Freie Universitat Berlin
FB Informatics / Mathematics
Cognitive Systems Seminar
Winter Term 2018/19
Instructor: Ana-Maria Olteteanu

Discussion about the paper ”A computational model of visual analogies in design” by Davies, Goel & Nersessian

Cedric Laier
Warschauer Str. 15, 10243 Berlin
cedric.laier@fu-berlin.de
Informatik, Master (Freie Universität Berlin)
5153575

1 Introduction

This essay focuses on a study conducted on the research of problem solving by using visual analogies. The particular paper discussed within this essay is: "A computational model of visual analogies in design" (Davies, Goel, & Nersessian, 2009). The research goal of this paper was to examine the role of visuospatial knowledge in enabling the transfer of the problem-solving procedure from the source to the target.

An *analogy* itself is the process of finding and using correspondences between concepts. The term *visuospatial* refers to the ability of represent, analyse, and mentally manipulate objects; *transfer* is the application of knowledge from the source analogue to the target analogue. Research has shown that visual analogies, which are part of visual reasoning with visual knowledge, are an important role when it comes to design. Goldman and Casakin have even described visual analogies, on a basis of case studies performed on architectural design, as a core design strategy in architectural design (Casakin & Goldschmidt, 1999). That's why Davies, Goel and Nersesian hypthothise in their publication that visuospatial representation of intermediate knowledge states, organized in chronical order can enable transfer of problem solving-procedures. The idea is that by looking a visual representation (e.g. drawn with a pen on a piece of paper) of a solution for a given problem, humans are able to transfer the learned knowledge and use it to draw correspondences between the solution and a new upcoming problem. Within the next paragraph an example will be described, where we have a written description and a sketch solution for the problem. So we as humans gained new knowledge for this particular problem. The goal now is to find out is if visual perception of the spatial relationships of objects from the solution can contribute to solve a problem by using an analogy.

An example for using this kind of visual analogy for problem solving is by taking the classical fortress and tumour problem (Duncker, 1926) and sketching it as done by Davies and Goel (Davies & Goel, 2001). The participants got the task to read a text about a problem solving situation: A general with a large army wants to overthrow a dictator who lives in a fortress. All roads to the fortress are armed with mines that will go off if many people are on them at the same time. Figure 1 shows the initial situation. To solve this problem he breaks up his army into small groups and has them take different roads as seen in Figure 2. The groups arrive at the same time and take the fortress.

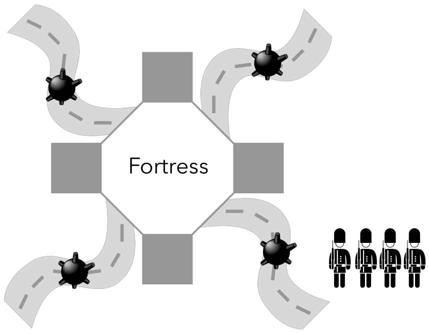


Figure 1: Initial situation of the fortress problem

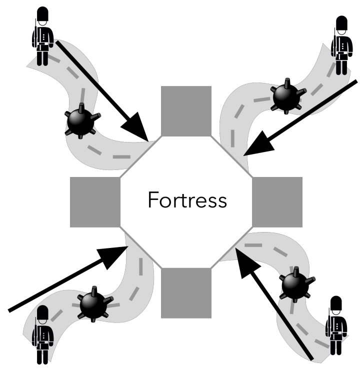


Figure 2: Solution for the fortress problem

Now they get a new different problem as stated as from Gick and Holyoak (Gick & Holyoak, 1980, 307-308): "Suppose you are a doctor faced with a patient who has a malignant tumour in his stomach. It is impossible to operate on the patient, but unless the tumour is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumour. If the rays reach the tumour all at once at a sufficiently high intensity, the tumour will be destroyed. Unfortunately, at this intensity the healthy tissue that the rays pass through on the way to the tumour will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumour either. What type of procedure might be used to destroy the tumour with the rays, and at the same time avoid destroying the healthy tissue?". Finally, the participants are asked to solve the tumour problem. The expected behaviour is now that the participants are able to find a solution by looking at the sketch and use an analogy they've learned from the fortress problem before. Figure 3 illustrates again the initial scenario and figure 4 the solution.

