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ANALOGICAL PROBLEM-SOLVING IN DESIGN

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ABSTRACT
The paper describes a conceptual framework for analogical problem-solving (APS) in Design. We will argue for the importance to include APS in the design process with the goal to develop innovative products. The fundament for APS consists partly of cognitive theories which will be described. Furthermore, we present two examples that illustrate how analogies can be utilized systematically in solving design problems. Finally, a study will be presented where the testing of analogies with different levels of abstraction is discussed and the role of APS for education is evaluated.

Keywords: Analogical problem-solving, creativity, problem abstraction, design methodology, innovativity.

1 INTRODUCTION

In the recent years, technological development and growth in industrial production has resulted in an increased need for industrial designers to conceive innovative products in order to provide a competitive edge. In this context, it is essential to employ methods and procedures to generate creative solutions to problems encountered in the design process. In some cases, design-related problems can be accommodated through the use of analytical approaches. However, when solutions cannot readily be deducted from the available information, utilizing analogical problem-solving techniques may be a more suitable strategy.

In design-related problems, lack of sufficient information is a typical impediment as the process of transferring abstract needs and requirements into a physical product often lacks applicable heuristic principles. This difficulty is often described as the *fuzzy front end*, illustrating how the design processes may be characterized by vague notions of how final solutions will be concretized. In order to meet these problems, one can put greater emphasis on analogical problem-solving (APS) strategies, which can turn out to be beneficial in situations where new and radical design solutions are necessary. APS is operationalized here as the process of constructing a solution to a target problem by adapting a solution from a source problem through recognizing a common pattern in source and target.

Through the development of methods, one could add analogical skills to the designer's repertoire alongside the more common analytical tools, and thereby provide a considerable advantage for the development of innovative products. Developing such methods is, however, not an easy task, and remaining focused on the problem at hand, we show some examples to do so.

This article will describe the importance of including APS in the design process. Our onsets are cognitive theories surrounding analogical problem-solving. Furthermore, two examples will be presented that illustrate how analogies can be utilized systematically in solving design problems. Finally, a study will be presented where the testing of analogies with different levels of abstraction is discussed and the role of APS for education is evaluated.

2 ANALOGICAL PROBLEM-SOLVING

Forming an analogy is a powerful tool when trying to understand a new situation or solving a new problem [1]. The word *analogy* refers to the relation between the terms the source and the target. In difference to metaphors, which are connected through a third relation (e.g. “head of the family”), analogies often possess a recognizable similarity. Analogies are used to project a structural relation between ideas and domains. The effective use of analogies can enable the transfer of insight from an example solution onto the problem at hand, resulting in an entirely new solution. APS activates an analogy from long-term memory and adapts it for current problem solving. It consists of two phases; the retrieval phase involving the search for an example that can assist in solving the target problem and the transfer phase where insight and information from the example is incorporated into the problem’s solution [2]. Holyoak [3] has described APS through five steps:

1. Forming a mental representation of the source problem and the target problem.
2. Generating a plausible analogy.
3. Mapping across features which are perceived to play the same role in both source and target.
4. Generating a solution for the target problem by tracing the shared underlying structure
5. Learning in the form of schema abstraction through comparing examples.

The source problem (and its analogy) lies in the long-term memory, and the effectiveness in using APS is a function of the probability of retrieving the relevant source problem when it is needed. Further, it depends on the problem-solvers ability to transform the source problem to a state where it can be applied to the target problem [3]. Both aspects may be improved considerably through the systematic application of methods aimed at triggering the recollection of relevant source problems and outlining the common structure.

According to Gero [4] unexpected design solutions are a product of the confluence of two schemas mediated through an analogy. Schema is, in this context, defined as “a mental template that automatically or intuitively guides our perceptions and interpretations of our experience” [5]. The first schema contains expectations regarding the outcome of the design process and originates in the definition of the problem, while the second schema is needed to understand the relevance of the unexpected result. A concept is considered as truly novel, at least to the problem-solver, when a schema, not previously taken into consideration, must be brought in, to understand the design concept. If the new schema can be understood and concretized in a satisfactory way, a starting point for an innovative design has been established.

One could argue against Gero´s model applied to design methodology that design tasks are sometimes performed without a deliberate problem formulation, or that problem-solving, may not always be apparent here. However, any design is associated with the intention of improving an existing state or simply to produce a good one. Therefore, Gero´s schemes definitely encounter an important problem: How is it possible to create a concept which corresponds to the envisioned state? [6] Recognizing design as a process involving some sense of problem-solving poses implications on how to understand this process. One of the most prominent of these implications is that the range of possible solutions is inherently restricted by the perception and definition of the problem.

