Developing Creativity through Design-by-Analogy with Word Trees

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The Asian Conference on Education 2020
Official Conference Proceedings

Abstract
This study aims to understand the effect of the Design-by-Analogy (DbA) WordTree method, proposed by Linsey (2007), on the individual's development of creativity. The method was introduced to two training workshops using near-sources and to two others using far-sources. The Creativity Assessment Packet (CAP) and the Kaufman Domains of Creativity Scale (K-DOCS) were used in the pre-test and the post-test for the participants, who were 100 students of a university. The progress of each participant's creativity was examined. Results reveal that the participants' domain-general creativity and domain-specific creativity both largely rose after taking the whole training workshops. The ideas generated in the workshops also show that the far source and the near-source are equivalent in enhancing idea generation by analogy. Future studies should conduct controlled experiments to compare the method with others.

Keywords: Creativity, Design Education, Word Trees, Design-by-Analogy

Introduction

Analogical thinking plays a vital role for designers to obtain inspiration in product design and development (Keane, 1987; Dahl & Moreau, 2002). Design-by-Analogy (DbA) is a method that helps designers generate creative solutions by searching for analogs which are similar to the target problem and blending the problem and analog (Linsey, 2007). In the process, we need not only some structures to map the problem and analogies (Larkin, McDermott, Simon & Simon, 1980), but also some principles to select potential sources of analogy.

Many analogical principles for source selection focus on the structural similarity between the target and source. Literature recommends that the best sources of inspiration for creative breakthroughs are those who have higher structural similarity and lower surface similarity to the target problem (e.g., Gentner & Markman, 1997; Ward, 1998; Han, Shi, Park, Chen & Childs, 2018). However, it is still arguable that how similar (or dissimilar) a source should be to the target being mapped (Chan, Dow & Schunn, 2015).

A new approach, namely, DbA-WordTree, has demonstrated the advantages of generating creative solutions in the domain of engineering design (Linsey, Markman & Wood, 2008). However, how effective is the approach to develop individuals' creativity remains a question. The present study is an attempt to find out how effective is the approach to develop general creativity.

Literature Review

1. Design-by-Analogy

Analogy is a promising tool for innovation by mapping from the inspiration source in a domain to the target problem in the other domain to make sense of the solution (Gentner, 1983). The former is typically called the source of the analogy, and the latter the target. For example, children can learn the concept of the atom by using the solar system as the source, because the structure and behavior of an atom are similar to that of the solar system.

In the cognitive process model for analogical reasoning, the process of human reasoning by analogy can be divided into four steps. Before a target problem is given, the person has encoded some source analogy and store it in memory. Once the problem is given, the person retrieves an appropriate analogy from memory. The next step is to find a mapping between the problem and the source. Finally, the person generates solutions by finding the inference based on the mapping.

Professional designers often use analogies at the ideation stages of design processes (Casakin and Goldschmidt, 1999; Christensen & Schunn, 2007). The use of analogy to assist designers in identifying and developing analogies, including examples, related cases, scenarios, and connected experiences, to solve design problems is called DbA (Linsey, 2007; Goldschmidt, 2001). How to identify and develop the best sources of inspiration for creative breakthroughs is a great challenge. Empirical studies reveal the principles of a better source are still controversial (Fu, Chan, Cagan, Kotovsky, Schunn & Wood, 2013).

Some studies assert the better sources for creative breakthroughs should be structurally (in terms of such relationship of object features as mechanically, spatially, and causally) similar but superficially (in terms of such object features as shape, material, and temperature) dissimilar to the target (Gentner & Markman, 1997; Ward, 1998; Holyoak & Thagard, 1996; Ward, 1998). More specifically, other research claims the better sources for novelty, quality, and flexibility of ideation should be conceptually far from the target sources (Dahl, D. and Moreau, P. 2002; Chan, Fu, Schunn, Cagan, Wood & Kotovsky, 2011; Chiu & Shu, 2012). In contrast, some studies find there are no obvious benefits from conceptually far source for creative thinking (Fu, Chan, Cagan, Kotovsky, Schunn & Wood, 2013; Chan & Schunn, 2014; Dunbar, 1997) or the effects of far and near sources have equal advantages (Malaga, 2000).