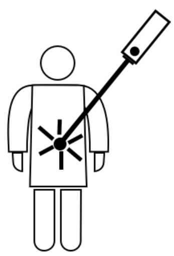


Figure 3: Initial situation of the radiation problem

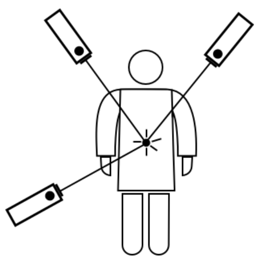


Figure 4: Solution for the radiation problem

Even though using this analogy was not obvious enough for the participants in the study of Gick and Holyoak as subjects had to explicitly get told that the military problem would be applicable to successfully solve the radiation problem, it should already give a better idea of how we might draw a solutions by using the source design case to the target problem.

A major difference to all the case studies that were performed on this topic before and this one is, that this paper hypothesizes that at least in design, humans can usefully represent the problem-solving procedures using visuospatial representations in which relation between cause, impact and intent is mostly implicit.

The following chapter will focus on the detailed research described and analysed based on a cognitive study conducted by Craig (Craig, 2001) on novice designers and it's respective results. The chapter will also describe the computer program (Galatea) they were using to simulate visuospatial in- and output representations of some of the participants that took part of the study. Closing with a discussion on the findings and a brief evaluation of the results.

2 Overview of Research

Basis of the analysis performed was Craig's (Craig, 2001) data that he captured in his doctoral publication about 34 novice designers from the Georgia Institute of Technologies. In this study 34 undergraduate students were shown a source design case about a clean room laboratory. This source design case contained a description of a design problem in a written form of text and a corresponding drawing of the solution for the given problem. Right afterwards the participants of the study were encouraged to solve an analogous design problem. This time the problem was represented with text only and it was up to the participants to draw a solution based on the solution of the first design case. The problem initially presented to the study participants deals with a scenario in which a computer chip manufacturer has to be very meticulous in ensuring that the environment within the chip manufacturing laboratory is as sterile as possible. The laboratory is a closed area with a gate that is the only way to get into the room. The highest goal is therefore to keep the environment in the laboratory sterile, dust-free and without unwanted gases. The gate is the weak point in the whole construction because every time an employee enters the laboratory, the seal (the gate) is broken or opened and dirt can enter. The company is now trying to develop a new door that allows employees to enter and leave the laboratory easily and uncomplicated, while mitigating the problem of contamination as much as possible. The solution to the problem follows the textual description of the problem by the computer chip manufacturer, in this case in the form of a sketch. The solution involves creating a form of intermediate area from the original gate and placing this area in front of the laboratory. This area can be imagined as a kind of pressure chamber, i.e. we have a sealed room with a door on both sides. One side of the opening faces the dirty outside world, the other side the clean laboratory. When the employee enters the gap through the outside world, he does not bring the dirt into the room into the laboratory. The door closes and the employee who is now in the room closed on both sides can be freed from all impurities (e.g. by showers or ventilation systems that suck the dirty air away). The chamber is now cleaned and the employee can enter the laboratory through the second door without risk. In summary, the concept is that employees enter a chamber with two doors. After the study participants have studied the first problem description and problem sketch, the second problem is presented to them in the form of a text. The second text is that the Ministry of Transport has designed a vehicle to cut grass at the roadside. For this purpose a long rod was attached to the side of the vehicle, at the end of which a kind of lawn mower was fixed. This enables the vehicle to drive along the roadside and at the same time remove the edges of the road from high grass. The problem here, however, is that it regularly happens that mailbox posts, lanterns or telephone poles get in the way and block the arm with the cutting mechanism. Since the posts are too high, it is not an option to simply lift the cutting arm over the blockade. Pulling in or folding away the cutting arm is also not an option as this would severely disrupt the grass cutting process. Therefore the Road Traffic Department tries to design a pole that can pass through the masts and posts without interrupting the cutting process. The solution to this problem is now to be provided by the study participants, taking into account the solution from the first case. In doing so, they should take into account every idea, however small, and record their approach to solving the problem as sketched. From the 34 participants 15 of them were able to create an adequate solution according to the requirements of the 2nd case. The correct solution for this problem has been to design a bar containing two locking doors in the cutting post. The lantern poles and telephone poles can now (analogous to the solution in the first case) be inserted into the pole via one door and out again via the second door on the other side via the two doors. Of course, such a solution requires that while one side of the cutter bar is open, the other side ensures that the device remains stable and vice versa. The concept of the solution therefore remains the same as in the previous scenario. It should also be noted that each of the 34 participants was presented with a version of two different initial versions. These versions differed slightly in the wording of the text and the solution to the first case was sketched slightly differently. In terms of content, however, both were identical. In the sketches of the 15 participants who were able to solve the problem correctly, many differences could be found in their editions. Figure 5 shows a table of all spotted differences in the drawings.

