The Effects of Language Stimuli on Design Creativity

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Abstract

We have been studying the effects of language stimuli on design concept creativity. We are motivated to study language and design because of the established relationship between language and cognitive processes central to design such as reasoning. As creativity is an important measure of design, many design methods use stimuli with the aim of increasing concept creativity. Language relationships such as the opposition relationship provide a systematic method of generating non-obvious stimuli that may increase concept creativity. In this paper, we summarize and discuss two experiments where participants used oppositely related and similarly related word stimuli in conceptual design. We found that designers using oppositely related word stimuli developed more novel concepts. We also observed that opposite stimuli elicited designer behaviours that may encourage creative concepts. These results suggest that opposite stimuli is a practical method for encouraging creative design.

Keywords: Engineering design, concept generation, design stimuli, creativity, language

1 Introduction

We have been studying the application of natural language, i.e., human language, not artificial language, to the process of conceptual design. Language appears inherent in people and also appears connected to cognition. Researchers have established a link between language and cognition, although the exact relationship is disputed; some have shown that language affects cognition (Levinson, 1996), while others have shown that language reflects cognition (Pinker, 2007).

Design is a cognitively intense task that has been characterized as an information gathering and manipulation task, a search task, and a decision-making task, amongst others (Simon, 1969; Gero et al., 1994). The cognition required of design implies that we can take advantage of the relationship between language and cognition.

For a product to be successful, it must have creative properties as well as functional and performance properties. Customers and end-users seek creative products although they may not explicitly indicate creativity as a requirement. So while creativity can be difficult to define and measure, it is still an important measure of design (Kan & Gero, 2007). Most researchers on the subject agree that creativity is associated with novelty and originality as well as other measures such as quantity, variety and usefulness (Shah et al., 2000; Kan & Gero, 2007).

In this paper, we will first present related work in language and design. Then we will describe and discuss our experiments with respect to the specific effects of different types of word stimuli on concept novelty. We will then discuss the effects of word stimuli on designer behaviour.

2 Related Work

Although natural language is not generally considered a conventional engineering tool, language and language concepts have been incorporated throughout the engineering design process. Language has been applied to requirements gathering (Nuseibeh and Easterbrook, 2000), concept generation and synthesis (Hacco & Shu 2002; Chiu & Shu, 2007a; Nagai & Taura, 2006), design representation (Stone and Wood, 2000), and design analysis (Dong et al., 2003).

Some concept generation and creativity methods explicitly use language. Nagai and Taura (2006) investigated the interpretation of noun-noun combinations for promoting creativity in concept synthesis. Our work in biomimetics uses functional keywords to systematically retrieve analogies from biological corpora for use as stimuli in engineering design (Hacco & Shu 2002; Chiu & Shu, 2007a). Our retrieval process relies on concepts from computational linguistics including lexical relationships (Miller et al., 1993), word frequencies, word collocations and syntax. It was in this biomimetics work that we first observed the relationship between language and cognition.

Methods implicitly using language include synectics and random input. In synectics (Gordon, 1961), which is related to design-by-analogy, metaphors and analogies are used to apply solutions from another domain, e.g., biology to engineering. The random input method involves randomly selecting a word or a picture to relate back to the design problem. The process of relating the problem to a random word or picture, which may be non-obvious and unexpected, may provide new perspectives (de Bono, 1992).

3 Experiments

In this paper, we discuss two experiments where we provided words as design stimuli to participants. The words were either oppositely related or similarly related to the desired function of the solution. Words were chosen as stimuli because words are the smallest unit of language carrying meaning. Word stimuli provided were verbs because they denote abstract actions or functions and not specific forms (c.f. Stone & Wood, 2000).

The opposite/similar relationship was used to generate stimulus words because it is one of the two valid verb relationships that can be used to systematically generate alternative words. The other relationship is the super-ordinate/sub-ordinate relationship where words are hierarchically related in either a more general or more specific manner. In language, the opposite/similar relationship is embodied in antonym/synonym pairs (Fellbaum, 1993). The concept of opposition is also found in concept generation, e.g., TRIZ, where problem parameters are identified as those to be improved, and those that are degraded as a result (Altshuller & Shulyak, 1996). Like random input, oppositely related stimuli may appear unexpected and non-obvious. Unlike random input, oppositely related stimuli can be systematically generated, e.g., with thesauri and WordNet (Miller et al., 1993).

3.1 Experimental Methodologies

Two types of experimental methodologies were used: Pen-and-paper and talk-out-loud. In both methods, participants were provided with several problems and related word stimuli on worksheets. In both cases, participants were instructed to review the problems and the stimuli, and to perform a functional decomposition before selecting stimulus word(s) and generating concepts to address the given problem. Participants were also instructed to relate concepts back to selected stimulus words. Differences are described below.

