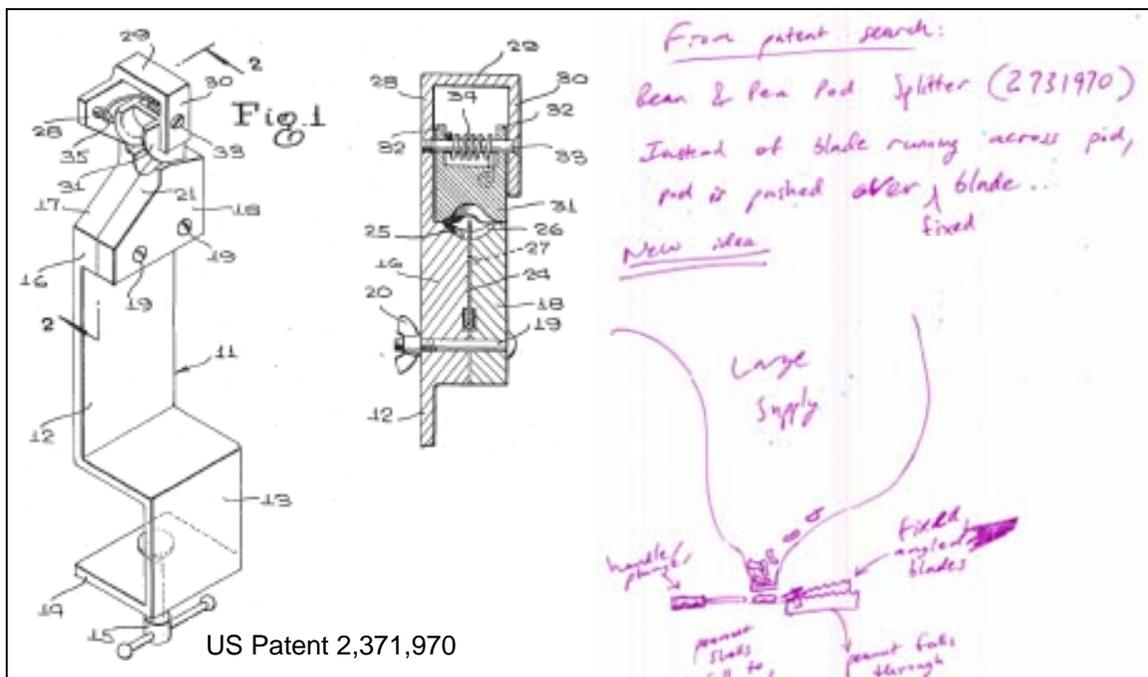


Figure 6: A device to split bean and pea pods, located by one of the WordTree condition participants, provides an analogous solution to the peanut shelling problem.



Figure 7: Participants in the control group only found within domain solutions to the peanut shelling problem. This solution is a hand-powered device that removes the shell from the peanuts (“Full Belly Project”, 2006).

6. TEAM DESIGN PROJECT RESULTS

To further evaluate the WordTree Design-by-Analogy Method and explore it in a more realistic design setting with a longer time scale, it was taught in the Senior Design Methods Course. The author of this dissertation taught the WordTree Method as part of a lecture series on idea generation which included brainstorming, 6-3-5, MindMapping and TIPS/TRIZ [25]. The method was not presented as a new method.

6.1. Procedure

As part of their Design Methods Class, 92 senior mechanical engineering students were required to use the WordTree Method. In the Senior Design Methods Class, students work in teams of four to six students redesigning a commercial product that they choose. The entire semester is spent learning and applying various design methods starting with identifying the customer needs through embodiment design [25]. To simplify the WordTree Method for the class, the steps of creating new problem statements and using a second team to assist in generating ideas were not included (Figure 8). The teams learned the method in one 50 minute lecture and then spent a second lecture period working with their teams to complete the method. During the second lecture period, the author reminded the teams of the steps in the process, answered any questions they had and helped guide them through the method. Many of the teams had their WordTrees finished and we left to research the analogies at the end of the second lecture period. Teams were required to hand in at least one WordTree with at least thirty words, five analogies, two analogous domains and five useful patents from their research. For extra credit, teams were asked to individually fill out an opinion survey.

