Expertise and the use of visual analogy: implications for design education

Hernan Casakin and Gabriela Goldschmidt, Faculty of Architecture and Town Planning, Technion—Israel Institute of Technology, Haifa 32000, Israel

A challenge of design education is the question of how to help designers develop skills in design problem-solving. How can designers be taught to use relevant prior knowledge to solve new design problems? To answer this question we must know more about differences between experts and novices regarding the use of prior knowledge to solve ill-defined problems. In design, visual analogy is used as a powerful problem-solving strategy; the evidence, however, is hitherto mostly anecdotal. In this study our objective is to determine empirically whether, and how, the use of visual analogy can improve design problem-solving by both novice and expert designers. Our results indicate that the use of visual analogy improves the quality of design across the board, but is particularly significant in the case of novice designers. These findings lead to conclusions regarding design training and education.

Keywords: design education, design knowledge, design problem, problem-solving, visual analogy

In addition to knowledge, skill is the single most important hallmark of expertise in any domain. Developing potent problem-solving strategies is a cornerstone of skill acquisition. In domains in which ill-defined problems are the rule, like architectural design, skills are acquired in a 'learning by doing', or 'trial and error' manner. Analogical reasoning turns out to be one of the strategies of which skilled designers make heavy use. This paper reports the results of empirical research that investigates design improvement as a result of the use of visual analogy in design problem-solving. After a short review of the literature, we give qualitative and quantitative descriptions of our experiments, with our interpretations of the results and conclusions regarding design education.

ELSEVIER
0142-694X/99 $ - see front matter *Design Studies* **20** (1999) 153–175
PII: S0142-694X(98)00032-5

1 *Expertise and problem-solving; experts and novices*

Differences in skill between novices and experts have been attributed to differences in their representation of knowledge. It is well documented in the problem-solving literature[1–3] that while novices may represent problems or task situations in terms of irrelevant features that do not lead to a correct solution, experts tend to focus on more profound features. As expertise develops, knowledge becomes more structured and better integrated with past experiences, so that it can be retrieved from memory in larger chunks. This has been examined in different domains; for example in studies of chess[4,5] where master players use larger and more meaningful structures of knowledge in encoding chessboard configurations than do novices. The same occurs in other domains like physics and electronics[6], where while experts tend to encode knowledge in terms of functional or more abstract principles, novices who lack such structured knowledge representations focus more on unimportant commonalties.

Some researchers[7,8] have reported that experts have a large domain knowledge base and tend to represent problems qualitatively. Even when solving ill-defined problems, in which the goal may not be clearly defined and possible alternative solutions might be too many, experts are generally aware of what type of relevant knowledge might be useful for solving the given problem.

2 *Ill-defined problem-solving and analogical reasoning*

Reasoning by analogy has been recognized by scientists, philosophers, and psychologists as a mechanism that has the potential to bring forth prior knowledge that can support the acquisition of new information[9]. The use of analogy entails 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*), where at least one of the related elements is not known[10]. An *analogy* is defined as a likeness of relations, as in A:B::C:D, or A is related to B like C is related to D. This implies that there is a higher-order abstraction that holds equally well for A:B and C:D. When establishing correspondences between source and target, the A, B, and C terms are generally given and the D term has to be established[11]. The transfer of knowledge is achieved by analogical mapping, whereby a system of relations concerning central properties is transferred from a base to a target situation [12]. 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.

1 **Anderson, J B** *Cognitive psychology and its implications* (3rd ed) Freeman and Company, New York (1990)
2 **Glaser, R** Expertise and learning: how do we think about instructional processes now that we have discovered knowledge structures? In **Klahr D and Kotovsky K** (eds) *Complex information processing: the impact of Herbert A Simon* Erlbaum, Hillsdale, NJ (1989) pp 269–282
3 **Newell, A and Simon, H A** *Human problem-solving* Prentice Hall, Englewood Cliffs, NJ (1972)
4 **Chase, WG and Simon, HA** 'Perception in chess' *Cognitive Psychology* Vol 4 (1973) pp 55–81
5 **Chi, MTH, Feltovich, PJ and Glasser, R** 'Categorization and representation of physics problems by experts and novices' *Cognitive Science* Vol 5 (1981) pp 121–152
6 **Mayer, R E** *Thinking, problem solving, cognition* Freeman and Company, New York (1983)
7 **Ericsson, K A and Staszewski J J** Skilled memory and expertise: mechanisms of exceptional performance. In **Klahr D and Kotovsky K** (eds) *Complex information processing: the impact of Herbert A Simon* Erlbaum, Hillsdale, NJ (1989) pp 235–267
8 **Medin, D and Ross, B** *Cognitive psychology* Harcourt Brace, New York (1990)
9 **Vosniadou, S** Analogical reasoning as a mechanism in knowledge acquisition: a developmental perspective. In **Vosniadou S and Ortony A** (eds) *Similarity and analogical reasoning* Cambridge University Press, Cambridge (1989) pp 413–437
10 **Vosniadou, S and Ortony, A** (eds) Similarity and analogical reasoning: a synthesis. In *Similarity and analogical reasoning* Cambridge University Press, Cambridge (1989) pp 1–17
11 **Pierce, KA and Gholson, B** 'Surface similarity and relational similarity in the development of analogical problem-solving: isomorphic and nonisomorphic transfer' *Developmental Psychology* Vol 14 No 3 (1994) pp 724–737
12 **Dejong, G** The role of explanation in analogy; or, the curse of an alluring name. In **Vosniadou S and Ortony A** (eds) *Similarity and analogical reasoning* Cambridge University

2.1 Analogy and expertise

The use of analogical reasoning was found to be dependent on skill-related individual differences[13–15]. Results of a number of studies[9,16] indicated that experts' skills in using analogical reasoning differ from those of novices. The level of expertise has been shown to play a role in problem representation, and this factor was recognized in a number of studies to be determinant in the use of analogy[17–19]. When a potential source and a target share surface features, novices tend to generate irrelevant analogies. On the other hand when the source shares structural similarities with the target problem, experts are likely to establish a relevant analogy more spontaneously than novices[15]. Gick and Holyoak[20] showed that when students are not explicitly required to use analogy, they have difficulty in spontaneously using new information that had just been acquired. Other studies[21,22] posited that the evaluation of correspondences between source and target changes as a function of the development of expertise. They argued that novices frequently fail to realize how new situations can be understood in terms of prior situations, and how the importance of identifying relevant features can be associated with recommendations for instructions. Coinciding with this view, Clement[23] reported that although abstract representations seem to facilitate the use of analogy, without expertise in the domains involved such abstract representations may be difficult to form. Contrary to experts, who usually succeed to transfer abstract schemes and are capable of forming context-free structural representations of the domain, novices generally fail to distinguish between representations of relevant concepts and source examples, and thus fail to transfer abstract relations.