2. Word trees

A word tree illustrates multiple parallel sequences of words to analyze unstructured texts. Based on the visualization of abstract tree structures, it is used to show which words most often follow or precede a target word or to show a hierarchy of terms. There are many tools developed in an interactive form of the keyword-in-context (KWIC) technique (Wattenberg & Viégas, 2008). The word tree tools developed by Fernanda Viégas and Martin Wattenberg (see http://hint.fm/projects/wordtree/) and Jason Davies (see https://www.jasondavies.com/wordtree/) are typical examples. The advantage of these interactive tools is threefold: (1) easy to spot repetition in the contextual words that follow a phrase, (2) clear to display the natural tree structure of the context, and (3) easy to explore the context further.

A novel approach, DbA-WordTree method, has been developed by Julie Linsey (2007) to systematically identify far sources and find a mapping between the source and the target. Since enhancing analogical retrieval requires that design problems are represented in multiple forms ranging from very domain-specific to domain-independent to provide a variety of related effective retrieval cues (Chan, Dow & Schunn, 2015). A tree structure or tree diagram is a way of representing the hierarchical nature of a structure in a graphical form. It is named a "tree structure" because the classic representation resembles a tree, even though the chart is generally upside down compared to an actual tree, with the "root" at the top and the "leaves" at the bottom. All the tree elements are called "nodes," and the lines connecting elements are called "branches". Nodes without children are the leaves. Every finite tree structure has a member that has no superior; this member is the root.

The WordTree method is a promising tool because it can create multiple linguistic representations by focusing on alternative functional representations. An experiment in workshops using the DbA-WordTree method shows that designers can identify a greater number of analogies and alters their search approaches leading to more unusual analogous solutions being located (Wattenberg & Viégas, 2008).

The process of the workshop comprises five steps:
(1) List key problem descriptors, which are single-word action verbs derived from the functions and customer needs in the problem statement.
(2) Re-represent the key problem descriptors using the WordTrees method through both the team's knowledge and a large lexical database of English, WordNet

(see https://wordnet.princeton.edu/). The team uses rotational brainwriting to create sticky note WordTrees, and using WordNet to retrieve additional keywords. Combining both the results to identify and search potential analogies and analogous domains, and create multiple problem statements.

(3) Generate ideas using WordTrees and rotational brianwritng.

(4) Summarize results and continue with the design process.

Although the WordTree method is a powerful approach for the re-representation of design problems and the generation of creative ideas in the engineering domain, how it works in the context of domain-general is worth studying.

3. Creativity assessments

Human creativity can be developed by training (Davies, 2011). If a group of participants is trained by the DbA-WordTree workshop, how their creativity changes should be measured. There are many tools for measuring cognitive aspects of creativity with certain reliability and validity. The cognitive aspects refer to basic thinking processes that lead to creative production, which include identifying, defining, and redefining the problem, selective encoding (Barbot, Besançon & Lubart, 2011).

In cognitive creativity measurements, the Creativity Assessment Packet (CAP) can measure the cognitive thought factors of fluency, flexibility, elaboration, originality, vocabulary, and comprehension (Williams, 1967; Williams, 1980). It is useful for the workshop which involves identifying and searching for action verbs.

Aside from the rather domain-independent approach to measuring cognitive creativity, there are some domain-specific assessment tools. The Kaufman Domains of Creativity Scale (K-DOCS) is a relatively new measure for assessing domain-specific creativity in five domains: everyday, scholarly, performance, science, and art (McKay, Karwowski & Kaufman, 2016; Kaufman, 2012). These five domains are consistent with the Big Five personality factors, extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience. That means K-DOCS is not only a measurement tool for cognitive aspects but also conative aspects.

K-DOCS is a 50-item self-report measure assessing the five domains. The instructions ask the participants to compare to people of approximately their age and life experience, how creative would they rate themselves for each of the items. Items were rated on a 5-point scale (much less creative too much more creative). K-DOCS is suitable for specifying which domain the participant's creativity progresses.

