THE ANALOGY RETRIEVER – AN IDEA GENERATION TOOL

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Abstract

Idea generation plays a vital role in design, but coming up with ideas, especially creative ideas, is often challenging. Analogy is considered as a fundamental component of creativity and a beneficial method for idea generation. This paper presents a computer-based tool, named the Analogy Retriever, for assisting designers in idea generation and prospectively in idea elaboration. The tool is based on an algorithm simulating aspects of the human cognitive process of analogy. It is focused on solving proportional analogy problems (A:B::C:X) by retrieving the unknown term X from a knowledge database. The Analogy Retriever has been indicated to be useful and effective for helping the designers concerned generate creative ideas through conducting a case study. The results indicate that the Analogy Retriever, in its current formulation, can significantly improve the quantity, quality, novelty, and variety of the ideas produced. The tool is suggested to be greatly beneficial to design space exploration and expansion.

Keywords: Creativity, Computational design methods, Conceptual design, Design tools, Analogy

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1 INTRODUCTION

Design is a natural attribute of the human brain, which tends to benefit from the generation of alternative ideas. Idea generation, also known as ideation, is the process of generating ideas in design activities. It is where a design concept begins, which essentially determines the type of design generated and the value of business achieved. Ideation is regarded as having a significant role in novel concept development and an essential factor to success in business (Howard et al., 2011).

Creativity is defined as 'the ability to imagine or invent something new of value' (Childs et al., 2006), which is considered as a primary element of business commercial performance (Childs and Fountain, 2011). It is creativity that drives business in the future (Stewart and Simmons, 2010). Design has been described by the UK Design Council (2011) as a specific end to the deployment of creativity. This indicates that creative ideas are necessarily needed for the development of innovative designs, and thereby promoting commerce. However, it is difficult to generate ideas, especially creative ones, due to, for example, lack of resource, time pressure, limited information, and numerous competing existing ideas. Childs (2014) identified that essential elements of producing creative ideas are an enormous amount of information, the willingness to produce ideas, and the capability to discard irrelevant information. There has been an increasing interest in recent years in developing methods or tools to assist the generation of creative ideas. Hundreds of creativity tools have been developed to assist designers in ideation, for instance, TRIZ and Mind Mapping. However, some of the tools rely heavily on users' knowledge and experience, some are rather complex and difficult to master, and others are inconsistent with the normal human thought process. Yan and Childs (2015) indicate that different tools are suitable for different personality attributes and different applications. Recently, several computational tools have been developed to help designers in idea generation, such as the Combinator (Han et al., 2016).

Analogy is widely considered as a fundamental component of creativity in both science and art (Goel, 1997; Boden, 2004; Ward, 2011; Ozkan and Dogan, 2013). It is a core process of human cognition, which is frequently used to generate inferences and produce new ideas (Gentner and Smith, 2013). In design, analogy has been regarded as a beneficial method for idea generation, as it can improve design space exploration and expansion by transferring knowledge from a source domain involving the analogous phenomena to a target domain containing the problem (Wilson et al., 2010). It has been used widely for design, for instance, the cyclone technology used by Dyson vacuum cleaners was an analogy reasoning of an industrial cyclone for removing particulates in factories and agricultural processes.

This study aims at developing a computer-based tool, named the Analogy Retriever, to assist designers in idea generation. It is proposed that the tool could also help designers with idea elaboration. The tool is based on an algorithm simulating aspects of the cognitive process of analogy, which is focused on exploring the unknown term X in proportional analogy (A:B::C:X). Sixteen commonly used analogy relations, which are categorised by the authors based on reviewing a number of analogy teaching materials, are implemented to facilitate the Analogy Retriever. A case study has been conducted to evaluate the usefulness and effectiveness of the tool. The Analogy Retriever is intended to benefit both novice designers and experienced designers in generating creative ideas effectively, which tackles the challenges of the rapid changing business environment.