2.2 The use of visual analogy in problem-solving

Research in *visual analogy* is almost absent from cognitive science. Exceptions are the studies achieved by Beveride and Parkins[24], and Gick and Holyoak[20], who have investigated the role of visual diagrams in ill-defined analogical problem-solving. Gick and Holyoak concluded that visual representations fail to add any improving effect to problem-solving. However, later experiments completed by Beveride and Parkins and Novick[15] demonstrated that problems related to the way diagrams are represented and interpreted were responsible for the failure. The way problems are represented was also considered a critical element of success or failure in analogical reasoning. Reeves and Weisberg[25] proposed that the identification of abstract representations as potential analogs can be much more effective when such representations are accompanied by specific examples that clarify how they might be used.

2.3 Visual analogy in design problem-solving

In the early stages of the design process, analogy and particularly visual analogy are seen as a helpful cognitive strategy for enhancing design

Press, Cambridge (1989) pp 346–365

13 Collins, A and Burstein, M Afterword: a framework for a theory of comparison and mapping. In **Vosniadou S and Ortony A** (eds) *Similarity and analogical reasoning* Cambridge University Press, Cambridge (1989) pp 546–565

14 Goldman, SR, Pellegrino, JW, Parseghian, P and Sallis, R 'Developmental and individual differences in verbal analogical reasoning' *Society for Research in Child Development* Vol 53 (1982) pp 550–559

15 Novick, LR 'Analogical transfer, problem similarity, and expertise' *Journal of Experimental Psychology: Learning Memory, and Cognition* Vol 14 No 3 (1988) pp 510–520

16 Brown, A L Analogical learning and transfer: what develops? In **Vosniadou S and Ortony A** (eds) *Similarity and analogical reasoning* Cambridge University Press, Cambridge (1989) pp 369–411

17 Daheler, MW and Chen, Z 'Protagonist, theme, and goal object: effects of surface features on analogical transfer' *Cognitive Development* Vol B No 2 (1993) pp 211–229

18 Marchant, G, Robinson, J, Anderson, U and Schadewald, M 'The use of analogy in legal argument: problem similarity, precedent and expertise' *Organizational Behaviour and Human Decision Processes* Vol 55 (1993) pp 95–119

19 Schiano, DJ, Cooper, LA, Glaser, R and Zhang, HC 'Highs are to lows as experts are to novices: Individual differences in the representation and solution of standardized figural analogies' *Human Performance* Vol 2 No 4 (1989) pp 225–248

20 Gick, ML and Holyoak, KJ 'Analogical problem-solving' *Cognitive Psychology* Vol 12 (1980) pp 306–355

21 Bransford, J D, Franks, J J, Vye, N J and Sherwood, R D New approaches to instruction: because wisdom can't be told. In **Vosniadou S and Ortony A** (eds) *Similarity and analogical reasoning* Cambridge University Press, Cambridge (1989) pp 470–497

22 Needham, DR and Begg, IM 'Problem-oriented training promotes spontaneous analogical transfer: memory-oriented training promotes memory for

problem-solving. The reason is likely to be related to the observation that designers are in the habit of availing themselves of rich assortments of visual displays during the process of designing. Goldschmidt[26,27], who has been studying the use of visual analogies in design, has pointed out that in the search process the designer may identify displays as candidate source analogs and establish mappings through structural or surface relations. There are a number of anecdotal examples in the design literature of master architects using successful analogies to illustrate this claim. Among the most prominent cases we can cite Le Corbusier, who made frequent use of various objects as sources (an ocean liner, a bottle rack, a crab shell and many more) and Calatrava, whose sources are to be found primarily in nature (i.e. animal skeletons or tree branches). However, beyond these and other anecdotal examples we have no evidence of the role of analogy in designing. Moreover, we do not know if designers who are less accomplished than, say, Le Corbusier or Calatrava, use similar analogical design strategies. To assess these questions, we have undertaken the empirical research plan which is described in the following sections.

3 Empirical research

The empirical research is based on qualitative and quantitative analyses of architectural design problem-solving episodes, as reported below.

3.1 Objectives and hypotheses

The main objective of the empirical study is to verify to what extent the use of visual analogy helps novice and expert designers to improve design problem-solving. We would like to know whether all designers, as opposed to a group of top 'great names' that make it into the professional literature, use analogical reasoning and whether this strategy, if used, contributes to the quality of their work. In addition we would like to know whether expertise is related to the use of analogical reasoning, and if so, in what way.

Our major hypotheses are that an explicit requirement to use analogy, when visual displays from which source analogs can be drawn are given, leads to an improvement in the quality of design performance. We further hypothesize that such improvements are more significant in the case of novice designers, as compared to experienced ones.

3.2 Description of the empirical research

3.2.1 Subjects

61 architectural designers participated in the experiments conducted in this study. They belong to three groups representing different levels of

training' *Memory and Cognition* Vol 19 No 6 (1991) pp 543–557

23 Clement, CA 'Effect of structural embedding on analogical transfer: manifest versus latent analogs' *American Journal of Psychology* Vol 107 No 1 (1994) pp 1–38

24 Beveridge, M and Parkins, E 'Visual representation in analogical problem-solving' *Memory and Cognition* Vol 15 No 3 (1987) pp 230–237

25 Reeves, L M and Weisberg, R W 'On the concrete nature of human thinking: content and context in analogical transfer' *Educational Psychology* Vol 13(3 and 4) (1993)

26 Goldschmidt, G Visual analogy in design. In **Trappl R** (ed) *Cybernetics and systems '94*. World Scientific, Singapore (1994) pp 507–514

27 Goldschmidt, G Visual displays for design: imagery, analogy and databases of visual images. In **Koutamanis A, Timmermans, H and Vermeulen I** (eds) *Visual databases in architecture* Avebury, Aldershot (1995) pp 53–74

professional experience. The first group, counting 17 subjects, consisted of experienced designers: all architects with at least seven years of experience. The second group included 23 advanced architecture students, in their third, fourth or fifth year of undergraduate studies. They were seen as possessing a moderate amount of experience. The third group of subjects was made up of 21 beginning architecture students, in their first or second year of undergraduate studies. Most subjects engaged in more than one experimental exercise (see below). All subjects were volunteers who received neither payment nor course credit in return for their participation.

3.2.2 *Experiments*

Two experimental conditions in which individual subjects were asked to solve design problems were enacted as follows:

Test condition: Solving design problems with visual displays provided and with explicit requirement to use analogy.

In this condition, subjects were given a design problem and a task sheet containing general instructions. In addition they were provided with a rich assortment of visual displays and were told that part of the graphic material may be used as potential source(s) for analogy. The displays consisted of a rich assortment of pictorial material, presented for each problem on a 1.00 × 0.70 m panel. On average, each panel included two dozen displays. They included images from the architectural design domain, to which the problems belong (within-domain sources), as well as images from remote domains (between-domain sources) like art, engineering, nature and science. ‘Dummy’ images from within or between domains that were not related to the task were also included in the panel. The subjects were required to identify relevant visual sources and use analogy to help themselves solve the design problems they were given.

Control condition: Solving design problems with visual displays provided but without explicit requirement to use analogy.

In the control condition, the same design problem and general instructions were given to subjects who were also provided with identical visual displays as in the test condition. However, subjects were not asked, or encouraged, to use analogy.

Three different design problems were developed: ‘The Prison’; ‘The Viewing-Terrace’ and ‘The Dwellings.’

