ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

RESEARCH ON DESIGN IDEA GENERATION SUPPORT THROUGH DESIGN PRACTICE

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ABSTRACT

The purpose of this research is to propose a method and a computational tool to support designer/engineers' idea generation so that they can find or discern potential but essential design problems and needs and devise creative and innovative design solutions to solve or meet them. As the first step of study on Design Idea Generation Support (DIGS) software tool which actively DIGS up ideas from designer/engineers' mind by stimulating their conscious/subconscious memory with word association suggestion, the experiments of word association by students working on design project (1) by heart, (2) by referring concept relationship type information, and (3) using software with computational concept dictionary. Word association by referring concept relationship type information turned out to be effective to increase variety of association link types when the computational dictionary does not always contain ideally rich vocabulary and association links. Word association using software with computational concept dictionary turned out to be effective to obtain associated word which user cannot think of by heart.

Keywords: idea generation, creativity

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1 INTRODUCTION

In the present competitive environment, it seems insufficient for designers and engineers to simply solve or meet obvious and known problems or needs through the evolution of existing approaches. This study aims to propose a method and a computational tool to support designers' and engineers' idea generation so that they can find or discern potential but essential problems and needs of people or society and devise creative and innovative design solutions to solve or meet them. Since the authors intend to cover idea generation for not only devising design solutions but also discerning problems and needs, the authors have adopted a word-association-based approach such as the KJ method (Kawakita, 1967) and the mind maps (Buzan and Buzan, 2005), because of its general-purpose nature.

The following is a classification of idea generation support (Young, 1991):

- Level 1: "Secretarial" support, which provides a convenient method for "capturing, recording, and mirroring back an individual's thoughts in order to facilitate their further development. Only input data originated by the user are used" (ibid).
- Level 2: "Framework-paradigm" support, which provides "frameworks or standard examples as starting points and thought organizing aids. Frameworks consist of standard categories or dimensions of the problem realm".
- Level 3: "Generative" support, which "generates and displays ideas for the users' consideration by synthesizing, associating, or transforming elements entered as input or retrieved from storage. The active generative functions of the computer comprise only certain steps within a user-controlled dialogue. The user remains the initiator and judge of what ideas are to be retained and further developed".

Some idea generation methods such as brain storming (Osborn, 1948), the KJ method, and mind maps may fall into level 1. Since the aim of this study is to more actively support idea generation, support at levels 2 and 3 is investigated in this research.

Regarding the history of developing design support software such as computer-aided design, in some cases such software was developed inside manufacturing companies for their own use and then commercialized as a software package for outside use (Lichten, 1984). Also, some researchers have discussed (Shah et al., 2000) and investigated (Kröper et al., 2010) the relationships between idea generation, creativity, and motivation. Here, 'motivation' can be rephrased as 'for internal/external reward' and 'against internal/external punishment' (Chakrabarti, 2010). The authors assume that an examinee with motivation for the design task needs to be used to evaluate the efficacy of a proposed method and a software tool. Otherwise, the difference in the results may be because of the difference in how seriously the examinee worked on the design task, not because of the efficacy of the method and software tool. Therefore, the authors are working on and improving idea generation support methods and tools through design practices not for research but for design itself by motivated users.

2 DESIGN IDEA GENERATION SUPPORT

2.1 Design idea generation supported by word association

Regarding idea generation for design, finding or discerning potential but essential problems and needs of people or society and devising creative and innovative design solutions to solve or meet them are important. As shown in Figure 1, designers and engineers should find the problem or need and design solution from their own thoughts about the problem or need (horizontally hatched nodes and their network in the word network space) and those about the design solution (vertically hatched nodes and their network). If a systematic method can support designers and engineers in expanding their thoughts (nodes and their network), however, they may achieve better problem and need discernment and a better design solution (as depicted by dashed lines). In this figure, the horizontal expansion of the word network corresponds to "how well does the method expand the design space?" (Shah et al., 2003) and the vertical elongation of the design solution and problem and need discernment corresponds to "how well does the method explore the design space?" (ibid).