2 ANALOGY

Analogy or analogy reasoning is described as: the ability to perceive and use relational similarity across different contexts, which is a crucial aspect of human cognition (Gentner and Smith, 2013); the application or projection of structured knowledge from a familiar domain to a less familiar one (Ward and Kolomyts, 2010); the process of decomposing an idea into its constituent aspects and then retrieving the idea in the target domain sharing a noted subset of those aspects (Liu and Singh, 2004); a form of combinational creativity that explores shared conceptual structure (Boden, 2009). Analogy is considered to be a fundamental cognitive process underlying most other cognitive processes (Ozkan and Dogan, 2013), such as creativity (Boden, 2009; Goel, 1997; Ward and Kolomyts, 2010), learning (Richland and Slimms, 2015), prediction and inference (Bar, 2007; Ward, 2011), problem solving (Ozkan and Dogan, 2013), and scientific discovery (Gentner and Smith, 2013). It is suggested that analogy is a significant cognitive mechanism that most distinguishes humans from other species (Gentner and Smith, 2012). Analogy plays an important role in education, for example it is involved in the GRE test. Studying and generating analogies can help students improve their reasoning abilities and critical thinking skills, as well as develop their comprehensions of vocabulary and concepts (Nessel and Graham, 2007). Therefore, analogy is significant to design in terms of delivering a creative idea as well as understanding a concept.

Analogy reasoning uses previous knowledge and experience to facilitate the generation of inferences and learn about new domains (Daugherty and Mentzer, 2008). More precisely, analogy involves the use of knowledge from one well-known domain (the source or base domain) and applying it to another less-known domain (the target domain) (Blanchette and Dunbar, 2000; Ward, 2011). In other words, the use of analogy transfers knowledge from a familiar situation to a less familiar situation that needs explanation (Casakin and Goldschmidt, 1999).

Analogy can be regarded as using what is known of one subject to comprehend or draw inferences about an unfamiliar one, that is, understanding Y by noting that Y is some way similar to Z (Ward, 2011; Gentner and Smith, 2012). The conventional form of analogy is often described in a likeness relation of A:B::C:D which means that C is related to D in the target domain similar to how A is related to B in the source domain (Casakin and Goldschmidt, 1999; Ward, 2011). For example, 'Earthquake : Tsunami :: Rain : Flood' indicates that 'Rain' is related to 'Flood' similar to how 'Earthquake' is related to 'Tsunami', because 'Earthquake' causes 'Tsunami' while 'Rain' causes 'Flood'. The conventional form of analogy is also called proportional analogy (Gust et al., 2008). It usually takes the form A:B::C:X when solving problems, in which terms A, B, and C are generally known and the unknown term X needs to be established. For instance, 'Bird : Wing :: Dog : X' can be interpreted as 'Dog' is related to the unknown term X as how 'Bird' is related to 'Wing'. The unknown term X can be inferred according to the provided information.

In analogy, especially proportional analogy, it is the specific relation that plays the vital role (Ward, 2011). An A:B in the source domain is used to determine the analogy relation for instructing the retrieval of an unknown analogue X based on a given term C in the target domain, as shown in Figure 1. Thereby, in problem solving, X can be achieved while the term C and the analogy relationship are known. In the previous example, 'Bird : Wing' in the source domain indicates the analogy relationship between term A and term B is whole-to-part, for 'Wing' is a part of 'Bird'. Therefore, based on the whole-to-part relation and the known term 'Dog' in the target domain, the solution of term X can be 'Paw'. That is 'Wing' is a part of 'Bird' similar to 'Paw' is a part of 'Dog'.

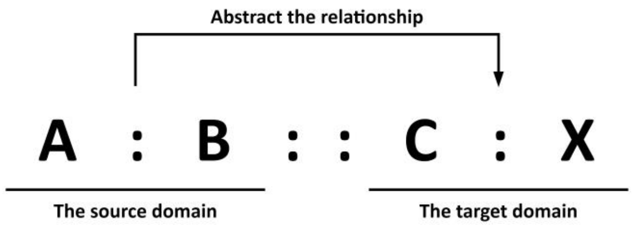

Figure 1. Proportional analogy in problem-solving

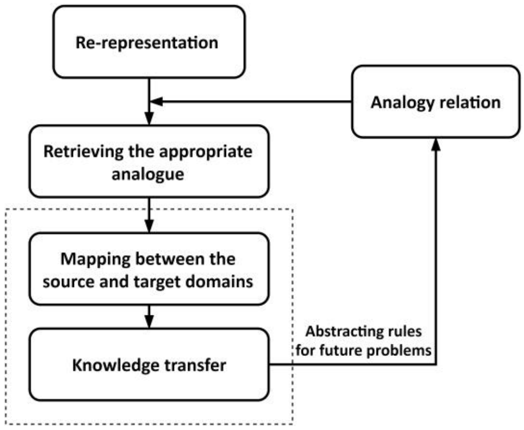

Figure 2. Cognitive process of analogy

As illustrated above, analogy relations are the vital elements of producing inferences while using proportional analogy for idea generation. The analogy relations are generally abstracted from the source domain and then applied in the target domain. In human cognition, these relations are stored as rules or principles that can be applied to future problems without the requirement of source analogues (Gentner and Forbus, 2011; Lopez et al., 2011; Linsey et al., 2012).