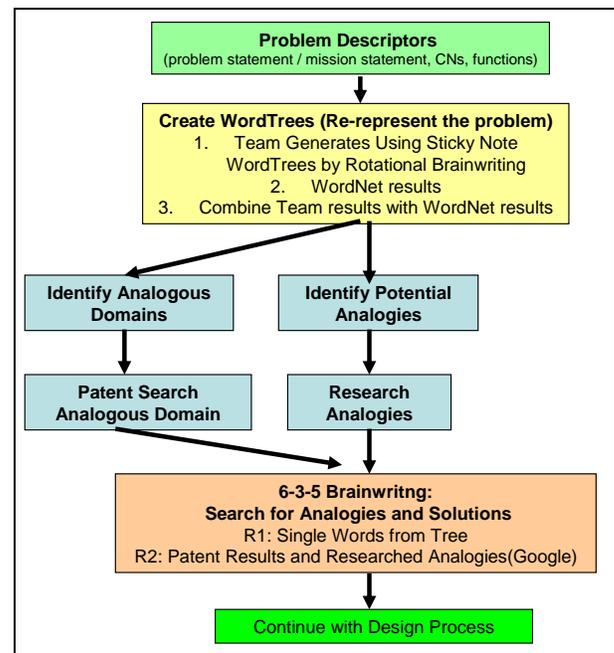


Figure 8: WordTree Method as presented to the Design Methods Class.

6.2. Results and Discussion

Figure 9 shows one team’s resulting analogies and analogous domains for the redesign of an automatic cat litter box. The team sought analogies for cleaning a cat litter box. The WordTree was created around the word “clean”. The WordTree method provided the team with analogies to a dump truck, panning for gold and dredging items from the sea floor. Panning for gold suggest using water to separate the cat waste and litter. These results are one example of a handful of very good results obtained by the teams.

The WordTrees for both the team-based and WordNet generation were generally carried out correctly and showed

positive results, but there also was significant variation in the resulting analogies and solutions. Some teams, like the cat litter box team, found very novel analogies and unexpected analogous domains. Other teams had more disappointing results for a number of different reasons.

Correctness of the method implementation varied. One team focused on changing the aesthetics, usability or ergonomics of the device rather than the function. Analogies can be made to the aesthesis of a device but the WordTree method is tuned for function. Other difficulties arose with using the wrong sense of the verb or creating WordTrees using the constraints of the design problem rather than functions or customer needs. Some of the customer needs, which are adjectives, were not converted to verbs and therefore WordNet provided a dismal set of results. Another team used the team generated, “sticky note” WordTree to identify their analogous domain rather than the WordNet generated one. In addition most teams had very focused problem statements, such as “extending battery life” or “reducing weight” rather than focusing on more general problems.

A few teams obtained poor sets of analogies even though the procedure of the method was correctly applied. Many teams had difficulty identifying distant analogous domains within the WordTrees. They tended to identify close-domain analogies. One reason for this may be the teams were focused on finishing this method quickly and the choice of more distant analogies has a higher risk of not obtaining useful results but greater potential for innovation. Distant domain analogies have more risk but also have much greater potential for innovative solutions. One solution to this issue is to alter the grading structure such that students believe the reward is worth the possible risk.

There was one generally consistent issue for almost all of the teams with the WordTree Method with a few exceptions such as the cat litter box team. The resulting words, analogies, analogous domains and patents were usually not carried to the next step in the process of 6-3-5 brainwriting. The teams did not connect their idea generation sessions to their previously generated analogies and possible solutions. This also likely means the ideas provided by the WordTree Method will not appear in the final solutions. From this evaluation it is not clear why this occurred but the issue will be investigated. The cat litter box team carried the results from the WordTree method through to idea generation.

7. ADDRESSING THE RESEARCH QUESTIONS

The results from the controlled study and implementation of the WordTree Method with design teams provide insights into the effectiveness and benefits of the WordTree Method. These results provide answers to the research questions.