As metrics for an idea generated, the quantity and variety for a set of generated ideas and the quality (feasibility of the idea, how close it comes to meeting the design specifications) and novelty of each idea have been proposed (Shah et al., 2003). As values of scientific works, accuracy, systematic importance, and intrinsic interest have been proposed (Polanyi, 2003), these three values appear to be

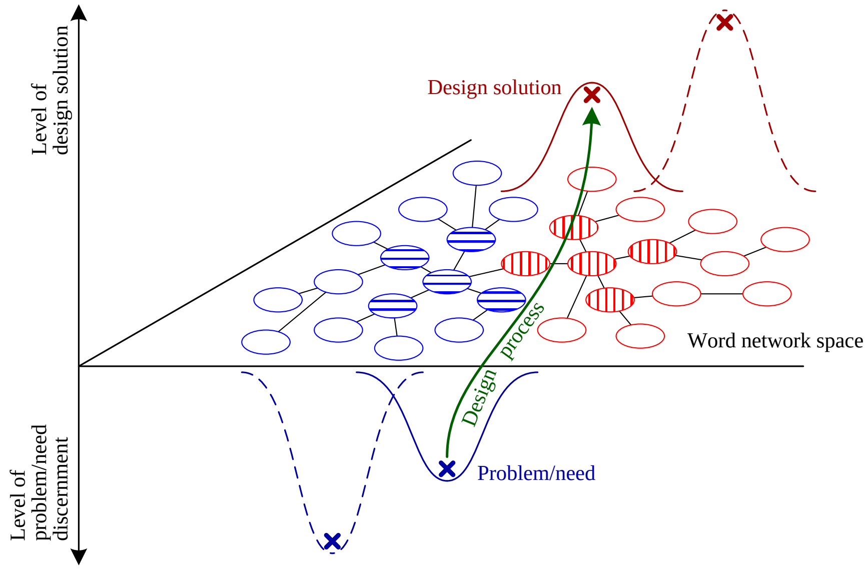

Figure 1. Design space expansion and exploration

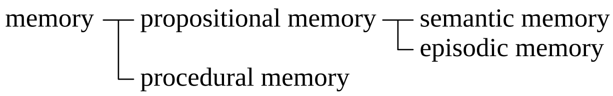

Figure 2. Categories of memory

suitable metrics for design ideas. Take the design of the iPhone by Apple Inc. for example. The reasons why the design is good are as follows: the design fully meets people's potential needs (accuracy), the operation is fun (intrinsic interest), and the design was followed by many other smart phones (systematic importance). As metrics for problem/need discernment, essentiality, latency, and comprehension of the problem or need are candidates.

2.2 Roles of designers, engineers, and software tools

The authors assume that design ideas come from designers' and engineers' conscious and subconscious memory by recalling memories as they are, or by intentionally or unintentionally modifying or combining them. Figure 2 shows the categories of memory.

– Semantic memory is "a mental thesaurus, organized knowledge a person possesses about words and other verbal symbols, their meaning and referents, about relations among them, and about rules, formulas, and algorithms for the manipulation of these symbols, concepts, and relations" (Tulving, 1972).
– "Episodic memory receives and stores information about temporally dated episodes or events, and temporal-spatial relations among these events" (Tulving, 1972).
– Procedural memory is "the system containing knowledge of how to do things. This kind of knowledge guides both physical activities like cycling or swimming, and (partially) cognitive skills like playing chess or speaking in public" (Timon and Rene, 1999).

Although in this study the authors investigate a method and a software tool for idea generation support by suggesting associated words using a computational concept dictionary or database, such a dictionary or database seems to correspond to only part of semantic memory. Episodic memory and procedural memory, which should store information on various experiences and events in the past with positive (e.g., satisfaction, delight) or negative (e.g., dissatisfaction, disappointment) emotions, seem to be unique to human designers and engineers. Therefore, the design idea generation support (DIGS) software tool investigated and implemented in this study does not generate design ideas from a computational dictionary or database but actively digs up ideas from designers' and engineers' minds by stimulating their conscious and subconscious memory by suggesting associated words. In other words, the expansion of the network of associated words by the DIGS software tool is not driven toward higher-design solutions or deeper problem or need discernment, as shown in Figure 1, and noticing words that may lead toward higher design solutions or deeper problem or need discernment is left to designers and engineers.

3 DEVELOPING IDEA GENERATION SUPPORT SOFTWARE

As the first step of the research, the authors conduct experiments to consider the difference in different approaches to word association for idea generation as described in the following sections.