The main purpose of identifying an analogy relationship is to transfer the knowledge from a familiar domain to generate inference about an unknown domain, in order to understand the less familiar domain. In design, identifying an analogy relationship from previous knowledge can generate inferences about the design context. This is beneficial for creative idea space exploration and design space expansion, which can improve context comprehension and idea elaboration.

2.1 Cognitive process of analogy

Psychologists and researchers studying analogy have conducted a series of research projects to investigate the cognitive process of analogy reasoning. According to the analogy processes proposed by Kokinov and French (2003), Gust et al. (2008), Gentner and Forbus (2011), Lopez et al. (2011), Linsey et al. (2012), Gentner and Smith (2012, 2013), analogy generally involves three core processes: retrieval, mapping and knowledge transfer, and abstraction. In addition to the three processes, concept re-representation is also a significant cognitive process in analogical reasoning, as well as in learning and scientific discovery (Yan et al., 2003). In analogy problem-solving, it increases the number of cues for analogue retrieval, and thereby expand design space exploration (Moreno et al., 2016). Thus, re-representing the concept or the problem before retrieving appropriate analogues is indispensable for improving creativity. The cognitive process of analogy proposed in this study is listed below, and illustrated schematically in Figure 2.

1. Re-representation: Re-representing or re-constructing a known term with a similar concept.
2. Retrieval: Searching for potential analogues from long-term memory according to the known situation, which involves the known term and re-representations as well as an analogy relation, in short-term memory.
3. Mapping and knowledge transfer: Aligning the representations of the source domain and the target domain, and transferring knowledge from the source to the target domain.
4. Abstraction: Generating schemas or rules (analogy relations) based on the results to apply in future situations, without requiring source analogues. As illustrated in the previous section, analogy relations are abstracted from A:Bs in the source domain.

2.2 Analogy relations

Analogy Relation	ConceptNet Relation	Description	Example
Synonym	Synonym	B is a synonym of A	Cheerful : Happy Great : Wonderful
Anatomy	Anatomy	B is an anatomy of A	Black : White Hot : Cold
Association	RelatedTo	A is related to B	Cow : Milk Bed : Sleep
Part-to-Whole	PartOf	A is a part of B	Trunk : Tree Pocket : Jacket
Whole-to-Part	HasA	B is a part of A	Bird : Wing Dog : Paw
Category (Instance)	IsA MemberOf HasContext	A is a type/member or an instance of B	Persian : Cat Car : Vehicle
Function (Purpose)	UsedFor	A is used for B	Ruler : Measure Pen : Write
Object and Action	CapableOf	A can typically do B	Knife : Cut Chef : Cook
Location	AtLocation	A is located at B	Student : Classroom Car : Garage
Cause and Effect	Causes	A is a cause of B	Earthquake : Tsunami Germ : Disease
Event and Subevent	HasSubevent HasFirstSubevent HasLastSubevent	B is a subevent of A	Swim : Dive Sleep : Wake Up
Characteristic	HasProperty	B is a property of A	Cookie : Sweet Ice : Solid
Object and Creator	CreatedBy MadeOf	A is created by B	Book : Writer Cheese : Milk
Similarity	SimilarTo	A is similar to B	Hot : Fiery Pure : White
Dependence	HasPrerequisite	A is depended on B	Cook : Ingredient Walk : Leg
Symbol	SymbolOf	A is a symbol of B	Dove : Peace Heart : Love

Figure 3. Analogy relation, ConceptNet relation, description, and example

A number of cognitive scientists and psychologists (for example, Gust et al. (2008), Gentner and Smith (2012, 2013)) have shown that analogy, especially the retrieval process, is closely related to human memory. Associative memory is the ability that allows human to learn and remember the relations between unrelated items through experience (Suzuki, 2005). For example, a person's face and other characteristics are recalled while the person's name is mentioned. As a result of this associative ability, a huge associative network involving items and their relations is stored in human memory. In this study, these stored items and their relationships are regarded as A:Bs in the source domain.