Besides, product-based assessment is required for assessing the achievement of a creative product resulting from workshops. Typically, these products are evaluated by experts of the domain using the Consensual Assessment Technique (CAT) (Amabile, 1982). The requirements of CAT include (1) judges should all have had some equivalent experience with the domain in question, (2) the judges must make their assessments independently, (3) the judges should rate the products relative to one another, rather than rating them against some absolute standards they might hold, (4) each judge should view the products in a different random order (Hennessey, Amabile & Mueller, 2011).

Given the literature review, the present study focuses on the relationship between the DbA-WordTree method and the individual's development of creativity. Hypotheses for the training include (1) the participant's domain-general creativity makes much progress after training, (2) the participant's domain-specific creativity makes much progress after training, and (3) the far-source is more likely than the near-source to enhance the participant's ideas generated by analogy.

Methods

1. Participants

Participants of the workshops were 122 second-year students from colleges of mechanical and electrical engineering (51), electrical engineering and computer science (9), engineering (23), management (24), design (12), and humanities and social science (3). They were randomly divided into 30 groups. Each group consists of four to 6 participants, who come from at least two different colleges.

2. Instruments

The participants' cognitive creativity was assessed using K-DOCS and CAP. The revised Chinese edition CAP (Wang & Lin, 1986), published by Psychological Publishing Co., Ltd, Taiwan, was used. The K-DOCS was translated into Chinese edition. The participants' product-based creativity was assessed by three experts who have three-month training of the DbA-WordTree method in a CAT way. The items of the assessments were to determine the following indexes:

(1) Ratio of valid nodes (Rn) = (the number of the nodes that indicate the clue for exploring or mapping the sources to the target) / (the number of all the nodes of the word tree)

(2) Ratio of valid analogies (Ra) = (the number of the analogies that are related to the valid nodes of the word tree) / (the number of all the analogies generated in a workshop)

(3) Ratio of valid ideas (Ri) = (the number of the ideas that mix the analogous source to solve the target problem) / (the number of all the ideas generated in a workshop)

Also, each workshop used specific worksheets to help participants focus on the design task given along with the DbA-WordTree method. Each worksheet contained the instruction, the sub-tasks in sequence, and background layout.

3. Procedures

Before attending the workshops, all the participants took the K-DOCS and CAP as the pre-test. When completing all workshops, they took the K-DOCS and CAP again as the post-test. Two workshops used the far-sources and the other two used the near-sources. All of the tasks were selected from (Van Gundy, 2005), which collected many analogical thinking activities. Either the far-sources (i.e., the unrelated stimuli of inspiration) or the near-sources (i.e., the related stimuli of inspiration) were available in various activities. Table 1 shows the tasks of the four workshops. The activities '#70 What's the Problem?' and '#82 Brain Purge' were used for workshops

with near sources, whereas the activities '#21 Tickler Things' and '#97 The Name Game' were used for workshops with far sources.

Table 1: Tasks of workshops

Near sources		Far sources	
Workshop 1	Workshop 2	Workshop 3	Workshop 4
#70. What's the Problem? Design a new tape dispenser.	#82. Brain Purge Design a new peeler.	#21. Tickler Things Design a method to recruit more club members.	#97. The Name Game Design a new mosquito trap.

The activity of each workshop contained two stages. In the word tree stage, each group was requested to complete a word tree using brainwriting for the initial problem given. Afterward, in the design stage, each group used their word tree as the structural guidelines to create ideas to solve the problem given.

In each activity, an initial problem was given. The original process of each activity, adopted from the book of Van Gundy (2005), was adapted to follow the five steps of the DbA-WordTree method, as described earlier. For each group, the sequence of each workshop activity was randomized to avoid the bias of the learning effect. Once all the workshop outcomes had been collected, the three judges examined the word trees created by each group in every workshop.