	L1	2	11	12	13	14	15	16	19	20	21	22	24	27	28	Total
Added objects	X	X		X	X	X	X	X	X	X	X	X	X	X	X	14
Center	X	X														2
Doors open, walls remain			X													1
Dotted object					X				X							2
Double line to line									X	X	X		X			5
Explicit simulation							X		X	X	X	X	X		X	6
Line to double line	X	X			X	X	X	X								6
Long vestibule						X						X				2
Mechanism added	X					X		X	X							4
Multiple doors									X							1
No vestibule/doors distinction		X					X								X	3
Numeric dimensions						X								X		2
Point of view change											X			X	X	3
Rectangle to line: door			X	X	X											3
Rotation	X			X	X	X	X	X		X		X		X		9
Sliding doors						X										1
Zoom					X						X			X		3
Total	5	4	2	3	6	7	5	4	6	4	5	4	3	5	4	

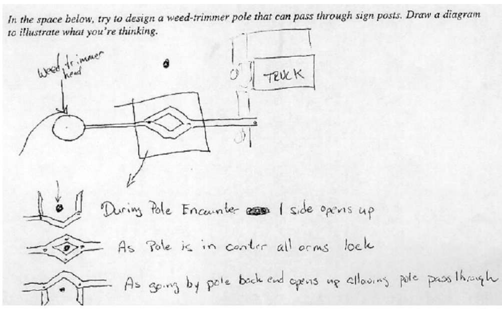
Figure 5: Observed differences in the drawings of the 15 participants. Type of the difference are shown on the Y axis, participant number on the X axis.

It could be observed that all participants who were able to transfer the analogy from the first case into their drawings were also able to find the correct solution to the problem. For the 14 participants who could not provide a solution, it is assumed that they understood the analogy but were not able to figure out how to use it effectively or simply ignored the hint to use the analogy. Based on the students' correctly produced drawings, 4 solutions were transferred using Galatea, a software program for modeling visual knowledge. Galatea allows multi-level problem-solving procedures to be represented as a set of states of knowledge and transformation between states. The elements of each state of knowledge are instances of visual elements, and the operations are visual transformations. States of knowledge consist of visual knowledge represented symbolically, the so-called *s-images* (symbolic images). The other 10 were transferred using pen and paper models. All the models, whether transferred using Galatea or pen and paper, are implemented based on a theory from Jim Davies' dissertation *Constructive Adaptive Visual Analogy* (Davies, 2004). This theory claims that visual knowledge is helpful in solving problems analogously and suggests a mechanism for achieving it. The same mechanism, in conjunction with the modelling language Covlan[1], which allows structures and internal processes to be defined at a higher level of abstraction, is here used for the mapping of the participants drawings to models. In order to be able to evaluate the 15 models, we investigated how well the models take into account the differences between the source sketch and the participant sketch. It should be noted that the solution sketch from the first case is very strongly derived from the actual image of the laboratory. It is so far derived, that