3.2.3 *Procedure*

The experiments were carried out in design sessions with individual subjects. Each session was devoted to one or more design problems, each lasting 10–15 min. The subject was given approximately 3 min to read the problem and the general instructions. He or she was then requested to think aloud as the session was video-taped (the camera was pointed at the work-surface and registered the sketches made by the subject). The experimenter answered questions but did not intervene during the session, except to remind subjects to verbalize their thoughts if they were silent for longer than a few seconds. A signal was given 3 min prior to the end of each session. It is important to note that since most subjects solved more than one design problem under the test or the control condition (with or without a requirement to use analogy), the number of statistical 'entries' exceeds the number of subjects. In each individual case, exercises in the 'control condition' always preceded exercises in the 'test condition'.

3.2.4 Assessment: design ideas and design solutions

Design performance was assessed according to the quality of design ideas and design solutions. In this study, a design idea is understood as a schematic or abstract representation of a design thought, and a design solution is conceived as a concrete representation of a design output.

3.2.5 Scale of assessment

An ordinal scale from 1 to 5 points was established to assess the quality of the design ideas and design solutions. A score of 1 or 2 points was assigned when the design idea or design solution did not satisfy the design requirements. A score of 3–5 points was assigned when the design idea or design solution was perceived as satisfying the design requirements.

3.2.6 Judges

The design outputs obtained from the various design sessions (sketches on the sheets provided to the subjects) were scored independently by three naive judges, all experienced architects who volunteered their time. They were provided with a set of randomly ordered photocopies of the subjects' sketches, which were coded to protect subjects' identity. A reliability analysis manifests a low disagreement rate (average of 3%) among the three judges in the assessment of the design ideas and solutions.

3.2.7 Statistical analysis methods

To test our hypotheses, the scores assigned by the judges were submitted to t-tests for statistical analyses. Differences between subject groups were considered significant at a level of 90% ($p = 0.1$). For statistical analysis reasons, the three design problems ('The Prison', 'The Dwellings', and 'The Viewing-Terrace') were grouped together, and the sum of their respective scores was calculated for each group of subjects.

4 Novices: qualitative results

In this section we show how successful and unsuccessful design solutions by novices can be seen as resulting from the use, misuse or lack of use of analogy. We do so by presenting one successful example and one unsuccessful example of solutions to the 'Viewing Terrace' problem. The problem called for the schematic design of a 30 m^2 viewing terrace at the top of a 16 m high precipice. The terrace was to be divided into two parts: one part had to have maximum contact with the ground, whereas the other had to have minimum contact with the ground. The problem solvers were two students who were given explicit instructions to use analogy, and the descriptions are derived from protocols based on the recordings that were made during the experiment.

4.1 Successful design problem-solving as a function of the use of deep analogies

The design session started with the student familiarizing himself with the problem. Consequently he contemplated the visual displays and noticed in particular one display that appeared to deal with the principle of digging into the ground. The displays this student commented on (and later referred to) are shown in Figure 1. At the outset, the student says:

> First, I would like to look at the pictures and think... I check everything, only afterwards I will stop [looking] at things [displays]. There are several elements of landscape design that are involved in digging into... into a place and go out of it [Figure 1(a)]

The next major step, before the student can map relationships from a source to his target problem, must be the identification of similarities that can potentially serve the purpose of establishing an analogy. Fruitful analogical reasoning depends on the identification of similarities of relationships, in the first place, and on the nature of such similarities. Deep similarities are likely to lead to success, whereas surface similarities may lead to failure. Our novice student scanned the displays and focused his attention on a number of displays, as follows:

> Mmmm...first of all the way that the water streams out [Figure 1(b)], and somehow the tree, in which a part of it is suspended in the air, and part of it is in contact with the ground [Figure 1(c)]... Those are the things that I am able to recognize...the rest [of the displays] are difficult for me to recognize. There is a spiral building that enters [Figure 1(d)]. There is also a siphon [Figure 1(e)]...

Principles dealing with the concept of 'digging into a place' are noticed here, like the tree roots and the spiral. But at this stage other displays, too, are still being investigated regarding their possible utility. The student continues to work and makes a sketch that illustrates his understanding of the site, and refers to the principle of penetrating the ground but also

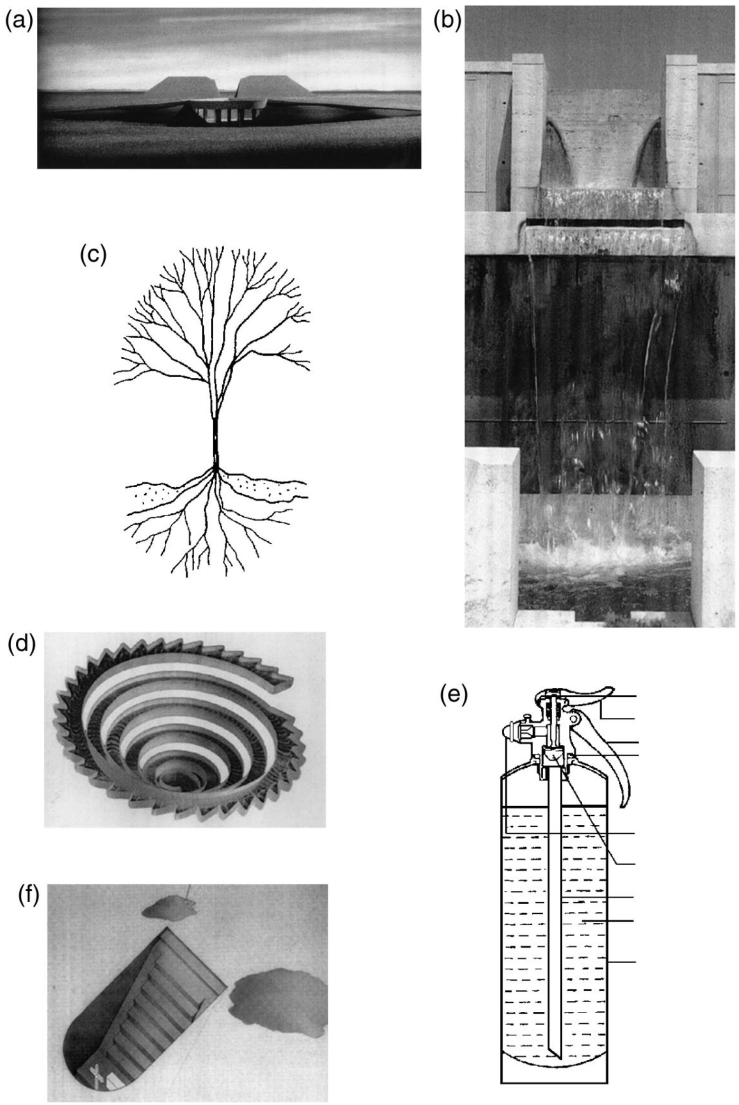

Figure 1 Displays for the 'Viewing Terrace' problem, set #1. (a) Protrusions of underground house by Emilio Ambasz; (b) water spout; (c) tree with exposed roots; (d) downwards spiral; (e) syphon bottle; (f) stairs into the ground

protruding above it. His sketches are reproduced in Figure 2. While sketching he says:

Now I will try to look at the site itself and see what I [can] do... The objective is to...that part of the place will be in maximum contact with the ground, and part will be detached from the ground [minimum contact with the ground]... Well, if I look at these forms [visual displays] here... there is an option to penetrate inside the ground... For example in this place...there is a sort of tomb with staircases that penetrate inside [the ground]... [Figure 1(f)] Or...covered shelter, which in fact it is an idea that I can Mmmm...really enter within the ground and only then, go out of it.

