USING VISUAL DISPLAYS TO STIMULATE CREATIVITY: IMPLICATIONS FOR ENGINEERING DESIGN

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ABSTRACT

Creativity is a primary and essential part of the engineering design process. So, multiple support tools are developed to aid engineers and designers in the creative design process. The use of visual displays is seen as a helpful and encouraging tool in design problem solving. The paper concludes a brief literature on the engineering design process, activities performed during its stages and various methods that can stimulate creativity in different steps of this process. This study describes analogy as a supportive and powerful tool mentioned in the literature for creative design. It helps to explain new problems in terms of familiar ones and involves the transfer of relational information between two situations. So, analogy can help designers to use visual displays in a new and creative way. The study presents the process of using visual displays in design and the results suggest that practicing with a large and diverse number of visual displays can help engineering designers in general, to spontaneously retrieve significant information, and to enhance their design abilities. It's especially crucial in generating creative ideas and therefore creative products.

KEYWORDS: *engineering design, creativity, analogy, visual displays.*

I. INTRODUCTION

Engineers are facing with a problem unique to those in other creative fields such as the arts and humanities. In order for engineering ideas to be considered creative, there is a greater need for utility as well as the ability to fit into the limitations of the physical world [1]. While aesthetic appeal may be important for engineers to consider, creative ideas should solve problems, prevent potential future problems, and create solutions that are useful and responsible to the problem limitations [2].

The National Academy of Engineering (NAE) recently released two reports on the Engineer of 2020 [3, 4] that identify the "flat world" [5] skills needed by engineers in the twenty-first century. These reports emphasize the need for engineers of the future to develop skills in practical originality and creativity as this is what will differentiate them from low wage engineers on the international market. In other words, the top paid engineers will be those that are skilled in developing innovative new products [6].

Development of numerous creativity support tools is investigated in design to aid engineers and designers in the creative design process [7]. Using visual displays is considered as an encouraging tool for solving design problems. During the design process, and particularly in the early stages of the process, designers are exposed to vast collections of visual displays [8]. Almost all design continues by transforming, combining and adapting elements of previous designs, as well as elements and aspects of other object, images and phenomena [9]. These are external representations, i.e., pictures, diagrams, or sketches, which provide designers with helpful explicit and non-explicit references.

Despite the importance of this pictorial material, only a small number of researches have dealt with the spontaneous use of visual displays as an aid in design problem solving [8]. Also there's an important question: if visual references play such an important role, when does the designer engage them in the designing? Of course, designers continually look through magazines and books as a background task not particularly directed to a specific design problem, and this background browsing may later provide motivating references. More directed use of visual references seems to happen

during what we will call the conception activities of design [10, 11], that is, when the designer engages mainly in exploring physical form, thinking less about the organization of the site, the architectural program, and the building system [11, 12].

There are many anecdotal examples about the use of visual references in the design literature [8], but the study of visual analogy has still not been awarded enough attention and its contribution to design has not been fully assessed. Since designers are in the habit of making recurrent use of visual displays, visual analogy is regarded as a valuable strategy for enhancing design quality.

As an alternative for designers, the present study examines the use of visual displays as stimulation sources, and its relationship to the enhancement of creative design product during the idea generation stage. Visual displays may take various shapes. A major aspect is that they enable the structuring of a problem from a new point of view that is really significant for creative activities like design.

In this study, first, the literature on engineering design and the importance of creativity will be reviewed briefly. Next various methods that can stimulate creativity in relation to creative process and engineering design will be explained.

Analogy, as one of these methods is discussed. This study presents different studies and experiments about the process of using analogy in problem solving. This strategy can be used to utilize visual displays in creative design process. So this paper presents the process of using visual displays in design, guided by analogy to enhance creative products and the results will be argued.

II. ENGINEERING DESIGN PROCESS

The process of design begins with a problem. Designers solve the problem by the output designed through the design process [13, 14]. The understanding of the design process is important both to manage the design activity and to aid the improvement of products and the overall efficiency of engineering based companies; it is also the foundation on which a lot of design research is based. It is suggested that understanding this process relative to the creative process will give insight into where and when resources should be focused in order to enhance creative performance and also the resulting 'quality' of the product designed [15]. So this part introduces a framework which defines the boundaries of the design process, and highlights the commonalities and differences between the phases.