In this study, we have summarised sixteen analogy relations which are generally used by people, through investigating a number of analogy teaching materials, such as (Nessel and Graham, 2007) and (Dulan, 2005). The sixteen common analogy relations (such as 'Synonym', 'Part-to-Whole', 'Cause and Effect') are listed in Figure 3 with descriptions and examples. For instance, the relation 'Whole-to-Part' is described as 'B is a part of A', and an example of which is 'Bird : Wing'. These analogy relationships are often used by human to retrieve corresponding analogues according to a target, and thereby generating inferences to comprehend the target domain.

A semantic net is a graph-structured artificial associative network representing knowledge in relation patterns (Sowa, 1992), which is a depiction of human associative memory as well as an associative model of cognition. ConceptNet is a knowledge base providing a large semantic net that represents general human knowledge and the common sense relationships between them (Liu and Singh, 2004; Speer and Havasi, 2012). Through analysing descriptions and examples, the generally used relations in ConceptNet, such as 'RelatedTo', 'PartOf', and 'UsedFor', are paired with the sixteen common analogy relations, as shown in Figure 3. Therefore, the ConceptNet database can be used as a lexical database for analogy retrieval, although it is limited in data size, coverage, and diversity compared with humans.

3 THE ANALOGY RETRIEVER

The Analogy Retriever is a piece of software developed to help users in idea generation. The tool is based on the human cognitive process of analogy reasoning which is considered as a fundamental element of creativity. The Analogy Retriever is focused on solving proportional analogy problems in the form of A:B::C:X. More specifically, the tool is designed to retrieve the unknown X or Xs from an existing knowledge base according to a known term C and an analogy relation abstracted from A:Bs. It can retrieve analogues in both text and visual forms according to the user's input, and thereby provoking the user in idea generation. The following sections demonstrate the novel algorithm, which is regarded as a human cognition simulation approach, used for developing the Analogy Retriever. This type of cognition simulation approach has been used in developing design support tools, such as the Combinator (Han et al., 2016), and has achieved a positive result.

3.1 The essential algorithm of the Analogy Retriever

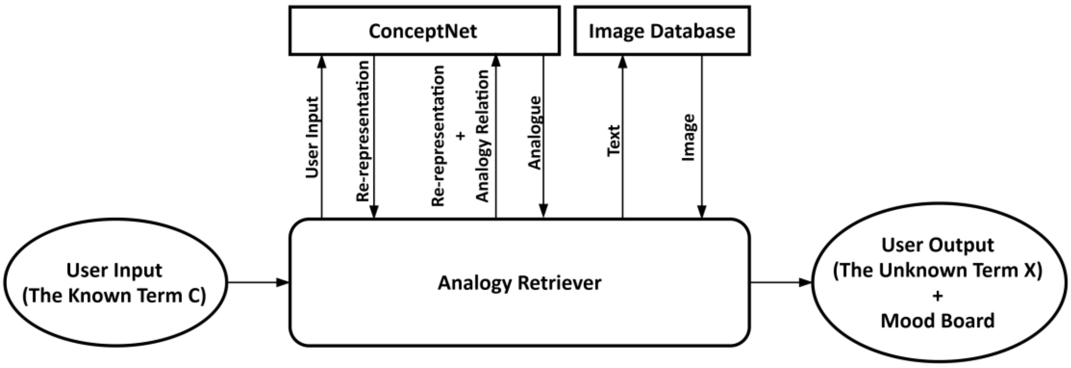

Figure 4. The essential algorithm of the Analogy Retriever © Ji Han

The essential algorithm of the Analogy Retriever, as illustrated in Figure 4, is a simulation of aspects of the cognitive process of analogy reasoning. The tool is aimed at solving the unknown term X in proportional analogy problems (A:B::C:X). The algorithm starts with delivering a user input, which is regarded as the known term C in the target domain, into the Analogy Retriever. The user input can be a design keyword, a desire, or an item that needs explanation. Re-representing a concept increases retrieval cues for analogues, and thereby expanding the design space exploration (Moreno et al., 2016). Secondly, linguistic re-representations (the most similar concepts of the input concept, which are considered as additional known term Cs) are retrieved from the ConceptNet database by the Analogy Retriever. Then, an analogy relation is selected according to the abstraction of the relation between term A and term B (A:B). Corresponding text-based analogues (the unknown term Xs in the target domain) are retrieved by the Analogy Retriever according to the re-representations and the analogy relation, and then shown to the user. The retrieval process involved in the algorithm is similar to how a human is understood to retrieve information from long-term memory. As illustrated above, the human cognition simulation algorithm of the Analogy Retriever conforms to the natural feature of the human brain in retrieving analogues for producing creative ideas.