1. The designers and engineers associate words by themselves.
2. The designers and engineers associate words based on concept relationships.
3. The designers and engineers select or associate words from associated word lists generated from conceptual dictionaries.

In this section, the design and implementation of the software used in the experiments are explained. As mentioned in section 2.2, as a tool for inputting concrete stimuli to dig up potential ideas, the authors focused on using conceptual dictionaries. A conceptual dictionary is a lexicon that defines and classifies different concept relationships between two specific words.

3.1 Concept relationships and conceptual dictionaries

3.1.1 Concept relationships

In a related study of design support methodology using a lexical database, similarity is used to associate target words closely related to the source word (Georgiev et al., 2008). In this study, however, various links between words such as antonyms, if available, should be used so that thought is expanded from various viewpoints. The classification of concept relationships between words varies from study to study (Okamoto and Ishizaki, 2001). The left two columns in Table 1 show the classification in this study, in which the authors classified different kinds of concept relationships that are as MECE (mutually exclusive and collectively exhaustive) (Rasiel and Friga, 2006) as possible.

Table 1. Concept relationships and links used in software

Concept Relationship	**Example**	**Japanese Wordnet**	**Word-classification lexicon**
Synonym	apple -> Malus domestica	words in the same synset	
Hypernym	apple -> fruit	hype	upper node of the tree
Hyponym	fruit -> apple	hypo	lower node of the tree
Coordinate	apple -> cherry		sibling node of the tree
Holonym	seed -> apple	hprt, hmem, hsub, dmnc, dmnu, dmnr	
Meronym	apple -> seed	mprt, mmem, msub, dmtc, dmtu, dmtr	
Attribute	apple -> red	attr (noun to adjective)	
Attributed	red -> apple	attr (adjective to noun)	
Domain (time or space)	apple -> winter, Aomori		
Has instance	apple -> Red Delicious	hasi	
Instance	Red Delicious -> apple	inst	
Entail	eat -> chew	enta	
Cause	eat -> full	caus	
Nominative	man -> eat		
Subject	apple -> eat		
See also	white -> light	also	
Similar	red -> passion	sim	
Historical idiom	apple -> Newton		

Here ‘historical idiom’ is a concept relationship that is defined through historical events or classical literature. Without the famous story of Newton discovering the universal law of gravity by witnessing an apple falling from a tree, the relationship between apple and Newton cannot be defined. Although this concept relationship has not appeared in previous studies, the authors have added it to the list. As reported in section 4, the authors conducted an experiment on word expansion using this list.

3.1.2 Concept dictionaries

A lexical database that uses a database based on concept relationships is called a conceptual dictionary. In this study, the authors developed prototype software for idea generation, using a word-classification lexicon (NINJAL, 2004) and Japanese WordNet (Bond et al., 2009).

The word-classification lexicon was developed by National Institute for Japanese Language and Linguistics. A lexicon as a whole has a tree structure, with groups of words at the bottom layer, which is then classified hierarchically by semantic classification. The relation between lower nodes and higher nodes is the same as the hypernym-hyponym relation in concept relationships.
Japanese WordNet was developed by National Institute of Information and Communication Technology and is based on Princeton WordNet (Miller et al., 1990). In Japanese WordNet, synonyms are grouped as "synsets". These synsets are linked to each other by concept relationships. In contrast with the word-classification lexicon having a tree-structure database, Japanese WordNet has a network structure database.

3.2 Software implementation

To study the difference between the human divergence process of words and that of a database, and to examine how a database can be used to support idea generation, the authors developed the software shown in Figure 3 with Java. This software uses the word-classification lexicon and Japanese WordNet as SQLite databases (SQLite, 2004). This software has two separate functions, searching for associated words, and searching for common words from associated words.