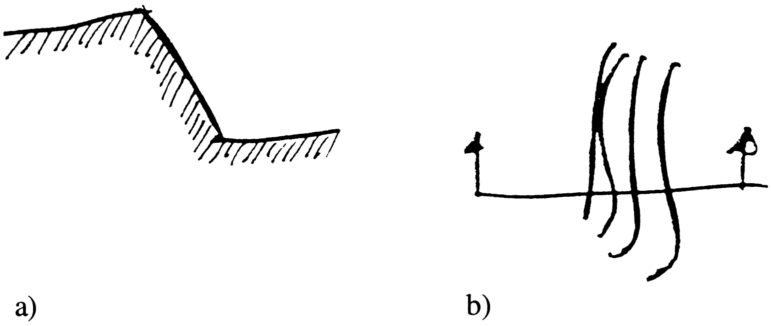

Figure 2 Sketch I by novice student 1 (successful solution). (a) Section; (b) diagram ('digging into... coming out again')

At this stage the student has sorted out the displays; the useful ones remain active in his working memory, whereas the others fade out. He makes a new sketch (plan and section, Figure 3), explaining that his design calls for a descent into an underground passage that leads to a protruding viewing terrace. This solution responds to the design requirement of maintaining maximum and minimum contact with the ground in different parts of the designed area:

I would think about a form [Figure 3]...that I take from here [Figure 1(f)], a form of staircases that penetrate inside the ground, and afterwards they stand out of it... and perhaps they have no contact with the ground.

The student has successfully completed the transfer and mapping of the relationship between underground and above-ground elements from a source analog to his target problem. A few points regarding this process deserve our attention. First, whereas the decisive display that turned out to become the source, the stairs to an underground tomb, belongs to the category of within-domain displays, other, between-domain displays, helped lead to the final establishing of the analogy: the tree, the spiral. Second, the process was not linear, by which we mean that the student did not start by defining precise goals, then choosing a suitable source analog and finally producing a solution. Due to the ill-defined nature of the

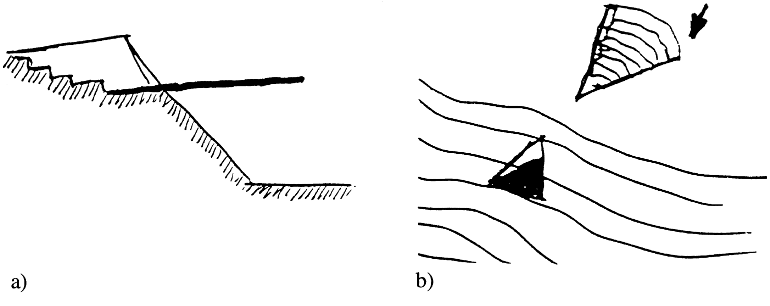

Figure 3 Sketch II by novice student 1 (successful solution). (a) Section; (b) plan

problem, he first considered a fairly large assortment of candidate sources, which he later sorted out while defining his goals, which led to the narrowing of his choices to an appropriate source. Finally, we notice that what the student transferred was a deep similarity of relations (inside–outside, relative to the ground), and not surface ones, like stairs alone, for example. It is therefore not surprising that this student has successfully solved the problem (his average score was 4.16).

4.2 Unsuccessful design problem-solving as a function of the use of surface analogies

As in the previous case, this student, a novice, starts by contemplating the displays and picking a few, illustrated in Figure 4, that she refers to specifically:

> So what is the relationship [between the visual sources and the problem]...? In [display] number five [Figure 4(a)] there is a relation between the air [oxygen] contained in the lungs and the air from the exterior. So the relation [to the problem] regards the surface of contact, which is very small... In contrast to this... for example the water contained in the toilet [Figure 4(b)] has a large surface of contact... They

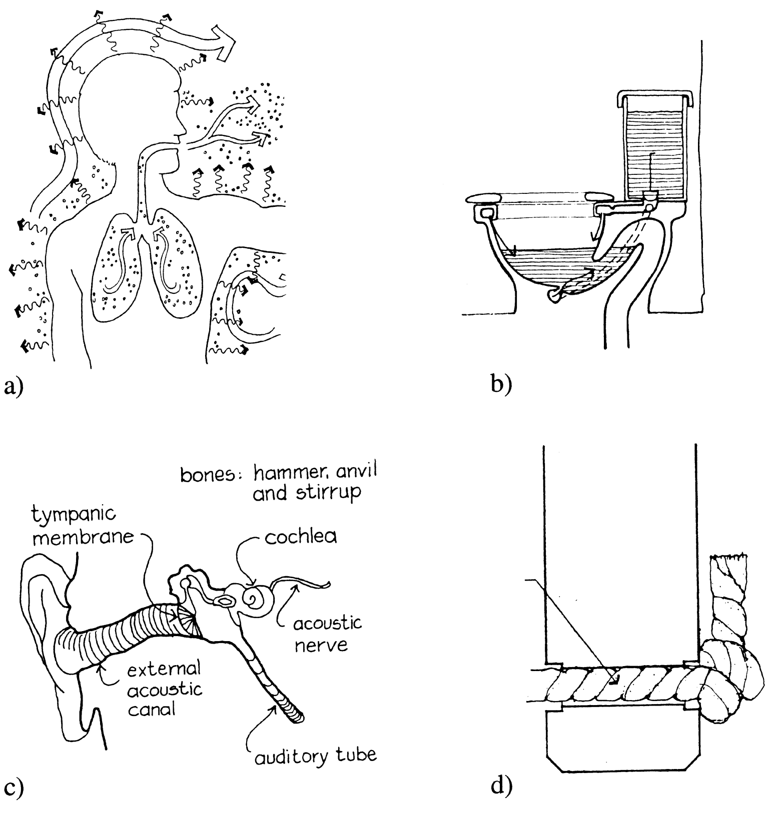

Figure 4 Displays for the 'Viewing Terrace' problem, set #2. (a) Respiratory and perspiration systems; (b) toilet with water tank; (c) ear; (d) rope threaded through hole in wall

[external water deposit and the toilet] are connected through a pipe, aren't they? Something that relates them but..., but not in a dominant way.

She goes on to identify more candidates for source analogs:

Now there is an ear [Figure 4(c)]. It is an ear, it seems to me?... Regarding the ear, there is an external part and there is an internal part. In a way they are related,... but related in a very, very delicate way. The relationship between them is very Mmmm... it is not bringing a...

The student realizes that she has not succeeded in finding a meaningful (deep) similarity. She continues to seek help in the displays, while producing the sketch that is reproduced in Figure 5.