3.1.1 Pen-and-paper Experiments

In this type of experiment, participants were provided with four problems and related stimulus sets on worksheets. The problems involved 1) Sunflower-seed shelling 2) Soft-material grinding 3) Egg orientation and 4) Bushing-and-pin assembly. Participants were allotted 10 minutes per problem and instructed to describe their concepts on provided worksheets that were collected for analysis.

While this method enables the collection of a relatively large number of concepts, often only final concepts were available, with no trace of participants' design cognition.

3.1.2 Talk-out-loud Experiments

In these individual experiment sessions, participants were provided with three problems and related stimulus sets on worksheets. Fifteen minutes were allotted for each problem. The problems involved 1) Bushing-and-pin assembly 2) Snow insulation of houses and 3) Coal storage. In contrast to pen-and-paper experiments, participants were instructed to verbalize all thoughts as they worked on the design tasks. The sessions were recorded and fully transcribed for analysis.

A concern some researchers have about this method is that talking about the task will change the task itself. However, Ericsson & Simon (1993) argue that since verbal on-line reporting draws on short-term memory, i.e., facts and thoughts already present and not requiring retrieval or reconstruction from long-term memory, such verbalization would not alter the task. Many precautions were taken to increase the validity of the data. For example, participants were instructed to report only thoughts as they occurred to them, and not to plan their verbalizations, nor to judge their thoughts.

Since this is a time and resource intensive method, the number of participants involved is usually small. A survey of design studies using this method reveals that the typical number of participants is low. For example, four participants in a design cognition modelling study (Benami & Jin, 2002), and 10 participants in a design education study (Atman & Bursic, 1996).

Despite the limitations outlined above, talk-out-loud remains one of the few methods to study internal cognitive processes. Talk-out-loud studies are generally accepted when used in conjunction with other supporting methods, i.e., pen-and-paper in our case, and a valid method for pinpointing phenomena (Visser, 2006).

4 Experiment 1 – Results and Discussion

The first experiment was a pen-and-paper experiment involving 42 fourth-year engineering students (Chiu and Shu, 2008a). Stimuli were verbs oppositely and similarly related to the functional keywords of each problem generated using various thesauri (e.g., Oxford, 2003), and to other words in the stimulus set.

We provided opposite and similar stimulus terms simultaneously rather than separately such as in either a full within-subjects or between-subjects experimental design. For example, for the Sunflower-seed problem that requires concepts that remove the seed from the shell, both the similarly related term "to empty" and the oppositely related term "to fill" were provided, along with three other pairs. Participants were not provided with the matched pairs, nor asked to match the terms.

4.1 Results

Participants who chose at least one opposite term generally developed more novel concepts. The exception was the Egg problem. In the Sunflower-seed problem, a T-test showed a significant difference in mean novelty for a subset of 20 functionally complete concepts, $t(18) = 1.98$, $p = 0.032 < 0.05$. Novelty was evaluated based on the number of concepts in each concept category, with concepts in smaller categories denoted as more novel. This is similar to how Shah et al. (2000) evaluated novelty. Figure 1 shows novelty for functionally complete concepts.

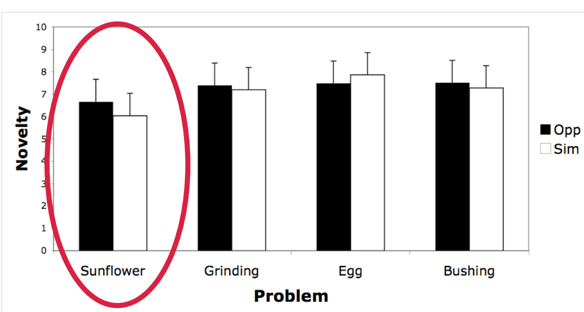

Figure 1: Concept novelty for concepts generated using at least one oppositely related stimulus word versus using only similarly related stimulus words

Concepts were also measured using the creativity metrics of quantity, the total number of concepts generated; and variety, the number of different types of concepts. Regarding quantity, in the first three problems, as opposite-term usage increased, the number of concepts increased. Regarding variety, in the first three problems, as opposite-term usage increased, the variety of different types of concepts increased. The concepts for the last problem may not have fit the quantity and variety trend because of fatigue and learning effects.