Producing only text-based results might have limitations, as sometimes it is difficult for users to retrieve corresponding images from their long-term memory. The human brain is activated mainly by visual perceptions (Luis-Ferreira and Jardim-Goncalves, 2013). The use of corresponding images to the generated text-based results was explored in order to provoke users. A live feed image web crawler was developed by the authors and implemented into the Analogy Retriever module. Corresponding images can be crawled in real-time according to the retrieved re-representations and analogues. The crawled images are presented in a mood board style, as shown in Figure 6. Mood boards are collections of images used in the early stages of design process, which can improve creativity and aid communication (McDonagh and Storer, 2004; Setchi and Bouchard, 2010).

3.2 Example of using the Analogy Retriever

The Analogy Retriever provides a simple user-friendly interface, as shown in Figure 5. The tool provides a user input box at the top allowing users to input their design keyword (the known term C). The analogy relationship (abstracted from A:Bs) option menu, which is located below the input box, provides seventeen relationship selections, such as 'Random' (randomly select an analogy relation), 'Association', 'Whole/Part', 'Function (Purpose)', and 'Location'. There are seven output windows, three for the input keyword and its re-representations, one for analogy relation, and three for analogues (the unknown term X). Two function buttons, 'Generate' and 'Show Image', are located at the bottom of the interface. The re-representations, analogy relation, and analogues are retrieved and presented, while the 'Generate' button is clicked. More analogues can be retrieved by clicking the 'Generate' button again, but the degree of relation between the analogues and the re-representations will decrease. Images of re-representations and analogues are shown to the users in a mood board style after the 'Show Image' button is clicked. The following example provides a demonstration of how the tool can be used for solving a design task.

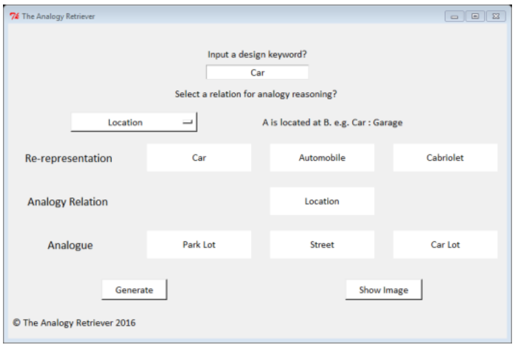

Figure 5. The Analogy Retriever interface

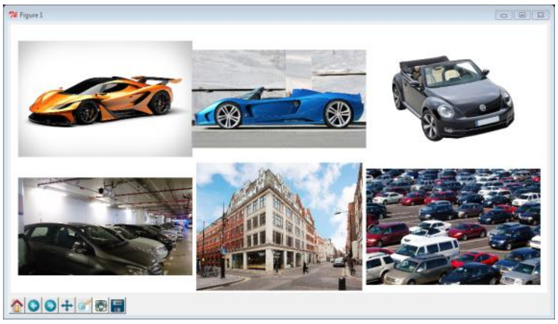

Figure 6. A mood board example

The design task asks designers to come up with new ideas for a car design. Using the Analogy Retriever, the design keyword 'Car', which is the known term C, is considered and entered. The analogy relation 'Location', which is abstracted from A:Bs, is selected for exploring where cars are commonly located. After clicking the 'Generate' button, two re-representations (regarded as extra known term Cs), 'Automobile' and 'Cabriolet', are retrieved. Three analogues, 'Park Lot', 'Street', and 'Car Lot', which are considered as the unknown term Xs, are retrieved according to the user input and the two re-representations as well as the selected analogy relation. The retrieved elements are presented in the output windows, as shown in Figure 5. A mood board containing images of the user input, re-representations, and analogues, as shown in Figure 6, is presented to the user while the 'Show Image' button is clicked. Therefore, the user can have a better comprehension of where a car is located, which can benefit design space explorations and expansions as well as provoke creative ideas. Similarly, the user can explore what parts cars possess, what functions cars have, and so forth. This simple example, albeit contrived, has illustrated how the Analogy Retriever functions in principle and demonstrated its potential capability for assisting designers in generating ideas.