2.1 Defining a solution space

The definition of a space in which the solution to a problem is believed to exist is latent in any problem formulation. This space is shaped through the requirements, restrictions and constraints imposed on the situation by the problem-solver interpreting the context of the product [6]. Furthermore, any problem formulation implies tacit, mental representations used by the problem-solver to comprehend reality. Passer and Smith [7] have defined such mental representations as "cognitive representations of the world, including images, concepts and principles that are foundations of thinking and problem-solving". The subjective perception of the constructs is an important aspect for the problem formulation as well but its discussion exceeds the framework of this paper.
The formation of the solution space is a necessary function in order to distinguish information relevant to solve the problem. However, when the optimal solutions are not included within this space the perceived boundaries of the solution space can effectively prevent the discovery of the best-fit solutions.

In relation to analogical problem-solving, the construction of a suitable solution space is essential, as the utility of the analogical information relies both on its relevance to the target problem and the contingency of identifying common patterns between source and target [2]. Solution spaces concerns both the scope and category variance of the considered solutions, and thus operates on two levels. Specialized knowledge can contribute to extending the scope of ideas within a certain domain, but at the same time, it may also impose restrictions on the number of categories included in the solution space. In order to avoid inappropriate restrictions in the solution space, abstracting the problem formulation to a more general level may reveal new domains capable of yielding example solutions resulting in successful application of APS.

2.2 Problem abstraction

The term problem abstraction covers techniques used in relation to problem-solving, aimed at expanding the scope of solutions through a critical assessment of the underlying motives behind the task. By approaching the problem from a more general perspective, counter-effective restrictions on the solution space may be identified and sidelined. Baxter [8] has described a simple procedure for problem abstraction, in which a problem definition is challenged through questioning why this solution is sought. The specified motive is then used as a basis for a new problem definition which might, in turn, reveal alternative solutions. If required, this approach may be repeated with the new definition, creating a ladder of abstraction levels.

2.3 Examples of methods for the systematic use of APS

2.3.1 Chakrabarti´s database

In order to generate innovative solutions for design problems, Chakrabarti et al [9] has suggested a method of compiling a database of biological and artificial example solutions and providing a computer interface aiding the generation of relevant analogies. The method is based on:

1. The construction of two databases, one describing natural systems capable of certain movements, and one containing mechanical systems capable of providing various behaviours.
2. Analyzing these databases to develop a common behavioural language which is not solely descriptive of the exhibited motions, but which also acts as a set of constructs aiding the comprehension of the functioning of the different systems.
3. The development of software with procedures for interactive, analogical generation of relevant solutions to the design problem.

The preparation of a functional behavioural language was given particular emphasis in this process and the aim was to arrive at “a way of viewing particular portions of the functional descriptions at particular levels of abstraction” [9]. Designers, once they have defined their specific problem, can translate the definition of the problem to this language and use the database to search for systems which exhibits the desired behaviour. Consequently, this approach incorporates both a method for problem abstraction through the translation into a behavioural language, and a procedure for acquiring relevant sources of analogical information by procuring software organizing example solutions in order of relevance.

Evaluating the benefit of this approach, Chakrabarti et al [9] conducted a series of six individual experiments where test subjects solved four different design-related problems. The results showed that the analogies provided by the software increased the generation of potential solutions by 65 percent, and that of all the proposed solutions, 47 percent where directly linked to utilization of the software. In addition to outlining the potential efficiency of such procedures, the study concluded that it was in the phase when the subjects had run out of other ideas that the software had its greatest impact. Thus, this experiment illustrated the importance of APS in situations where analytical strategies are insufficient.

2.3.2 TRIZ

The term TRIZ is a Russian acronym for “Theory of inventive problem-solving”. The theory was originally developed by Genrich Altschuller who studied more than 200.000 patent specifications in order to derive a set of general inventive principles. Since its birth in the 1940’s, much work has been added to the theory, and today, various software with an architecture similar to the one employed by Chakrabarti et al is available within the TRIZ methodology. The applied approach typically involves four steps:

1. Abstracting the problem to a terminology-free formulation in the form of a contradiction.
2. Comparing the contradiction to a matrix of inventive principles.
3. Entering the inventive principles into software producing example solutions based on a database containing information contracted from patent specifications.
4. Evaluating the solutions with regards to the increase of ideality in the system.

3 A STUDY OF THE RELEVANCE OF ABSTRACTION LEVELS IN ANALOGIES USED IN DESIGN-RELATED PROBLEM-SOLVING

3.1 Research design

In 2005, we performed a study in order to test if the use of analogical information based on different abstraction levels from the specific design task would expand the solution space of the problem-solver [10]. The study was based on a qualitative research design, where the test subjects where asked to generate various solutions to a presented design problem with the aid of a folder containing images potentially carrying analogical information. Two different folders where prepared, one including images of relevant product-specific features (direct analogies) which could inspire parallel solutions to the presented problem, and another containing images illustrating examples of how the problem has been managed in entirely different products and contexts (abstract analogies). The objective was to investigate whether two groups presented with the same problem, but with the aid of these different folders, would arrive at dissimilar ranges of solutions.