In [display] number nineteen [Figure 4(d)] I am not quite sure what I am seeing but Mmmm...But I am sure that there is a twist relation, which means that you do not get back what you put inside. There is a sort of transformation. I don't know...[Display] 16 is a tree [Figure 1(c)]. It is as if it reflects on itself..., but on one side it is something external and on the other side it is internal... I don't know what is the common shared principle! It seems to me that they [people] can pass through it, in a way it is connected with the entrance. And the second part that is more related to the view [from the terrace], and has minimum contact with the ground. And it seems to me that perhaps the relationship between them [both parts of the viewing-terrace] should be according to the principle that I think it is...shared by part of the displays, the relationship between the two parts can be...smaller. There is no need for such clear and strong relationship.

Interestingly, this student is aware of the fact that she does not 'know what is the common shared principle,' which does not permit her to map any relationships from the various source candidates to the target problem. But unlike the previous, more successful student who continued to scrutinize the images at his disposal until a suitable one was found, this student gave up and decided to renounce the use of analogy: 'there is no need for such a clear and strong relationship.'

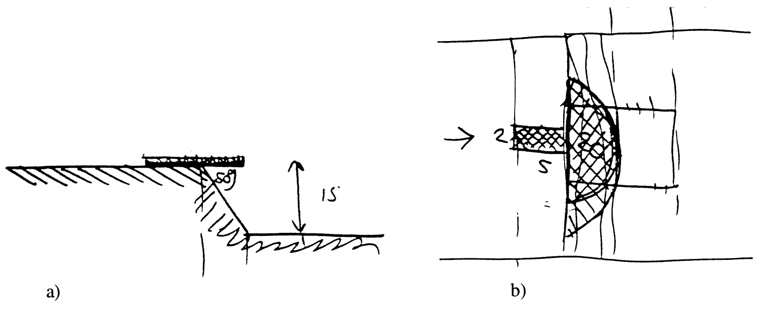

Figure 5 Sketch I by novice student 2 (unsuccessful solution). (a) Section; (b) plan

The student scored low on this exercise (average score: 2.00). Among others, we attribute her weak performance to her inability to take advantage of analogical reasoning. Possibly due to lack of experience, she did not detect useful correspondences between source and target, and identified only surface similarities, or plain wrong ones like 'a twist relation' suggested by a rope going through a wall [Figure 4(d)]. It is assumed that stronger domain (architectural design, in this case) knowledge structures could have possibly led to the identification of high-order relations[28], which in turn could have enabled analogical knowledge transfer. But as we learn from the first problem-solving account reported in section 4.1, which describes a successful process of analogical reasoning process by a novice designer, success or failure in this respect is not entirely dependent on experience. We measure the differences between our two novice groups, beginning and advanced students, in the next section.

5 *Novices: quantitative results*

In this section statistical results and conclusions regarding the use of visual analogy are presented for the two novice (student) groups. According to our hypotheses (section 3.1), it is expected that the quality of design ideas and design solutions by novices who are explicitly instructed to use analogy would be higher than those who are not explicitly instructed to use analogy.

In order to test this hypothesis, an experiment was conducted in which the performance of novices (23 exercises by beginning and 27 by advanced students) who received instructions to use analogy is compared to the performance of students in the control condition. In the control condition subjects (22 exercises by beginning and 22 by advanced students) received the same tasks under similar circumstances (exposure to the same visual displays), but did not receive instructions to use analogy. The work of each student on each problem was assessed twice: once for the design idea, and once for the design solution. Tables 1 and 2 give the results of comparisons between the test condition and the control condition for these two assessments (see section 3.2 for the method used).

28 **Gentner, D** 'Structure-mapping: a theoretical framework for analogy' *Cognitive Science* Vol 7 (1983) pp 155–170

Table 1 Novices: quality of design idea as a function of receiving instructions to use analogy (A.R—explicit requirement to use analogy; D—provision of visual displays)

Experimental conditions				*Beginning students*			*Advanced students*		
D	A.R	D	A.R	P	F	M.D	P	F	M.D
Yes	No	Yes	Yes	< 0.001	3.14	0.863	< 0.001	3.23	0.876

Table 2 Novices: quality of design solution as a function of receiving instructions to use analogy (A.R—explicit requirement to use analogy; D—provision of visual displays)

Experimental conditions				*Beginning students*			*Advanced students*		
D	A.R	D	A.R	P	F	M.D	P	F	M.D
Yes	No	Yes	Yes	< 0.002	2.95	0.822	< 0.006	2.60	0.714

As Tables 1 and 2 show, the prediction that giving explicit instructions to use analogy when visual displays are provided results in improved design problem-solving by novice designers, was fully confirmed. These findings are in line with research that affirmed that the effectiveness of the use of analogy in problem-solving is increased when guidance is provided[15,20,28,29]. The present findings differ from previous ones in that we concentrate on visual analogy only, which is believed to be of paramount importance in tasks that require visual representation (such as drawings in different domains). In further experiments, not reported here, we added an experimental condition in which the visual displays were omitted. The results indicate that visual displays contribute to the quality of design problem-solving, albeit in different measures for different groups of designers. These results validate earlier studies that state that the design process is characterized by a broad use of images and pictures[26]. The activation of visual analogy is obviously related to visual displays of one sort or another, and we may conclude that analogical reasoning, in the visual modality, appears to be a successful cognitive strategy in design problem-solving. Giving explicit instructions to use analogy, in the case of novice designers who have not yet developed strong knowledge structures and strategic ‘rules of thumb’, results in better design ideas and solutions. This is consistent with Vosniadou[9], who claims that although the use of analogy is critically limited by the information included in the problem solver’s knowledge base, analogical reasoning can act as a mechanism for modifying and restructuring the knowledge base itself.

Before we discuss the possible implications of these findings for design education, we need to check whether expertise affects the patterns of design performance regarding the use of visual analogy. In the next two sections we therefore turn our attention to experienced architects.

29 **Gentner, D** The mechanisms of analogical learning. In **Vosniadou S and Ortony A** (eds) *Similarity and analogical reasoning* Cambridge University Press, Cambridge (1989) pp 199–239

6 *Experts: qualitative results*

The individual design processes that we describe in this section are taken from protocols, based on recordings that were made during experimental design sessions with experienced architects. In the cases below, the designers solve the ‘Prison’ problem. The requirement was to provide a schematic floor plan for a single-storey jail, containing 80 cells. At least one wall of each cell had to be exposed to the exterior. In addition, different functions and areas, including prisoner and guard facilities, had to be located in a way that allows guards to easily control the inmates. The experimental settings were similar to those described for novices—visual displays were provided and the subjects were explicitly asked to use analogy in their problem-solving processes.

6.1 Successful design problem-solving as a function of the use of deep analogies

The subject in this session was an architect who started by scanning the displays and choosing to relate to a small number of them, all within-domain images, as reproduced in Figure 6.