Question 1: Does the WordTree Method increase the number of analogies identified? Does the WordTree Method produce unexpected, useful analogies and solutions? The WordTree Method provides designers will a systematic tool to identify effective analogies for obtaining innovative solutions. It increases the number of analogies identified by the designers through linguistic re-representation of the design problem which also allows for the location of analogous domains. Analogous domains provide an avenue to search for existing solutions that are outside the problem domain. The controlled experiment showed a statistically significant increase in the number of analogies identified. The other applications of the method illustrated a number of unusual and effective analogies found for the design problems.

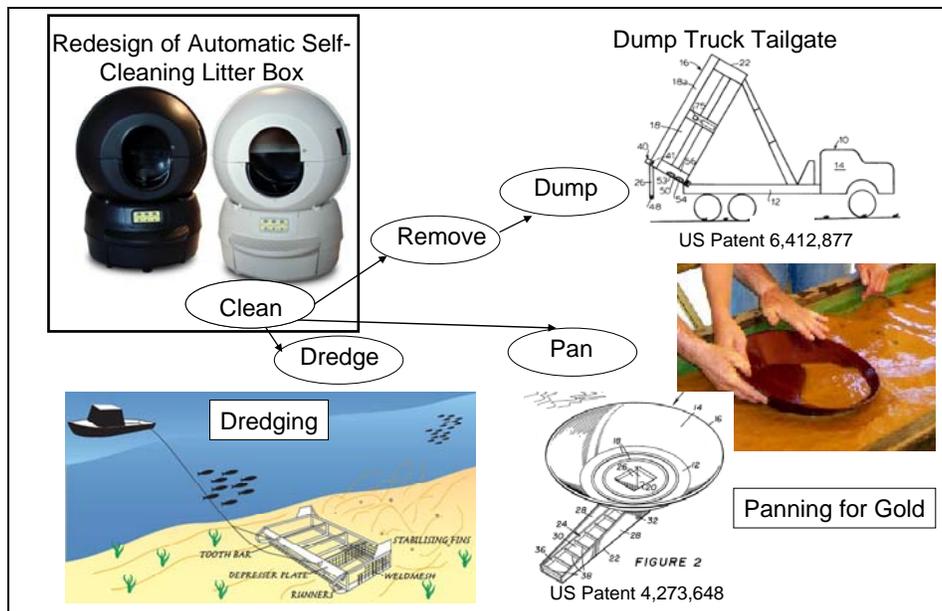


Figure 9: Analogies and analogous domains identified by a team who was redesigning a self-cleaning cat litter box.

Question 2: Does the WordTree Method change how designers search for solutions using databases as compared to the control group? Designers who were using the WordTree Method used a distinctly different strategy for seeking analogous solutions. They expanded their searches to analogous domains which then provided novel analogies for them.

Question 3: What are some of the avenues for improvements to the WordTree Design-by-Analogy Method? As with any new method, there are avenues for improvement. A more streamlined and simplified version of the WordTree Method would be ideal. The presentation of the method needs to include more powerful examples and strongly highlight the high level purpose. For reasons that are not completely clear, the engineers are not effectively using the analogies they identify. The WordTree needs to support this process better.

8. CONCLUSIONS AND FUTURE WORK

The WordTree Design-by-Analogy Method provides a systematic approach for identifying analogies and analogous domains for a given design problem. Through re-representation of the design problem, unexpected analogies and analogous domains can be explored. The controlled experiment shows that this method allows designers to identify a greater number of analogies and alters their search approaches leading to more unusual analogous solutions being located. Teams working on redesigns of commercial products successfully implemented the WordTree Method on their redesign projects and found unexpected analogies and analogous domains. One team redesigning a cat litter box identified dredging and panning for gold as analogies for their problem of cleaning a litter box. The WordTree Method is a powerful approach for the re-representation of design problems.

Many other avenues for enhancing design-by-analogy are possible and will be future research. For example, even though the WordTree Method guided the participants in identifying analogies, only a small percentage were incorporated into solutions even though participants felt they had run out of ideas before time was over. Future research will focus understanding why designers quickly disregard provided information and evaluating if designer experience is factor.

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