4 EVALUATION OF THE ANALOGY RETRIEVER

4.1 Evaluation methods and processes

Outcome-based evaluation is commonly used for evaluating an idea generation method, while process-based evaluation is barely used as it is time-consuming and difficult (Shah et al., 2003). Psychometric measurements have been used extensively for decades as an outcome-based approach in terms of assessing creativity. Shah et al.'s (2003) psychometric evaluation method, which measures the effectiveness of an ideation method and the creativity of solving a design task, is applied in this study to evaluate the Analogy Retriever. The four metrics used in this methods are quantity, novelty, quality, and variety. Quantity is the total number of the ideas produced. It is generally considered that producing more ideas indicates a higher chance of occurring better ideas. Novelty is the unusualness of an idea comparing with existing ones. Novel ideas are usually the result of design space expansion. Quality is the feasibility of an idea and to what extent it meets the design specifications. A high-quality idea implies the idea has a high design success rate. Variety, which reflects the exploration of the design space, is the categorisation of the generated ideas through measuring how different each idea is from another. Producing diverse ideas indicates high variety, and thereby higher probabilities of exploring better ideas in the design space.

A case study has been conducted in order to evaluate the usefulness and effectiveness of the Analogy Retriever as well as the creativity level of the ideas produced by using the tool. The case study was a controlled experiment involving participants to solve a design challenge. It compares participants generating ideas with and without using the Analogy Retriever. In order to provide a fairer comparison, the participants without using the Analogy Retriever have the access to Google Image, as both of the tools provide images. The design challenge was to design a new bicycle to help children fight obesity, as childhood obesity has been widely recognised as a serious public health threat. The design idea's feasibility and specifications such as easy to learn, attractive to children, and safe to ride are required to be considered.

Sixteen participants, with an average age of 27, conducted the design challenge voluntarily. Among them, there were twelve PhD students, one Master student, one undergraduate student, and two employees. The participants were from different backgrounds, ten from engineering, two from design, two from design and engineering, and two from other domains. Two participants having over three years of design experience were considered as experienced designers in this study. The others were considered as novice designers based on their design experience. All the participants were highly interested and intrinsically motivated in participating the design challenge. Moreover, they would be rewarded with a piece of high-quality stationery after completing the challenge. The sixteen participants were divided into two groups having similar capabilities, with eight participants in the control group and eight in the experimental group, according to their background and experience. The experimental group produced ideas by using the Analogy Retriever, while the control group generated ideas without using the tool but using Google Image as an assistant tool. Google Image also acts as the image source of the Analogy Retriever. Each of the participants from either group conducted the case study separately within the same amount of time. The ideas generated by the control group and the experimental group were collected and mixed together before evaluation to eliminate bias. The ideas were evaluated by two experts respectively under the same inter-rater agreement (5 for excellent, 4 for good, 3 for fair, 2 for poor, and 1 for very poor) in order to avoid subjective judgement. Both of the experts had over three years of design engineering experience, and were considered as qualified assessors. The final metric scores were the average scores marked by the two raters.

Based on the evaluation method illustrated above, the four metrics of the ideas produced by the control group and the experimental group were measured respectively as follows. Quantity was measured by counting the total number of the ideas produced by a group. Novel and quality were applied to individual ideas. Novelty was assessed by scoring 1 to 5 (from 'very poor' novelty to 'excellent' novelty), comparing with existing children's bikes on the market. Quality was calculated through scoring 1 to 5, from the worst quality to the best quality, considering an idea's feasibility and to what extent it meets the design specifications illustrated above. Variety was applied to an entire group of ideas, which was measured by counting the total number of idea categories. The ideas were classified according to the different physical design principles considered, such as three-wheel bike and single-wheel bike. Due to the different quantities of ideas generated by each group, it is more effective to use average scores instead of overall scores to describe the novelty and quality of the produced ideas.

4.2 Evaluation results

The Evaluation results of the case study are shown in Table 1. The experimental group generated 35 ideas in total by using the Analogy Retriever, while the control group produced 14 ideas by using Google Image. The experimental group achieved 3.64 in novelty, which is 0.50 higher than that of the control group. In terms of quality, the experimental group and the control group scored 3.57 and 3.26 respectively. Twenty varieties were demonstrated by the experimental group and nine varieties were shown by the control group.