Shortly after having scrutinized the panel, the architect questions the utility of the displays:

In reference to the design problem... it’s a problem of packing. These are drawings that I am familiar with. These are drawings from town planning, which pack different

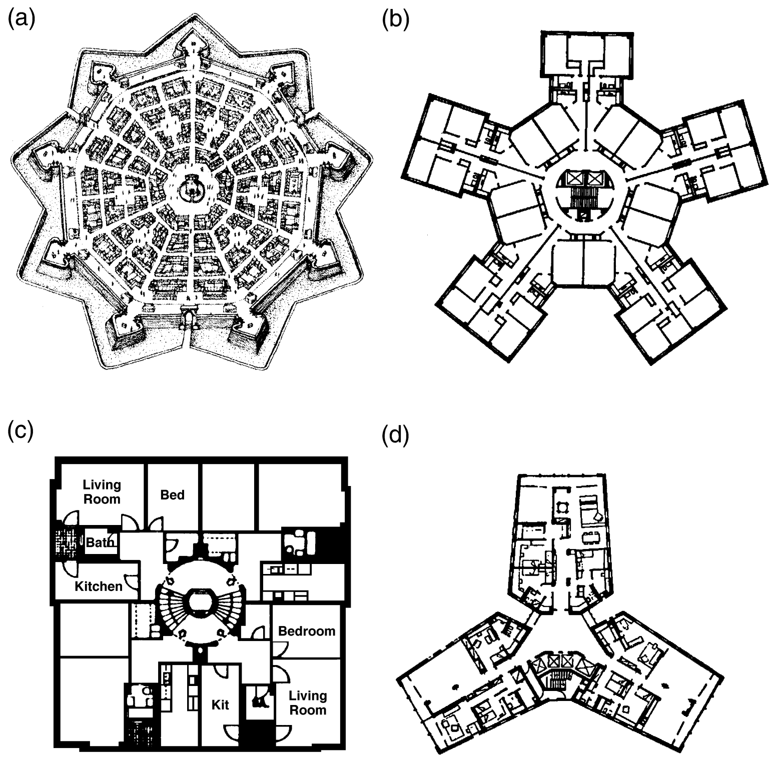

Figure 6 Displays for the ‘Prison’ problem, set #1. (a) Plan of fortified medieval city; (b) floor plan, star-shaped building; (c) floor plan, square building; (d) floor plan, triangular building

functions, Mmmm... in a compact manner. I don't know... how can it [Figure 6(a)] help me to solve the prison problem?...

He goes on to examine other displays, looking for properties that might be relevant to his target problem:

There are... there are some schemes [displays], for example the schema of the star [Figure 6(b)] which without considering functional aspects, seems to be a relevant schema. It can provide an answer to the problem of the prison... it allows a correct packing around a central area. It has a larger external perimeter than for example the city... [Figure 6(a)]. And... also in my opinion... the schema that relates to a square [Figure 6(c)] has a small external perimeter, and therefore cannot provide any answer to the problem. Perhaps... [I would select this] [Figure 6(d)].

A discriminating criterion has been selected: a long perimeter, which was conceived as necessary in order to satisfy the requirement that calls for one free wall per cell. The architect is now ready to add another criterion—cell organization:

But regarding the type of problem we have to solve, if we had to choose between [this display] [Figure 6(d)] and [that display] [Figure 6(b)], I would prefer [Figure 6(b)] because it provides better possibilities to organize the 80 cells... It allows the organization of [cells into] small clusters; the other schema [Figure 6(d)] generates bigger clusters. The fact that you [guards] can look at [prisoners]... in my opinion, is like if it produces a better feeling or better control over everything.

At this point the subject feels that he has established sufficient correspondence between the source displays and his design problem to concentrate on a single image which would, from that point, serve as an only source. So much so that the selected display almost becomes a model, which the architect now develops into his solution. He makes a sketch [Figure 7] and continues working:

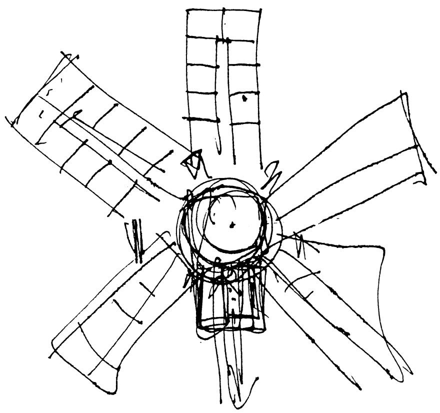

Figure 7 Sketch I by architect 1 (successful solution)

I will try to formalize it [Figure 7]. This means that if we choose to design five main areas... so how many [cells] do we have [in each branch]? Sixteen [cells] allocated in each branch means eight cells facing each side, which seems to be a possible option... Let's try the principle [of Figure 6(b)] say 8 cells allocated in each side, with a corridor here [in the middle]... In this way we can complete it and obtain a star.

The subject has transferred and mapped the (deep) structural relations between the five wings of the residential 'star' and its common center to the prison plan. This takes care of the two major design requirements, namely control and exposure to the outside. The experienced architect has also made some calculations, while producing his version of the star plan, in order to make sure that the right number of cells is accommodated in his proposed plan. But his experience leads him to add an additional requirement, one that was not included in the task sheet, but which he deemed essential: a lateral entrance to the core area:

It is clear that the star should be modified in order to generate an (external) entrance to this (central) area.... if we could develop an entrance here... we would be able to solve it. Yes, I think that it's good! It can be appropriate... That's it, the star [organization] allows the packing of the prison.

Interestingly, the architect did not, in this respect, adhere to the source which provides access to the core area via central stairs and elevators. By adding an entrance block the architect showed himself capable of using analogical reasoning which calls for transformations of a within-domain source analog, and adapting it to fit the problem requirements (entrance to a single storey building). This cognitive process differs from one in which an individual indiscriminately follows a model. The solution was seen by the judges as successful and scored 4.8 on the average.

6.2 *Unsuccessful design problem-solving as a function of the use of surface analogies*

The second architect started, as did every other subject, by scanning the displays and trying to discover in them a clue that bears resemblance to the problem at hand. The displays he referred to are illustrated in Figure 8:

The pictures and the drawings are clear to me. There is a group [of examples] with central points. It is difficult to see the central point in the symbol of 'Shell' [Figure 8(a)] which is not symmetrical. Despite some variations... [in the] building... [Figure 8b] there is still something more or less centralist... a center that partially reminds the 'Shell' symbol. Well... [Figure 8(c)] is similar to [Figure 8a]... in that both of them are not symmetrical. The [position of the] center changes in the snail [Figure 8(d)]. The clock [Figure 8(e)] has a similar form. Also in [Figure 8(f)], [and] in the plate [Figure 8(g)], in [this plan] [Figure 6(d)], in the windmill [Figure 8(h)], and in the plan of the town [Figure 6(a)] the center is very clear.