The test subjects were art and design students between the age of 16 and 18 years. In order to reduce the possible impact of technical or specific knowledge on the results, the problem used in the study dealt with an ordinary product perceived with a clear function and low degree of complexity. The subjects were given fifteen minutes to generate as many viable solutions to the presented task as possible in the form of written descriptions or sketches. These results were subsequently analyzed with respect to relevance, variance and number of solutions.

3.2 Results

The study revealed two tendencies. First, the total number of solutions generated by the subjects aided by the direct analogies was higher than that of the subjects who were handed the abstract analogies. Second, the solutions proposed by the subjects using the abstract analogies were spread over a larger variance of domains. However, due to a limited number of test subjects the results show only tendencies and could not be verified within a satisfactory significance level.

3.3 Evaluation

Although clear tendencies were recognized in this investigation, a larger sample would be needed to obtain significant results. Further improvements of the study could have been achieved through including a control group solving the problem without the aid of analogical information. This could have contributed in benchmarking the results and enabled a more general evaluation of the benefit of APS in design. Additionally, testing alternative presentational media, could have elucidated whether images are suitable intermediaries for analogical information.

4 CONCLUSION

Today there is an increased tendency in education to incorporate problem solving as a key component in the curriculum. This need for learners to become successful problem solvers is for example reflected by Gagne, who believed that "the central point of education is to teach people to think, to use their rational powers, to become better problem solvers" [11]. However, even if problem solving is one of the most important activities in human life, todays´ curricula do not sufficiently meet the necessity to systematize problem solving related to real life situations. Students are rarely, if ever, required to solve meaningful problems as part of their education but often encounter more or less well-structured (narrative) problems. One consequence of this lack is that graduates struggle with the ambiguity between the formal education that design schools provide and complex ill-structured problem solving that is needed in reality.

The test performed with the students in our study indicates that if ASP is carried out effectively, the problem solver can become more successful in handling a situation. Moreover, it has been indicated that by including different abstraction levels in the APS procedure, the potential benefits of the approach may be enhanced. By working with simpler problems, students gain confidence and are motivated to activate prior knowledge, apply skills, understand the context of the problem situation, and choose the appropriate strategy in solving the problem. It also seems that ASP promotes innovative solutions to the target problem. We consider APS as a supplement to more analytical design methods. We do not think that APS in the curriculum is replacing declarative knowledge but that both are in concert with each other*:* the analytical methods have to be mediated in a way which can be systematized for ASP. The saying goes 'If you do what you've always done you'll get what you've always got'. If one of the challenges in business is to generate new ideas, identify better solutions to problems and find new opportunities to exploit, one could say that APS has the potential in these areas to contribute to remove barriers to creativity and to think about learning in different ways.

REFERENCES

[1] Yanowitz K.L., Transfer of Structure-Related and Arbitrary Information in Analogical Reasoning. *The Psychological Record, Vol. 51*, 2001.

[2] Muldner K. and Conati C., Using Similarity to Infer Meta-Cognitive Behaviors During Analogical Problem Solving*. User Modeling 2005, Proceedings Lecture Notes in Artificial Intelligence 3538*, 2005, pp.134-143.

[3] Robertson S.I., *Is Analogical Problem Solving Always Analogical? The Case for Imitation.* HCRL, The Open University, 1993.

[4] Gero J.S., Creativity, Emergence and Evolution in Design. *Second Intl. RoundTable Conf. on Computational Models of Creative Design*, Sydney, 1992, pp.1-28.

[5] Myers G. M., *Social Psychology*. McGraw-Hill, New York, 2002, p 104.

[6] Kolle A., *Analogisk problemløsning i designrelaterte oppgaver*. NTNU, Trondheim, 2005.

[7] Passer M.W. & Smith R.E., *Psychology: Frontiers and Applications.* McGraw-Hill, New York, 2001.

[8] Baxter M., *Product design: Practical Methods for the Systematic Development of New Products*. Harwood Academic Publishers, Singapore, 1995.

[9] Chakrabarti A., Sarkar P., Leeavathamma B. & Nataraju B.S., A Functional Representation for Aiding Biomimetic and Artificial Inspiration of New Ideas. *Artificial Intelligence for Engineering Design, Vol. 19*, pp 113-132.

[10] Kolle A., Analogical Problem-Solving in Design. *Produktdesign 9 fordypning.* NTNU, Trondheim, 2005.

[11] Gagne R.M., *The conditions of learning*. Holt, Rinehart, &Winston, New York, 1980.