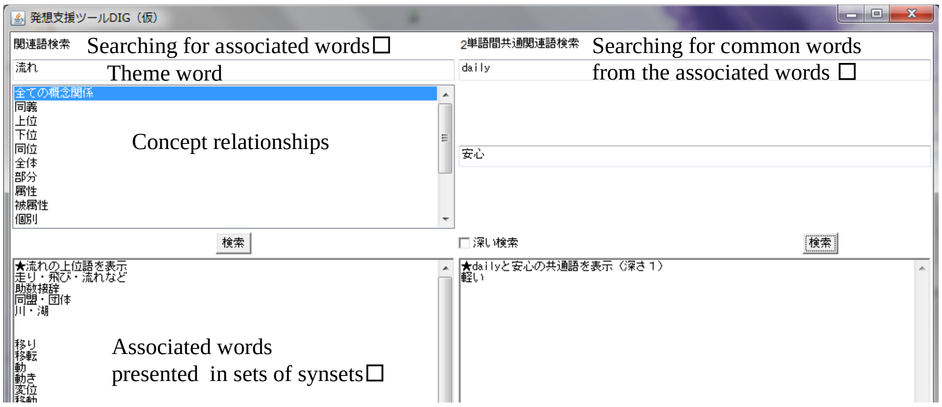

Figure 3. Interface of the DIGS software

3.2.1 Searching for associated words

When searching for associated words, the user can search for either all associated words defined in the database or words linked with a certain concept relationship. All the concept relationships in Table 1 excluding coordinate, domain, nominative, subject, and historical are available for this function. The database browsed for each concept relationship is shown in the third and fourth columns in Table 1.
In this function, when the user searches for all associated words, only one word chosen automatically from each synset is shown when browsing Japanese WordNet. This is to represent a wider variety of words using fewer words. When the user searches for a certain concept relationship, the program adds a new line between each synset to show each synset as a group.

3.2.2 Searching for common words from the associated words

In this function, the user can search for common words among all the words associated with two different words. If there are no common words in the two groups of associated words, the user can select a "deep search" to expand the word group by searching for associated words from the existing associated word groups. This function was developed for use when there are several different themes to consider, but it is not used in the experiments discussed in section 4.

4 EXPERIMENTS USING CONCEPTUAL DICTIONARIES

4.1 Experiments applied to different phases in design process

Many models have been proposed in the field of creative problem solving and human thought processes (Kawakita, 1967). In these experiments, the authors have divided the design process of realizing a specific idea into three processes: divergence, convergence, and embodiment processes. This model is based on research on developing creative thinking support systems (Kunifuji, 1993). Below is an explanation of each process.

Divergence is the first process in the thinking process. In this process, the designer "starts from making clear what the problem, or the theme is, and collects whatever information is related, with an open mind to get the hold of the problem or the theme" (Kunifuji, 1993). The process of obtaining primary information from the environment and secondary information from primary information (Kiyokawa et al., 2010) can also be interpreted as the divergence process.
The convergence process is to "pursue the true nature of the problem through the information earned at the divergence process" and to "make possible answers or ideas" (Kunifuji, 1993).
The embodiment process is the process of picking "the most effective idea for the problem" (Kunifuji, 1993) and modifying the idea as a final solution.

4.2 Details of experiment

As motivated examinees, as explained in section 1, the examinees here are students who attend classes where they work on a design competition and design exercises that are completely unrelated to this research. Here students are interested in and motivated to create good designs. The evaluation in this study is carried out through the design practice for the design competition and design exercises by the students. Below are the activities the students participated in, along with the number of students.

1. Participation in a design contest of Advanced Institute of Industrial Technology with the theme "nagare" (flow) (6 students).
2. Participation in a collaborative lecture of The University of Tokyo and Tokyo University of the Arts with the theme "toki no katachi" (figure of time) (8 students).

The experiment is separated into three parts. The details of the experiments are given below, in which "flow" is the theme word.

4.2.1 Experiment 1

Each subject of the experiment expanded words from the theme word using the following divergence processes. The time limit for each process is given in parentheses.

1. Subjects wrote down words associated with the theme word all by themselves. (15 min)
2. Subjects were shown a concept relationship list (the same as the left two columns in Table 1) and wrote down associated words based on the list (15 min). This should be a type of "framework paradigm" support, explained in section 1.
3. Using the software, a list of all words associated with the theme word was created by the function discussed in section 3.2.1. The numbers of words associated with the theme words are 218 for "flow", 293 for "time", and 155 for "figure". Subjects were shown this list and wrote down any of the words that made sense to them (15 min). This should be a type of "generative" support explained in section 1.