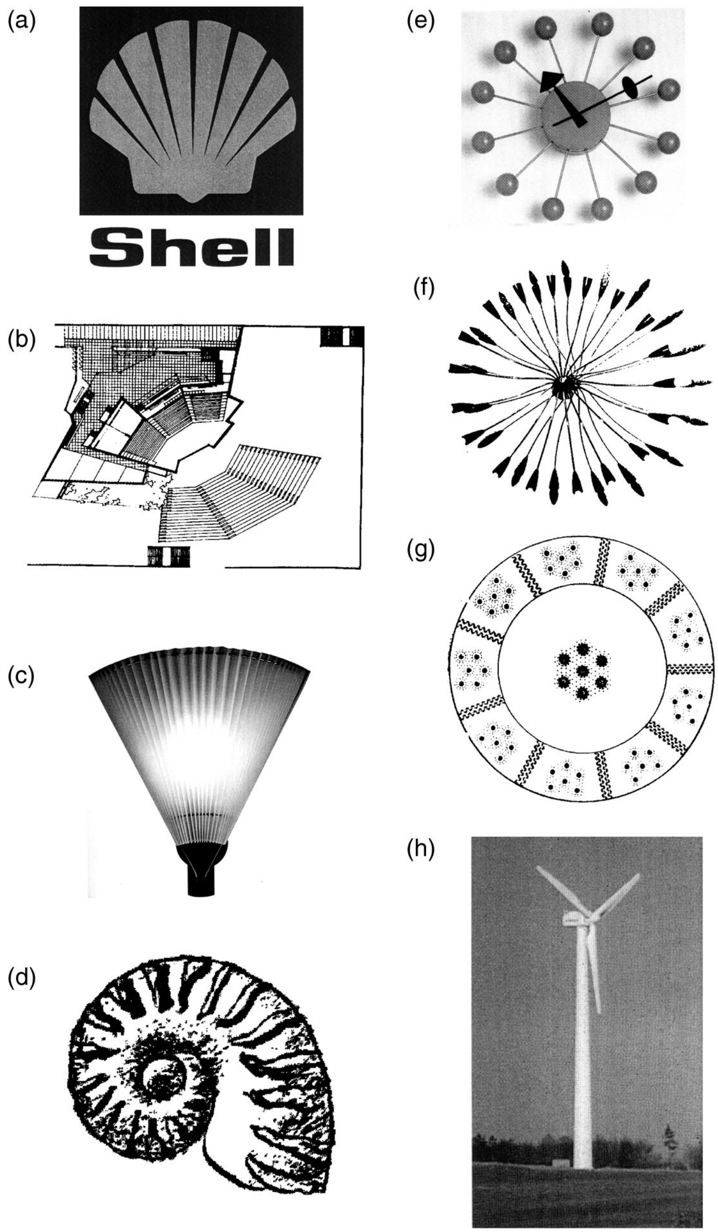

Figure 8 Displays for the ‘Prison’ problem, set #2. (a) ‘Shell’ company logo; (b) theater plan by Alvar Aalto; (c) standing lamp; (d) snail; (e) clock; (f) chandelier; (g) plate; (h) windmill

Interestingly, this architect focuses almost exclusively on between-domain displays such as a snail, a clock or the ‘Shell’ company logo. They are chosen because they share one property: all have a marked center point. Without asking himself, at least not explicitly, why this is relevant to the prison problem, the architect starts sketching. His first sketch, reproduced in Figure 9, does not appear to be influenced by the displays or by his attention to the center point they share.

While drawing, the subject explains what he is doing:

Now we will try to generate a division into eight [main] clusters... [A, Figure 9]. Each of them will allocate ten cells. How can we allocate the guards? Suppose we put the bathrooms here [B, Figure 9]... Each couple [of clusters] will have one bathroom... If we could enlarge the clusters here Mmmm... [C, Figure 9], we could allocate the block of the guards [D, Figure 9] and provide exits to the exterior.

The subject is not satisfied with his plan and starts afresh. He makes a second sketch (Figure 10) in which the cells are arranged in five clusters around a central area, which proves to be too large:

Well... we can try another alternative. We can have sixteen cells [Figure 10]... Here we have the second cluster... the third cluster, the fourth and the fifth cluster. I think that this [central] space will be too big, and we should reduce it... it is not clear yet how could we arrange them.

In order to reduce the large central space, the subject tries to modify the local organization of the cells (sketches and verbalizations are not presented here), but realizes that the new arrangement conflicts with the outside exposure requirement. The exercise ends with a poor outcome: the

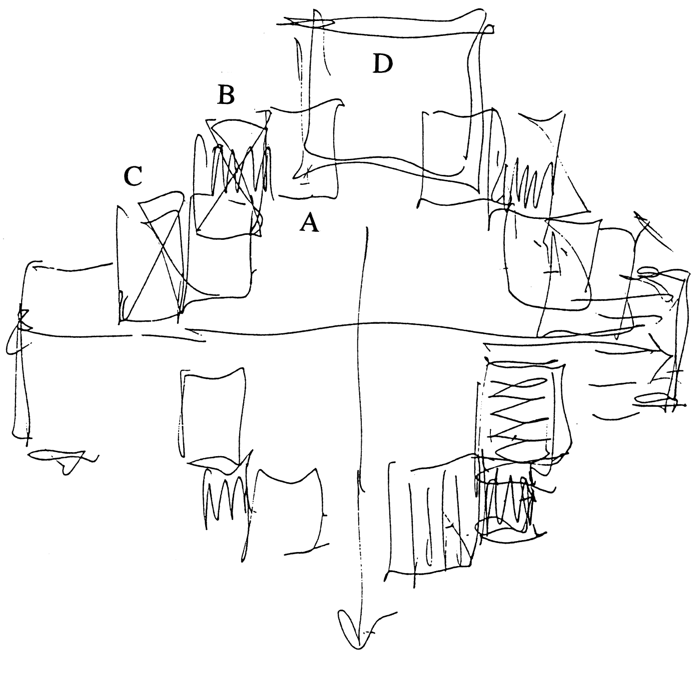

Figure 9 Sketch I by architect 2 (unsuccessful solution)

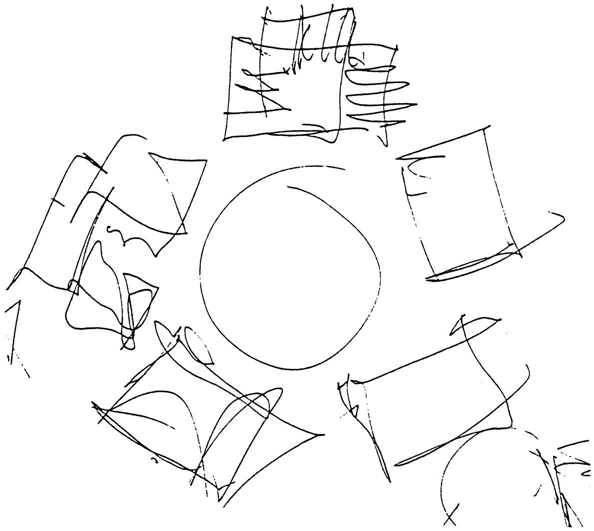

Figure 10 Sketch II by architect 2 (unsuccessful solution)

average score was 3.5. We attribute the relative failure to this architect's inability, or unwillingness, to transfer deep relations from a source, or several sources, to the target problem. He picked a surface property—a center point—as the lead for similarity. This could not work because the target plan could not have a center point; rather it had to have a central area. Since other design requirements were ignored, the central area became too large and turned into an obstacle (wasted space), and no analogical mapping of relations could occur.