4.2 Discussion

A specific type of opposite term, the contradictory opposite term, appeared to contribute most to increased concept novelty. A contradictory pair imparts mutual exclusivity, such as "live/die", "succeed/fail", i.e., someone cannot succeed and fail at the same time (Fellbaum, 1993). A converse pair is another type of opposite relationship involving the same action but from different perspectives, such as "give/take" or "buy/sell", i.e., a book that was sold is a book that was bought. Converse stimulus pairs tended to result in the development of similar concepts when either term was selected. For example, in the Egg orientation problem, participants were required to develop concepts to orient eggs such that the pointed ends faced one direction. The opposing pair "select/reject" was provided which resulted in similar concepts that involved either "select correctly oriented egg" or "reject incorrectly oriented egg".

The two types of opposite-terms appear to affect problem objects that are named as nouns, e.g., the eggs from the Egg problem, differently. Nouns associated with specific verbs have what are called semantic filler roles. For example, the eggs from the Egg-orientation problem fill the patient role (the role, or object, that is being acted on) of the verb "to select" and "to reject". Other examples include the instrument role "knife" for the verb "to cut", and the location role "cafeteria" for the verb "to eat" (Lyons, 1977).

Contradictory opposite terms appear to force participants to either shift existing roles, or to introduce new roles to accommodate the use of the contradictory term. For example, in the sunflower-seed problem, the similar term "to empty" makes sense when applied to existing roles such as seeds and shells, e.g., "empty shell". However, the contradictory opposite term "to fill" cannot be used on existing roles, e.g., "fill shell" does not make sense. A new role or object must be introduced to allow the contradictory opposite term to be used in such a way that it makes sense, e.g., "fill *tank* with sunflower seeds". Comparing the mean rate of new-role introduction by all contradictory terms (N = 7) and the mean rate of new-object introduction by all converse terms (N = 5) (excluding terms which were descriptive or idiomatic) shows that contradictory terms introduce significantly more new roles, $t(10) = 3.98$, $p = 0.001 < 0.05$.

Experiment 1 suggests that the use of opposite terms, specifically contradictory opposite terms, may increase novelty and other measures associated with creativity. A fully between-subjects experiment, where participants are provided with only similar or only opposite stimuli, is required to remove any confounding pair effects such as those of converse or contradictory opposite pairs.

5 Experiment 2 – Results and Discussion

Experiment 2 was a talk-out-loud experiment involving six participants generating concepts for a total of three problems. For one of the problems, the Snow problem, three participants received oppositely related stimuli only and the other three participants received similarly related stimuli only. (Chiu & Shu, 2007b, 2008b). While each participant worked on three different problems in total, this analysis focused on the Snow problem, as this was a balanced between-subjects experiment. The Snow problem is stated below:

<u>Snow Problem Statement</u>: *In Canada, snow is readily available in the winters and has good insulation qualities due to the amount of air in it. However, if the snow is packed to the point it becomes ice, it is less insulating due to the loss of air. Generate concepts to enable snow to be used as an additional layer of insulation for houses in the winter*

The opposite stimulus set was generated using "to pack", where although "to pack" is part of the problem statement, it is functionally undesired. The similar stimulus set was generated using "to insulate", which is a functional requirement of the problem.

5.1 Results

To examine novelty, we first identified participant concepts from the transcripts. The concepts were then provided to two independent raters recruited to judge each concept based on novelty. Raters scored concept novelty using a scale of 0-10, where 10 indicated the most novel concept. A marginally significant correlation was found between the two raters, $r = 0.51$, $p = 0.054 > 0.05$, where, r, Spearman's correlation factor ranges from 0, indicating no correlation, to +/-1, indicating perfect positive correlation or perfect negative correlation. This correlation was most apparent when raters agreed on the *most* novel and the *least* novel concepts. No training was provided to the raters in an attempt to prevent biasing them towards the investigators' perception of novelty.

Generally, the most novel concepts involved opposite stimuli, and the least novel concepts involved similar stimuli. However, a dependent T-test for each rater showed no significant difference in mean novelty ratings between the two groups. Figure 2 illustrates the raters' mean novelty scores for concepts generated with opposite stimuli versus those generated with similar stimuli.

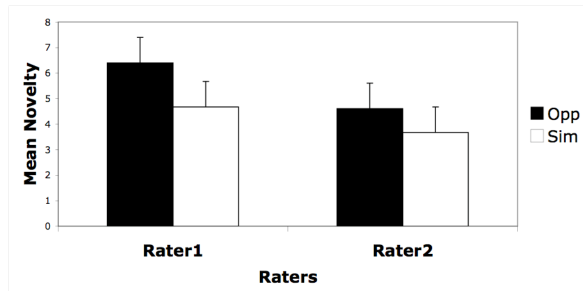

Figure 2: Mean novelty as judged by independent raters.