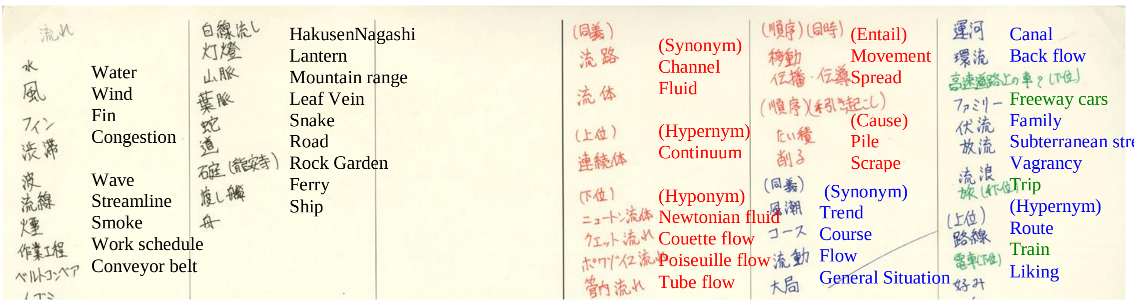

Figure 4. Sample of words for experiment 1

The following bullet points are supplementary explanations.

- Subjects were only allowed to write down words that were directly associated with the theme word. For this reason, the words were written in itemized form.
- A sample of associated words is shown on Figure 4. The words were written on A3 paper. The black words in Figure 4 are from the first process, the red words are from the second process, and the blue and green words are from the third process. The blue words are directly taken from the word lists, and the green words are self-associated words inspired from the word lists.
- The entire process was recorded using a video camera.

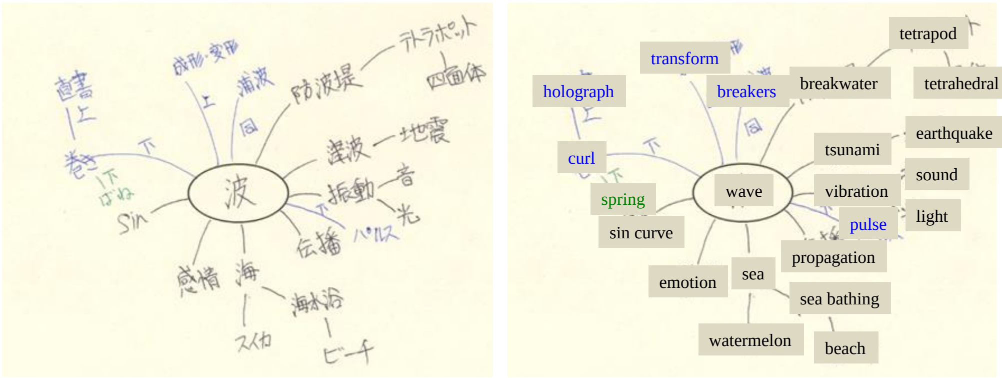

Figure 5. Sample of words for experiment 2 (left: original in Japanese, right: translated in to English)

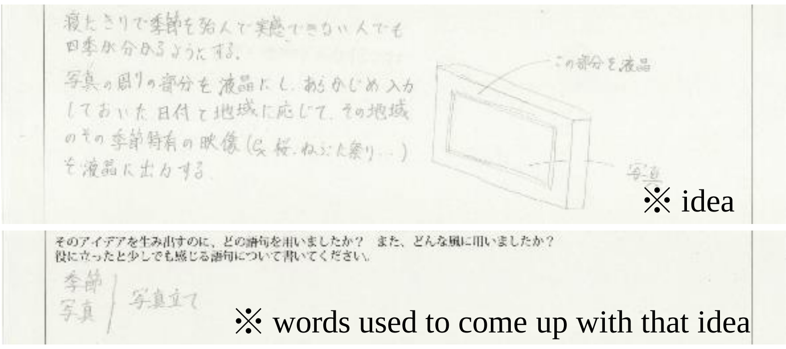

Figure 6. Handout form for experiment 3

4.2.2 Experiment 2

In the second experiment, further expansion of the list of associated words was conducted using the word list made by subjects in the first experiment (Figure 4).

1. Subjects each chose six words which they thought useful for generating ideas in the subsequent design process from the list made in the first experiment.
2. For each word chosen, subjects connected associated words as shown in Figure 5. Subjects were allowed to look at the concept relationship list, since they had already seen it in the first experiment (15 min, 2.5 min for each word).
3. Subjects were instructed how to use the software, including the function of searching for associated words. Using this software, the subjects wrote down more words (15min, 2.5 min for each word).

The following bullet points are supplementary explanations.