In the last few decades, the design process has become more systematic, so that novice designers are capable of applying the suggested procedures in making their designs [13, 16].

Engineering design is viewed to involve more `science' and less `art'. Although engineering design requires creativity and inventiveness (`the art'), it is a process that can be taught, learned and successfully implemented to solve engineering problems (`the science') [17, 18, 19].The engineering design process can be divided into five broad sequential steps: needs assessment/problem definition, conceptualization, preliminary design, detailed design and production. The main tasks done during each of these steps are summarized in Table 1. It must be emphasized that engineering design is an iterative process often requiring cycling between the steps based on what is learnt later on [19].

The starting point of any design activity is a need or an idea, and the end point is a product that fills the need and embodies the idea. In the needs assessment/problem definition and preliminary design stages, the tasks are more certain and structured following a step-by-step process, often referred to as `mechanical' tasks in the literature [19, 20].

Table 1. Summary of activities performed during design stages [18, 19]

Design Stage	Typical activities/tasks
Needs assessment/ Problem Definition	Statement of what design should accomplish; listing of constraints; decomposition to smaller manageable problems; compilation and weighting of customer needs; definition of criteria to be used to evaluate final design.
Conceptualization	Involves two steps: (1) External search: determine what has been done in the past. Achieved by looking at competitors' products, patents, published literature, discussions with experts, etc. (2) Internal Search: generation of several concepts by the design team to best solve the sub-problems and the overall problem.
Preliminary design	Further development of concepts shown to be feasible. System and component design requirements are established. If applicable a working prototype is built and tested.

Detailed Design	Final manufacturing and assembly drawings are generated. Systems specifications are developed (operating parameters, maintenance and testability provisions, material requirements, design life, packing requirements, etc.)
Production	Determination of production sequence of operations, selection of jigs, fixtures and tools; production of product.

During a designing process, one of the hardest parts for a designer is the idea part. For those designers, there are different thinking methods for ideas which are being developed and used. Conceptualization is a very important stage in this process. At this stage designer considers the alternative concepts to find the best design to solution problem. The selection of concepts is a decision making process which is carried out in terms of trade– offs [21].

In the conceptualization stage, the tasks are less certain, less structured, more dynamic, and requires more creativity from teams. This design phase is often referred to as `radical' (also referred to as `innovating') in the literature [19, 22]. Design tasks in this phase suggest operating in a dynamic environment, emphasizing initiative and risk taking [23]. Idea generation, in the conceptual stage or the act of generating novel, applicable ideas, is the activity most frequently associated with creative problem solving [21]. Thus creative thinking should happen in this stage.

In the engineering design literature, it has been noted that visual displays of critical importance during concept design—the front-end portion of the design process. During concept design, the designer attempts to generate a core technical concept around which the entire design will be built [24]. It is suggested that visualisation enhances the ability to generate and configure new design concepts.

III. METHODS WHICH CAN ENHANCE CREATIVITY

In engineering design, the idea generation is important and not always understood. The method is important and noticeable in this process and has a key role in creativity. Creativity helps us solve problems in various fields [25]. Creativity, as a concept of bringing forward new ideas, is seen by many as the driving force in the design process of a wide variety of fields, from architecture to mechanical design [15].

The common explanation of creativity includes two major aspects: novelty and appropriateness [15, 27]. Some researchers use different synonyms for these two fundamentals, and sometimes add other factors to the two, based on the focus of the related disciplines. Howard et al. [15] collect different keywords involving creativity. The elements in the table are ‘‘unobvious’’, ‘‘adaptive’’, ‘‘leap’’, ‘‘change’’, ‘‘unexpected’’, ‘‘communicated’’, ‘‘transformation’’, ‘‘comparisons’’, and ‘‘resourceful’’. They are considered as supplementary elements to the major elements in that they are less distinctive in contrast with the major ones.

With increased complexity in the design world, innovation, originality or the stimulus for creative thought should no longer rely on talent or chance alone. This section presents the most popular, creativity enhancements methods used currently by corporations. The methods differ in their underlying principles, reflecting the various theoretical approaches for the creative process. The process of design begins with a problem [14]. Designer solves the problem by the output designed through the design process [13].