The standard deviations (SD) of the novelty scores of the ideas, and the quality scores of ideas were calculated respectively to quantify the dispersion of the data values. As shown in Table 1, all the standard deviations are relatively low, and thereby all the data values are close to the means of their data sets respectively. Therefore, the data values are consistent and stable, which indicates that the data are valid and useful.

Table 1. Evaluation results of the case study

Metrics \ Groups	Control Group Using Google Image	Experimental Group Using the Analogy Retriever	Improvement
Quantity - *Total Number of Ideas*	14	35	150%
Novelty - *Average Score (SD)*	3.14 (0.55)	3.64 (0.71)	16%
Quality - *Average Score (SD)*	3.26 (0.34)	3.57 (0.51)	10%
Variety - *Total Number of Categories*	9	20	122%

Interviews were conducted among the experimental group to investigate their user experience. All the eight Analogy Retriever users provided positive feedback, indicating the Analogy Retriever as a useful and effective tool for promoting idea generation. The tool users pointed out that the tool had produced a number of useful analogues and re-representations that were closely related to 'bike', which had improved their design space exploration and expanded their design space. The mood board was considered by the users as an additional bonus that had enhanced their creative thinking during the idea generation. However, some users indicated that some of the analogues generated by the tool were common knowledge. This is a limitation of the common sense database used by the Analogy Retriever.

5 DISCUSSION

Table 1 presents the psychometric evaluation results of the case study. Comparing the experimental group using the Analogy Retriever with the control group using Google Image, quantity was increased by 150%, novelty was enhanced by 16%, quality was improved by 10%, and variety was expanded by 122%. Therefore, comparing with the control group, the ideas generated by the experimental group are better in all the four metrics and especially in quantity and variety. This indicates that the Analogy Retriever can improve better idea occurrence, design success rate, design space expansion, and design space exploration, for the group concerned. The psychometric evaluation result has reflected the high effectiveness of the tool and the high creativity of the outcomes. As a result, the case study suggests that the Analogy Retriever is capable of benefiting the designers concerned in generating creative ideas effectively and simply, albeit based on a limited sample. Comparing with the human brain, the Analogy Retriever has advantages in ideation exceeding 30 minutes. It is noted that a human's idea generation rate and idea quality generally decrease in 30 minutes and 20 minutes, respectively (Howard et al., 2011). The tool can continuously provide a user with useful stimuli, which can maintain the user's idea quality and ideation rate (Howard et al., 2011).

The capability of the Analogy Retriever could potentially be improved by implementing an additional technical database, such as the one used by Shi et al. (2016). In addition, the Analogy Retriever has the potential in new analogy-making based on the simulation algorithm through further developments. For example, the tool can identify that 'Coke' is an instance of 'Soda' and 'Sprite' is an instance of 'Soda'. Therefore, 'Coke' and 'Sprite' can be a pair of new analogues for sharing the same deep relationship which they are both instances of 'Soda'. This type of deep analogy relationships can be stored as new rules or principles for applying to future analogy problems. The analogy-making potential of the tool can help designers generate highly creative ideas through distant analogical reasoning.

6 CONCLUSION

Design has been described as a specific end to the deployment of creativity, but coming up with creative ideas is challenging. Analogy is considered as an essential element of creativity. This study was undertaken with the aim of developing a computer-based tool named the Analogy Retriever, which is based on analogy, to assist designers in idea generation and prospectively in idea elaboration. Through investigating the cognitive process of analogy, the paper proposed an analogy cognition simulation algorithm for developing the Analogy Retriever. The tool is focused on solving proportional analogy problems (A:B::C:X) by retrieving the unknown term X from a knowledge database, and thereby helping designers in ideation through expanding and exploring the design space.

The Analogy Retriever has been indicated to be useful and effective in helping the designers concerned to produce creative ideas through conducting a case study. The case study results have revealed that the tool can significantly improve the quantity, quality, novelty, and variety of the ideas for solving the design challenge. It is indicated that the tool can enhance design space exploration and expansion, as well as improve design success rate and better ideas occurrence, albeit based on a limited sample. The cognitive simulation approach used for developing the tool can be further applied to design support tools development. However, the capability of the Analogy Retriever can be potentially further improved by enhancing its database. Further research is planned to improve the effectiveness and efficiency of the Analogy Retriever, as well as to measure the tool's capability of assisting designers in idea elaboration. In addition, an analogy-making tool is going to be developed based on the algorithm.

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