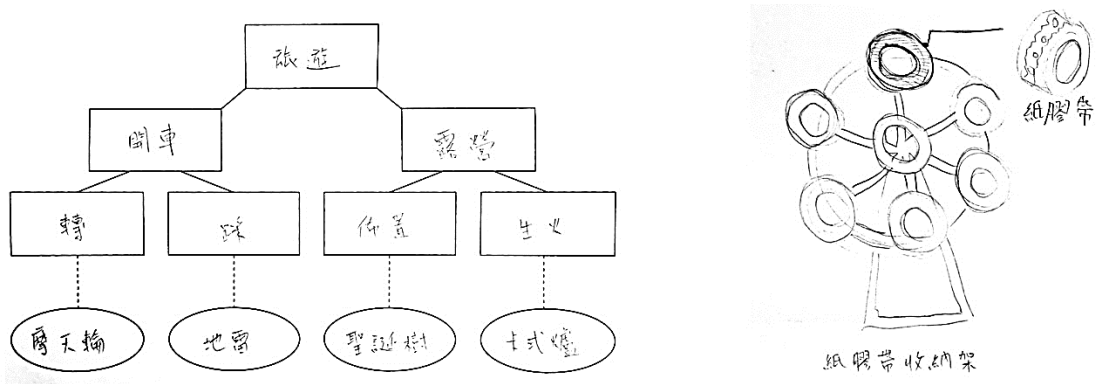
For instance, the activity for the first workshop is '#70. What's the Problem?', adapted from the Synectics of William Gordon (1961). The objective was to help the participants reverse their natural tendency to exhaust all conventional solutions and then declare they have run out of ideas. The target problem for each group was to design a new tap dispenser by following the steps:

(1) Describe a general, abstract problem (how to remove unpleasantness and avoid worry) without revealing the target problem (how to design a new tape dispenser).
(2) Use word trees to generate ideas for the abstract problem.
(3) Reveal the real problem and instruct the group members to examine the ideas for the two abstract problems and use them as stimuli for new ideas.
(4) Write down any ideas on posters for evaluation.

Results

Only 100 participants of 26 groups completed the whole process, from the pre-tests, the four workshops, to the post-tests. Figure 1 illustrates an example completed by a group in the first workshop. The word tree, as shown in Figure 1(a), is developed for the abstract problem about removing unpleasantness. The root is "to travel," which has two children nodes, "to drive" and "go camping". These two nodes respectively have two leaves. For example, the leaves of the node, "to drive", is "to turn" and "apply brake". When the key verbs for the abstract problem have been obtained, each of them is related to an object that most represents the key verb. For example, "Ferris wheel" is chosen as the representative of the verb, "to turn". Afterward, each object is seen as the inspiration source to develop ideas for solving the real problem,

"designing a new tape dispenser". The sketch, as shown in Figure 1(b) depicts a tap dispenser using the Ferris wheel as a source of DbA.



(a) (b)

Figure 1: Example worksheets completed by a group in workshop 1

1. Progress of creativity

The pro-test with the pre-test was compared to determine the effect of the training through four workshops on the participants' creativity. First, the participants' pro-test of CAP made extremely significant progress (24.3%, p<.01), as shown in Table 2. The greatest progress made was the elaboration factor (113.4%) while the other factors, originality (30.3%), fluency (15.8%), and flexibility (13.2%) also had relatively large progress.

Second, the comparison of the pro-test and the pre-test was displayed in Table 3. Except for the creativity in the everyday domain, all the others had extremely significant growth (p<.01). Both domains of the performance (13.9%) and science (12.9%) have much progress, though the progress of Scholarly was much lesser (3.2%). Still, the domain of art increases (9.6%, p<.05).

Table 2: Pre-test and pro-test of CAP

Factor	Assessment	N	M	SD	Progress	*t*-value
Fluency	Pre-test	100	10.10	3.17	15.8%	-4.564**
	Pro-test	100	11.70	1.69		
Comprehension	Pre-test	100	24.88	8.52	1.6%	-.373
	Pro-test	100	25.27	6.06		
Flexibility	Pre-test	100	6.65	2.18	13.2%	-3.036**
	Pro-test	100	7.53	1.91		
Originality	Pre-test	100	17.03	7.21	30.3%	-5.461**
	Pro-test	100	22.19	6.11		
Elaboration	Pre-test	100	9.30	7.39	113.4%	-9.930**
	Pro-test	100	19.85	7.63		
Vocabulary	Pre-test	100	13.87	6.43	9.1%	-1.569
	Pro-test	100	15.13	4.80		
Total	Pre-test	100	81.83	27.35	24.3%	-5.730**
	Pro-test	100	101.71	21.35		