Table 2. Classification of various methods that may stimulate creativity in relation to phases of the creative process [28]

Creative process phase	Methods
Problem definition	Assumption Busting; Assumption Surfacing; Backwards Forwards Planning Boundary Examination; CATWOE; Chunking; Five W’s and Hs; Multiple Redefinition; Other Peoples Definitions; Paraphrasing Key Words; Why Why Why
Idea generation	Analogy; Attribute Listing; Biomimicry; Mind Mapping; Morphological Analysis; Nominal Group Technique; Pictures as Idea Triggers; Pin Cards; Random Stimuli; Talking Pictures; TRIZ; Brain Storming
Idea selection	Advantages, Limitations and Unique Qualities; Anonymous Voting; Consensus Mapping; Idea Advocate; NAF; Plusses Potentials and Concerns; Sticking Dots; Unique Qualities
Idea verification	PDCA; QFD; Six sigma

In human creativity researches (e.g. Boden [29]), several processes are frequently described: 1) combining ideas from different domains; 2) the use of visual imagination, metaphor, and analogy, and 3) expanding and varying the search space of alternatives. Therefore these three aspects of creativity are briefly reviewed here [11, 12]:

1) Combining ideas from different sources
   An often referred source of creativity is the combination of ideas. Creative ideas are resulting by combining different ideas from other domains with the problem at hand.
2) Visual metaphor and analogy
   In many accounts of creative acts visual metaphor or analogy—'seeing as'— plays a key role, for example Kekulé's seeing benzene's carbon ring structure as a snake biting its tail, or Faraday's seeing the universe as patterned by "lines of force," which led to the electric motor. The use of analogy and metaphor features prominently in many discussions of design methods and processes.
3) Expanding the search space
   Newell, Shaw, and Simon [30] describe creative thinking as a special case of problem solving, to be worked by heuristic search. In engineering design, Gero [31] suggests that expanding the space of design possibilities with larger knowledge bases can inspire creativity. The search space can be expanded both by relaxing constraints on existing parameters and by introducing new search space dimensions, viewing design not as simply search but as exploration [12].

As reviewed in this section, Analogy is mentioned in creativity studies. Furthermore visual thinking and displays are really important in design. So, visual analogy can be a powerful tool to stimulate creativity in engineering design.

IV. ANALOGY AND PROBLEM SOLVING

Reasoning by analogy has been recognized by scientists, philosophers, and psychologists as a mechanism that has the potential to support the achievement of new information [32]. Schunn and Dunbar [33] have shown that in science, priming enhances access to previously acquired knowledge, which can be and is used to solve current problems, among others through analogical mapping and transfer. This process is implicit and in an experiment, subjects were not aware of what made them think of the particular knowledge they were able to elicit in order to successfully solve a novel problem. The use of analogy entail the transfer of relational information from a known situation (usually referred to as source or base), to a situation that needs explanation (referred to as target), (figure 1) where at least one of the related elements is not known [32].

Gentner and Medina [34] who conducted experiments involving the use of analogy with children have come to noticeable conclusions. They stress that not only do subjects perform better when they had previously solved analogous problems, but that long-term learning can be shown to occur in which abstract concepts are better understood, abstracted, and applied in subsequent appropriate situations.

As mentioned earlier, analogy helps to explain new problems in terms of familiar ones [35]. Thus it may be a powerful problem-solving strategy [32] for ill-defined problems. The use of analogical reasoning on creativity has been examined in different domains; such as manufacture, industrial design and architectural design [36, 37, 38].

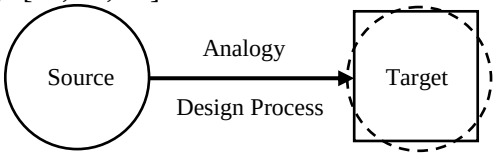

Figure 1. Transfer of knowledge from source to target in analogy

Analogy can be viewed as a mapping of knowledge from one situation to another enabled by a supporting system of relations or representations between situations [39, 40]. The identification of a similarity between possible relations in the target situation and known relations in the source situation leads to the creation of an analogy. This process of comparison fosters new inferences and promotes construing problems in new insightful ways. The potential for creative problem solving is most noticeable when the two domains being compared are very different on the surface [33].