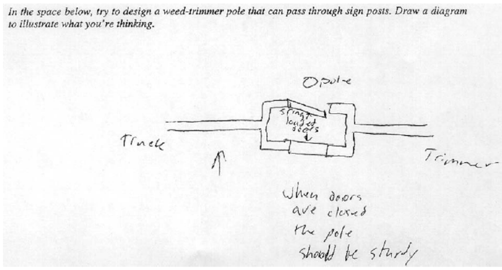
[1]Covlan is a visual knowledge representation language for representing visual knowledge and supporting visual reasoning (Davies & Goel, 2007)

the functionality which results from the sketch could have been transferred one-to-one to the solution of the cutting arm without changing the solution sketch. Later in this essay, it will be shown that each participant has deviated slightly from the source solution. These differences between the participant's sketch and the solution sketch indicate the differences between the participants. Later in this essay, it will be shown that each participant has deviated slightly from the source solution. These distinctions between the participant's sketch and the solution sketch indicate the differences between the participants. In order to be able to continue with the modelling according to Craig's theory, it was necessary to bring the source sketch and, as already mentioned, the participants' drawings into Covlan format.

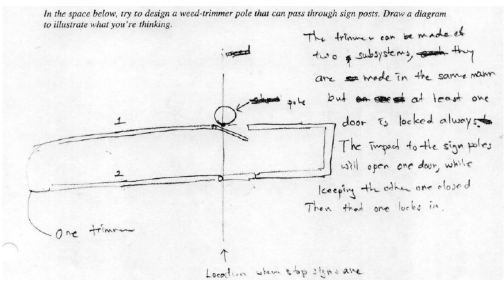
As can be seen in Figure 5, however, each participant deviated slightly from the source solution.



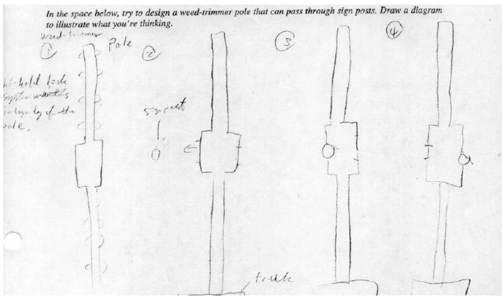
(a) Participant L15



(b) Participant L16



(c) Participant L22



(d) Participant L24

Figure 6: An extract of the some correct drawings created by the participants

3 Discussion / Critical Evaluation

References

Casakin, H., & Goldschmidt, G. (1999). Expertise and the use of visual analogy: Implications for design education. *Design Studies*, *20*(2), 153–175.

Craig, D. L. (2001). Perceptual simulation and analogical reasoning in design.

Davies, J. (2004). *Constructive adaptive visual analogy* (Unpublished doctoral dissertation). Georgia Institute of Technology.

Davies, J., & Goel, A. K. (2001). Visual analogy in problem solving. In *Ijcai* (pp. 377–384).

Davies, J., & Goel, A. K. (2007). Transfer of problem-solving strategy using covlan. *Journal of Visual Languages & Computing*, *18*(2), 149–164.

Davies, J., Goel, A. K., & Nersessian, N. J. (2009). A computational model of visual analogies in design. *Cognitive Systems Research*, *10*(3), 204–215.

Duncker, K. (1926). A qualitative (experimental and theoretical) study of productive thinking (solving of comprehensible problems). *The Pedagogical Seminary and Journal of Genetic Psychology*, *33*(4), 642–708.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive psychology*, *12*(3), 306–355.