*p<.05, **p<.01

Table 3: Pre-test and pro-test of K-DOCS

Domain	Assessment	N	M	SD	Progress	*t*-value
Everyday	Pre-test	100	3.24	.66	9.3%	-1.401
	Pro-test	100	3.54	.66		
Scholarly	Pre-test	100	3.78	.62	3.2%	-3.229**
	Pro-test	100	3.90	.60		
Performance	Pre-test	100	2.67	.88	13.9%	-2.788**
	Pro-test	100	3.04	.99		
Science	Pre-test	100	2.95	.88	12.9%	-3.176**
	Pro-test	100	3.33	.84		
Art	Pre-test	100	3.24	.90	9.6%	-2.416*
	Pro-test	100	3.55	.89		

*p<.05, **p<.01

2. Creativity of ideas

Independently examining each group's DbA-WordTree per workshop, the three judged identify the number of nodes, analogies, and ideas that were related to the target problem to calculate the ratio of valid nodes (R_n), the ratio of valid analogies (R_a), and the ratio of valid ideas (R_i). Table 4 exhibits the difference between these ratios of the near-source workshops and far-source workshops. Results show that the far-source workshops had a significantly higher R_a than did the near-source, though the difference was trivial (3.2%, $p<.05$). The other two ratios, R_n and R_i between the near-source and far-source workshops were not significantly different.

Table 4: Pre-test and pro-test of K-DOCS

Item	Source	N	M	SD	Change Rate	*t*-value
R_n	Near	26	3.24	.66	9.3%	0.70
	Far	26	3.54	.66		
R_a	Near	26	3.78	.62	3.2%	0.03*
	Far	26	3.90	.60		
R_i	Near	26	2.67	.88	13.9%	0.09
	Far	26	3.04	.99		

*p<.05, **p<.01

Conclusion

The first two hypotheses are supported, but the third one is not supported. As the results of the CAP showed that the participants' domain-general creativity largely rose, the first hypothesis is not rejected. Also, since the participants' domain-specific creativity mostly rose to a certain degree, the second hypothesis is not rejected. It is noticed that the present study adapted the DbA-WordTree method of (Linsey, 2007). It did not involve using WordNet database, and its activities were designed for laymen instead of specific professionals. Still, the groups were of cross-domains instead of the engineering domain. Despite the adaptation, the results supported the findings of many researchers, such as (Linsey, 2007; Linsey, Markman & Wood, 2008; Linsey,

Markman & Wood, 2012), and recommend that the method can enhance the participants' creativity.

After the training by the four workshops, the participants' creativity assessments mostly rose. Either the far-source or the near-source contributed to developing the participants' cognitive and conative creativity to a certain extent. This raises a question on the usefulness of even random sources as stimuli for DbA. Future research needs some controlled experiments to compare the effect of the DbA-WordTree method and other methods.

The third hypothesis is rejected. Although the far source was more likely than the near-source to generate valid analogy, yet the far-source does not have an advantage over the near-source in developing valid word trees or valid ideas. The results were consistent with the findings of Malaga (2000), where the effects of the far-source and the near-sources have equal advantages.

In the studies of Linsey and her peers (Linsey, 2007; Linsey, Markman & Wood, 2012), all the participants were engineering students. In contrast, the majority of participants in the present study came from engineering-related colleges (83, 68%), and the rest were from non-engineering colleges (39, 32%). The effect of the cross-disciplinary grouping on the individual development of creativity and the collaborative idea development is worthy of future study.

To sum up, the major advantage of the DbA-WordTree method may lie in the fact that it requires the participants to use action verbs for identifying and mapping more potential concepts towards the target design problem. This leads them to better control divergent thinking to move forwards the target.

Acknowledgments

The author thanks the support of MOST [grant numbers 108-2221-E-027-019], Taiwan, R.O.C.

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