V. THE USE OF VISUAL DISPLAYS IN DESIGN GUIDED BY ANALOGY

Designers in all disciplines live in a visual world. They are sensitive to the appearance of artifacts and environments, as a matter of course. Needless to say, the visual qualities of their design products are, with practically no exception, of great importance to them (as well as to clients and users) [37, 41]. Studies of design method and process often identify visual analogy, metaphor, and visual references as important activities in creative designing [12, 29]. Therefore, it is not surprising that visual information is well-known and important in the design process [41]. They appear to use a wide variety of sources of inspiration, including previous design cases, analogies, works of art, and objects and phenomena from life and nature [42].

Within the participatory design approaches, use of visuals is one of the generative techniques to elicit people's experiences and thoughts about a product's scenario of use [43]. Most researches in cognitive science have focused on the domains of vision and visual perception. Visual thinking and visual analogy have always been seen as important aids in design problem solving [37].

In design tasks, where visual thinking is largely employed, designers are frequently assisted by visual stimuli such as visual displays. According to the moments of design, the image can play different roles. Three principal functions of the image are identified here: [38]

1) The reference image: in the early phases of the design, the image serves as an ideas search support. By copying or interpreting a physical image, the designer will construct mental images in relation with his project situation.
2) The analogous image: the designer will search and identify possible solutions by making correspondence between the image of an object or a work and the imagined solution of a project,
3) The model image: in the more advanced design phases, the image plays the role of a model of a conceived work. It will be used for the project communication [38].

The use of analogy in design is common. Kalogerakis et al [44] found that analogies are widely used by professionals working at design and engineering companies. The designers' reference to visual displays, explains why visual analogy is an appropriate strategy for enhancing design problem solving. Visual displays play a significant role in the early stages of the design process. These visual sources are most helpful when they embrace analogical principles that can potentially aid in solving design problems [45].

Malaga [46] reported an experiment in which participants were asked to generate ideas in response to a specific task, having been shown word, picture, and combined word and picture stimuli. The use of picture stimuli elicited more creative ideas than word or combined stimuli. Cardoso and Badke-Schaub [47] found that when subjects are shown examples that are too realistic they fixate more often. When abstract examples are shown the resulting designs are rated to be more original, which indicates less fixation [48]. Ozkan and Dogan [49] studied the relation between level of expertise and participants' selection of source categories, the stated reasons for their selection, and the type of similarity they established between source and target.

The degree of difficulty of establishing an analogy is mainly determined by how remote is the source from the target (also called 'metaphorical distance' between source and target), as well as by the manner by which a target situation is represented, and a visual display is accessed [50]. Ball and Christensen [51] claim that the distance between the selected source and the target relates to the purpose of the designer.

Casakin [45] mentioned the main processes of analogical reasoning in his research. This process can be used in the design process to use visual displays and is consist of: (1) identification and retrieval; (2) mapping and transference. These are described as follows:

1) Identification and retrieval: Subjects identify and represent the target situation according to various features that may hold abstract solution principles. These features provide memory retrieval hints, which are useful to access significant knowledge about known situations. A number of experiments have been carried out to study the retrieval process through the hint/no-hint paradigm. These included the provision of sources containing instructions, key words, or visual hints such as diagrams harboring a solution principle similar to the target problem.

2) Mapping and transfer: When a potential source analog is retrieved, subjects establish correspondences between objects and between relations among objects, in the source and the target situations, and strive to see how an analogical principle can be transferred. This process is considered to be of critical importance for the analogical reasoning process. Successful mapping increases the possibility of a successful transference of a solution principle from source to target increases

VI. RESULTS AND DISCUSSION

The results of the current study showed that the use of visual displays plays an important role in problem-solving and therefore design problem solving, where unexpected analogical relations between visual sources and the design problem can be found.

As the result of reviewing 3 major processes in creativity (combining ideas from different domains; the use of visual imagination, metaphor, and analogy, and expanding and varying the search space of alternatives [11, 12]), it generally can be implied that a focus is placed on surface and irrelevant features of the visual display, which usually leads to an unsuccessful or successful solution. It is suggested that the accessibility of a rich collection of visual displays help designers to search for a number of original and unpredictable design solutions, and to enhance the quality of their design solutions. The large and expanded set of relevant and irrelevant visual displays and combine them in a novel way, may have contributed to the retrieval of deep relations between visual references as source and the design target.