- Two words connected by a line indicated that they are directly associated.
- A sample of associated words is shown in Figure 5. The words were written on A3 paper. The black words are from the second process, and the blue and green words are from the third process. The blue words are directly taken from the word lists, and the green words are self-associated words inspired from the word lists.
- The entire process was recorded using a video camera.

4.2.3 Experiment 3

After experiments 1 and 2, the authors asked the students to continue with their divergence and embodiment processes on their own. They were given a form in which to write their ideas. The form included an entry field to write down their ideas and an entry field to write down any of the words used to come up with the ideas as shown in Figure 6.

5 RESULTS OF THE EXPERIMENTS

5.1 Quantity of generated words

Table 2 shows the total numbers of words generated in all processes in the experiments. In each phase of the experiments, there were a reasonable number of generated words, resulting in the expansion of the word network space.

5.2 Classification of self-generated words by concept relationships

First, we attempted to classify the self-generated words written in the first process of experiment 1 by concept relationships. We could not classify all the words but found something in common. The difficulty of classification was for several reasons.

- Some of the words can be associated with the theme word by different concept relationships.
- Some of the words require a conceptual leap between the words and the theme word, making it impossible to directly connect by a concept relationship.
- The human thinking process was too complicated to explain using a concept relationship.

On the other hand, many of the classified words included "hyponym" and "attributed" concepts, which represent more concrete and specific concepts. Examples for each theme word are as follows.

- Flow: Many of the words were related to the subject (attributed, acting as adnominal modifier) of the flow (car, water, time, blood, etc.).
- Time: Many of the words were measures of time (minute, noon, etc.) and related objects (watch, time machine, etc.).
- Figure: Many of the words were types of shapes (round, square, etc.) and miscellaneous objects (clay, furniture, etc.).

Since all the subjects were motivated to build a concrete idea of their own and the theme word was rather simple, it can be assumed that these caused the subjects to come up with such words.

5.3 Classification and variety of other words generated by concept relationships

For the words obtained from the last two processes in experiment 1 (words based on the concept relationships and words selected from or associated with the word list made by the software), we evaluated the variety of concept relationships. It was considered that words associated with a greater variety of concepts could cover a larger word network space.

5.3.1 Gini-Simpson index

To evaluate the variety of concept relationships of expanded words, we used the Gini-Simpson index (Jost, 2006) (1). This index gives the probability that two samples taken at random from data represent a different type.

$$V = 1 - \sum_{i=1}^{R} p_i^2 \quad (1)$$

(p_i: the proportion of words of category i relative to the total word number. R: the number of categories.)

5.3.2 Variety of generated words

Table 3 shows the number of words classified in each concept relationship and the variety of words for each subject in the second and third phases of experiment 1. It was found that, the variety of associated words based on the concept relationships was higher in every subject than the variety of words from the software. It can be assumed that this is due to the deviation of the links in the database. This suggests that the word association process by humans is still effective for widening the word network space because the dictionary does not always contain sufficiently rich vocabulary and association links.

5.4 Ideas generated in experiment

Table 4 shows all the words that appeared in the form mentioned in section 4.2.3, classified by the different processes of where the word came from. We confirmed that not only the self-generated words but also the system-generated words were used to generate ideas.

5.4.1 Example of idea originating from tool-generated word

Figure 7 introduces one of the ideas that came from a software-generated word. In this idea, the student might have only thought about linear flow at first, until he saw "kadou" (vortex), which reminded him of rotating and circulating flow.

Table 2. Numbers of words generated from theme "Flow" (left: exper. 1, right: exper. 2)

Subject	F1	F2	F3	F4	F5	F6
Self-generated	20	32	40	31	39	41
By list	9	17	24	5	16	14
From software	47	22	40	17	29	26
Total	76	71	104	53	84	81

Subject	F1	F2	F3	F4	F5	F6
Self-generated	51	101	85	72	110	68
From software	31	22	44	31	22	33
Total	82	123	129	103	132	101

Table 3. Variety of words generated from "time" (by concept relationships / from software)