7 *Experts: quantitative results*

As in the case of novices (section 5), this section presents statistical results and conclusions regarding the use of visual analogy by expert designers. According to our hypotheses (section 3.1), it is expected that the quality of design ideas and design solutions by experts who are explicitly instructed to use analogy would be higher than those who are not explicitly instructed to use analogy.

To verify our expectation, an experiment, similar to the one described in section 5 (with novice designers) was carried out. In the test condition 21 exercises were produced by architects and in a control condition, architects achieved 19 exercises. Each participant received the same design task(s) and was exposed to the same visual displays. The results were evaluated by judges who scored them for design ideas and design solutions. In the test condition subjects were explicitly asked to use analogy whereas in the control condition they were not asked to use analogy. Tables 3 and 4

Table 3 Experts: quality of design idea as a function of receiving instructions to use analogy (A.R—explicit requirement to use analogy; D—provision of visual displays)

Architects				*Experimental conditions*		
D	A.R	D	A.R	P	F	M.D.
Yes	No	Yes	Yes	= 0.000	3.98	0.871

Table 4 Experts: quality of design solution as a function of receiving instructions to use analogy (A.R—explicit requirement to use analogy; D—provision of visual displays)

Architects				*Experimental conditions*		
D	A.R	D	A.R	P	F	M.D.
Yes	No	Yes	Yes	< 0.002	3.03	0.623

summarize the comparison between the test and the control conditions for design ideas and design solutions.

As Tables 3 and 4 show, the judges found significant differences between the performance of architects who were and were not asked to use analogy. The design problems with which the architects dealt in this experiment were not particularly complex, and it is highly likely that given sufficient time, and the possibility to engage in a long search-cycle, all architects would have arrived at a satisfactory solution. But in this experiment they had only a very short amount of time to arrive at results (approximately a quarter of an hour), and therefore the experiment tests how well they perform when only a short search-cycle is possible. In our view this is an important point that touches on the question of 'cognitive economy.' A characteristic of expertise that we cannot expect in the performance of novices is, that experts are able to use strategies that 'mobilize' knowledge retrieved from memory so as to quickly solve problems, at least when they are not particularly complex, or novel. The use of analogy appears to be one of these strategies and as our results show, it does indeed serve this purpose.

8 Novices versus experts

In the analyses presented thus far, we tested the effect of instructions to use analogy on design quality within peer groups, i.e. designers of the same level of experience. We would now like to look at differences between groups that received the same instructions regarding the use of analogy, but who differ in the amount of experience they possess. As in the previous analyses, we repeat the tests for design idea and design solution scores. The results are reported in Tables 5 and 6.

These results are of great interest because they indicate that whereas there is a marked difference between the quality of design ideas and solutions produced by architects and beginning students who use analogy, no significant differences are found between the performance of advanced students and the two other designer groups. We take this finding to mean that a considerable amount of experience is required before a designer masters the cognitive strategies that enable him or her to perform productively in an 'economical' manner, i.e. engaging in the shortest possible search-cycle. This may explain why the training of architects tends to take longer than that of other professionals. Obviously, the search-cycle length depends on several variables other than the designer's experience, such as the problem solver's thinking style and talent, but also the nature of the problem, its novelty etc. But whereas variables related to the nature of the task and the innate characteristics of the designer are beyond our control, the mode in which experience is gained during the architectural education process can and should be within our control, indeed, our direct responsibility.

Table 5 Quality of design idea as a function of expertise (A.R—explicit requirement to use analogy; D—provision of visual displays)

Experimental condition		*Advanced vs architects*			*Beginning vs architects*			*Beginning vs advanced*		
D	A.R.	P	F	M.D	P	F	M.D	P	F	M.D
Yes	Yes	< 0.168	0.97	0.209	< 0.018	0.75	0.541	< 0.108	1.25	0.331

Table 6 Quality of design solution as a function of expertise (A.R—explicit requirement to use analogy; D—provision of visual displays)

Experimental condition		*Advanced vs architects*			*Beginning vs architects*			*Beginning vs advanced*		
D	A.R.	P	F	M.D	P	F	M.D	P	F	M.D
Yes	Yes	< 0.100	1.30	0.289	< 0.032	1.91	0.499	< 0.228	0.75	0.210

9 *Implications for design education*

Experience and knowledge in a specific field are general pre-conditions for the development of expertise[30,31]. Expertise includes the mastery of acquired problem-solving methods as well as fluency in the use of relevant generic cognitive strategies in a particular domain or type of task. Analogical reasoning belongs to the latter in ill-defined problem-solving; visual analogical reasoning is particularly suited to designing—a par excellence example of ill-defined problem-solving.

In every domain, the accumulation of knowledge and the practice of methods require training. Cognitive strategies, on the other hand, are at the problem solver's disposal as the first steps of professional training. However, novices are usually not aware of their utility in the process of solving problems. Architectural design education is founded on the acquisition of design skills through repeated exercising, largely based on trial and error or, in a typical studio situation, on trial and feedback. The experiments reported in this paper show that instructions to use a fruitful strategy like visual analogy allows even novices to significantly improve their performance. Novice designers do not need to be taught how to use analogy: they already have this cognitive capacity. They do need, however, to be shown how and why it can be helpful to harness this ability for successful design problem-solving.

The use of analogy requires the identification of abstract knowledge structures that correspond to the similarities between known and unknown situations[32]. The successful results obtained in our experiments suggest that the generation of new relevant structures through the use of visual analogy can provide a basic mechanism to develop skills in design problem-solving. According to Goldschmidt[33] the structuring of a design problem through transformations, the ability to make long interrelated chains of moves (larger knowledge chunks retrieved from memory) and the capacity to identify clues are some of the skills of the expert designer. The use of analogy supports these skills. In the architectural studio it is possible to show how the use of analogy enhances these skills. It is believed that students who understand how analogical reasoning serves their design processes can, over time, learn to appropriate and master this strategy with or without explicit instructions to do so.

Acknowledgments

This paper is largely based on Hernan Casakin's Doctoral dissertation *The role of analogy and visual displays in architectural design*, supervised by

30 Dominowski, R L Productive problem solving. In **Finke, R A, Ward T B and Smith, S M** (eds) *The creative cognition approach* MIT Press, Cambridge, MA (1995) pp 73–95

31 Finke, R A, Ward, T B and Smith, S M *Creative cognition: theory, research and application* MIT Press, Cambridge, MA (1992)

32 Gick, ML and Holyoak, KJ 'Schema induction and analogical transfer' *Cognitive Psychology* Vol 15 (1983) pp 1–28

33 Goldschmidt, G Development in architectural designing. In **Franklin M B and Kaplan B** (eds) *Development and the arts* Erlbaum, Hillsdale, NJ (1995) pp 79–112

Gabriela Goldschmidt. The Technion's generous financial aid to Hernan Casakin during the writing of the dissertation is gratefully acknowledged. The writing of this paper was partially supported by a grant to Gabriela Goldschmidt from the Fund for the Promotion of Research at the Technion.