Although the use of visual displays contributes to the enhancement of problem solving, instruction to use analogy plays an important role to play in further improving the quality of the design solutions. Practicing in the explicit use of analogy through a trial and feedback method, can help designers gain a better understanding of how meaningful knowledge structures can be retrieved from visual displays, and transferred to the problem at hand [45]. Designers who become familiar with this strategy can progressively learn to use analogy, even when no explicit instructions are provided. The process of using visual displays in design, with employing analogy is presented here:

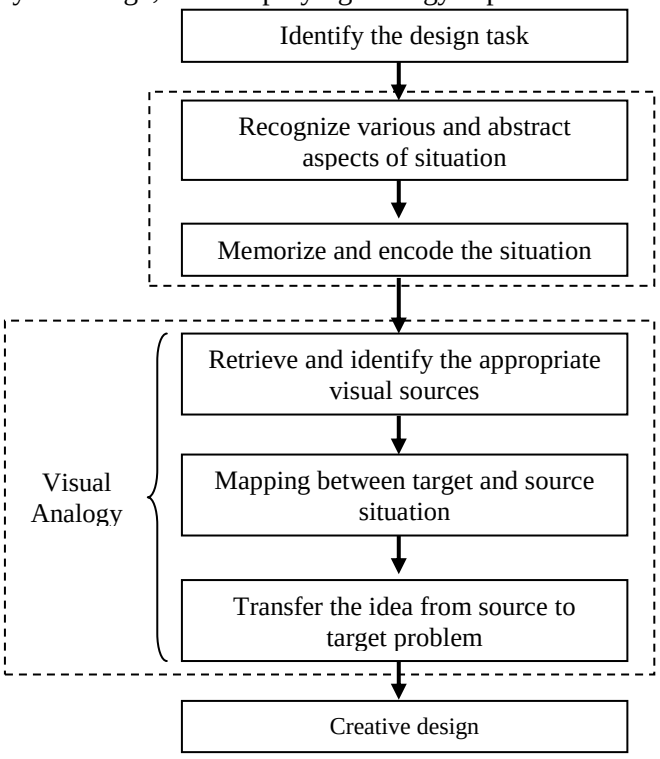

Figure 2. The process of using visual displays in design, guided by analogy

The identification and representation of a target situation according to certain features can provide the problem solver with memory retrieval hints, which are practical to access relevant knowledge

included in the visual sources. Poor results of analogical use of visual displays in problem solving are related to the identification of superficial attributes rather than deep ones. The retrieval stage is noticeable in this process. Applying and utilizing appropriate sourced can lead to better result. Mapping and transfer stages are crucial. It can be said that retrieving appropriate previous solutions and transferring the knowledge by mapping the relevant pieces of information are difficult and effective parts of this process [51]. Successful mapping increases the opportunity to have a successful transference of a solution principle from source to target

VII. CONCLUSION AND FUTURE WORK

Creativity as a primary and essential part of the engineering design process is studied in many recent studies. So, there are multiple support tools to aid engineers and designers in the creative design process. In this paper, engineering design and its diverse stages was discussed. Also various methods are introduced in creativity research which can stimulate creativity enhancement. Analogy is one of these methods and it has been referred many times.

The use of visual displays is seen as a helpful and encouraging tool in design problem solving. There are many anecdotal examples about the use of visual references in the design literature, but the study of visual analogy has still not been awarded enough attention and its contribution to design has not been fully assessed.

This article explained deeper understanding of analogy and its use in creative design. This will enable more effective products to be created and utilized, helping the engineering designer to produce more original ideas or to reach them more quickly. Moreover, the process of using visual displays guided by analogy was presented.

The results show that, the design process starts with identifying the design task, and is followed by recognizing abstract aspects of situation and encoding the situation. After this stage the designer looks for appropriate source in his visual memory or visual representations. The next steps are the main steps of using visual displays to reach creative product by the guidance of analogy. These steps (Retrieve and identify, Mapping and Transfer) are very important and influencing in the quality of the design. By searching and using a wide range of visual displays to enrich visual sources, the designer can provide creative supports for his design.

Visual display have an important, but not fully understood role, so in future work prescriptive studies should be conducted with engineering designers to test the impact of the different types of visual displays on creative inspiration at different stages of the engineering design process. It is clear that studies must be conducted with engineering designers to review existing visual information and sources used as design stimulation.

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