Linguistic analyses were conducted to determine how stimulus words were used, and their effects. A part-of-speech (POS) analysis was done to determine whether stimulus words were used as nouns, verbs or adjectives. Arguments of the stimulus words were then examined for new words and phrases introduced by the stimulus words. These new words and phrases represent new roles, actions, or properties introduced to the design process.

Overall, participants provided with opposite stimuli used stimulus words significantly more often as verbs, $t(4)$, $= 5.609$, $p = 0.005 < 0.05$. The difference between POS use is illustrated in Figure 3.

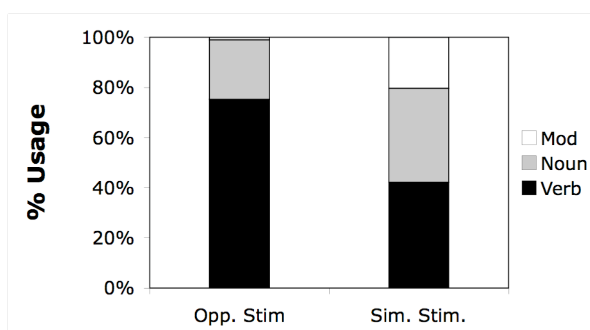

Figure 3: Difference in POS stimulus use between opposite and similar stimulus groups.

Examining the arguments, i.e., words and phrases, associated with stimulus words used, reveals that opposite stimuli introduced significantly more new arguments, $t(4) = 2.19$, $p = 0.047 < 0.05$. This is shown in Figure 4.

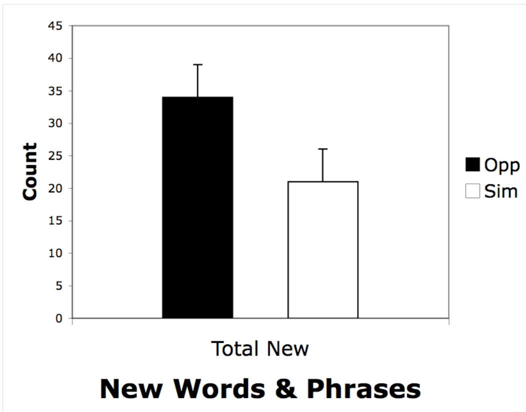

Figure 4: New arguments, words and phrases, introduced by opposite and similar stimuli.

5.2 Discussion

Overall, Experiment 2 suggests that opposite stimuli increases concept novelty. In terms of stimulus use, participants provided with opposite stimuli used the stimulus words differently than participants provided with similar stimuli. First, opposite stimuli appear to result in stimuli being used as verbs more often. Verb use in concept generation may be advantageous because verbs are more flexible, or mutable, as they can take on different meanings depending on their noun arguments (Gentner & France, 1988). This is partly due to the fact that verbs have more meanings, or senses, than nouns (Fellbaum, 1993). The increased number of senses and mutability allow verbs to be interpreted and used in a variety of ways while still "making sense". For example, "*constrict* heat" and "*constrict* snow", have very different meanings and introduce different ideas into the concept generation process.

Second, opposite stimuli appear to introduce more new words and phrases, into concept generation. New words and phrases can be seen as new concept elements that have been expressed, or lexicalized. Newly introduced words and phrases may be related to the ability of verbs to include semantic filler roles, as observed in Experiment 1. The inclusion of new semantic roles appears advantageous for concept generation and may connect verb use to concept novelty due to the verb's ability to facilitate introduction of new lexicalized concepts.

6 Summary

We are motivated to investigate language and design because of the connections between language, design and creativity. In two experiments, we observed the effects of oppositely and similarly related stimuli on concept creativity measures and how designers used language in concept generation. Oppositely related stimuli may have advantages of being unexpected and non-obvious while available in lexical resources for systematic retrieval.

Results from Experiment 1 (pen-and-paper) and Experiment 2 (talk-out-loud) show that opposite stimuli may increase the following:

1. Concept novelty as well as other creativity metrics;
2. Introduction of new concept elements.

Current work includes analyzing the data collected from the other two problems in Experiment 2. Additionally, a control condition was added where no stimuli were provided to participants. This will allow for a more complete comparison of designer behaviour with regards to language use, and a more complete comparison of the factors affecting concept creativity.

Other future work includes addressing how to train raters so that they are not biased towards the investigators' perception of concept novelty. The issue of concept identification should also be examined in more detail.

Further investigations into the application of language to conceptual design will enable us to increase our overall understanding of conceptual design. This understanding will enable us to use the relationships between language and cognition to increase design innovation and creativity.

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