Subject	T1	T2	T3	T4	T5	T6	T7	T8
Synonym	1/2	2/3	1/4	1/1	1/3	1/2	1/3	7/1
Hypernym	1/6	1/4	3/2	4/9	4/4	1/4	2/3	1/0
Hyponym	1/16	7/9	0/15	0/14	3/18	1/23	2/14	3/8
Coordinate	1/0	3/0	1/0	1/0	0/0	1/0	2/0	1/0
Holonym	1/0	0/0	1/1	1/0	0/0	0/0	2/0	1/0
Meronym	1/0	0/0	3/0	4/0	0/0	1/0	4/0	3/0
Attribute	2/0	3/0	3/0	2/0	2/0	4/0	5/1	4/0
Attributed	0/0	0/0	3/0	0/0	0/0	0/0	1/0	0/0
Domain	1/0	1/0	1/0	2/0	0/0	0/0	2/0	2/0
Has instance	1/0	0/0	0/0	0/0	2/0	0/0	3/2	0/0
Entail	1/0	0/0	3/0	0/0	0/0	0/0	0/0	0/0
Cause	2/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Nominative	1/0	4/0	0/0	1/0	2/0	4/0	1/1	1/0
See also	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Subject	1/0	1/0	0/0	0/0	2/2	4/0	0/0	0/0
Similar	1/0	2/0	0/0	0/0	0/0	0/0	2/0	0/0
Historical	1/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
Total	17/24	24/16	19/22	16/24	16/27	17/29	27/24	23/9
Variety	0.93/0.49	0.84/0.59	0.86/0.49	0.83/0.52	0.84/0.52	0.82/0.35	0.89/0.62	0.83/0.2

Table 4. Grouping of words used as ideas in different phases of experiment 1

Theme word	Self-generated words	Words generated by concept relationships	Generated words based on list of all associated words from software
Flow	Time, food, period, congestion, working process, electric current, man, transportation, air, cloud, ocean current, shooting star	Heat, river	Plan, vortex
Time	Sense, darkness, sunset, sunrise, nostalgia, discontinuity, photo album	Ambiguity, the earth, creature	Chance, suitable time, discount sale, preceding, limit, clearance time, waste
Figure	Color, space	Appearance	

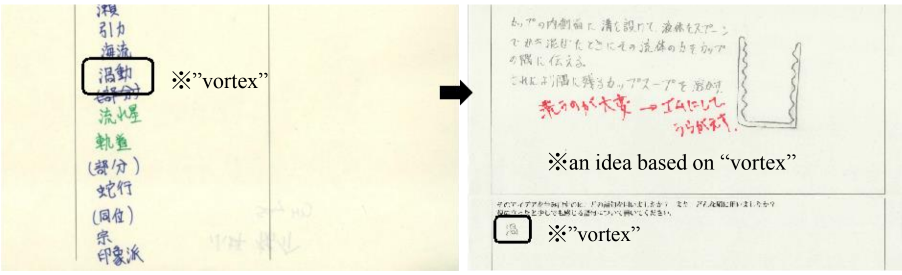

Figure 7. Example of idea derived from tool-generated word

5.4.2 Other thoughts and discussion on ideas

Below are other points that may be effective in supporting idea generation.

- The theme word "time" includes the meaning "chance". Since there were no self-generated words for this meaning, "chance" might be an effective word to help generate words from such minor definitions.
- Words such as "discount sale" and "clearance time" are rather rare and cannot be seen on a daily basis. These minor words and words for which it is difficult to understand the relation with the theme word might be effective in inspiring one's thoughts.

6 CONCLUSIONS

As the first step of a study on design idea generation support (DIGS), the experiments on word association by students working on a design project obtained (1) from memory, (2) by referring to concept-relationship-type information, and (3) using software with a computational concept dictionary are conducted.

Word association by referring to concept-relationship-type information turned out to be effective for increasing the variety of associated links when the computational dictionary does not contain sufficiently rich vocabulary and association links.

Word association using software with the computational concept dictionary turned out to be effective for obtaining associated words that the user cannot recall from memory.

Future directions include evaluating the quality of ideas and proposing a methodology and implementing a software tool for DIGS by combining word association methods (1), (2), and (3) for maximum efficacy, and confirming their validity through design exercises.

ACKNOWLEDGMENTS

This research was carried out by the Design Innovation Laboratory, Department of Mechanical Engineering, The University of Tokyo, and sponsored by Fuji Xerox Co., Ltd., Toppan Printing Co., Ltd., Toyota Motor Corporation, YANMAR Co., Ltd., Sekisui House, Ltd., Uchida Yoko Co., Ltd., and KDDI R&D Labs., Inc.

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