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INTERDISCIPLINARY ANALOGICAL INFORMATION TRANSFER IN DESIGN: DIFFERENCES BETWEEN KNOWLEDGE LEVELS

Ö. H. Özkan and F. Doğan

Keywords: analogical reasoning, distance of source domains, analogy levels, expertise levels, creativity

1. Introduction

Interdisciplinary analogical information transfer can be characterized as a potential strategy for creativity, originality, novelty and innovation as well. The transfer mechanism which is called analogy occurs by taking parallel ideas from other interdisciplinary fields and create new insights [Hesse 1966], [Dunbar 1999]. Analogy is understanding an unknown phenomenon via a known one [Hesse 1966], [Koestler 1964], [Hofstadter 1995] and [Holyoak and Thagard 1997]. In this respect it is considered as core of cognition [Hesse 1966], [Dunbar and Blanchette 2001] and knowing [Hofstadter 2001]. In addition, analogy is an instrument which facilitates the transfer of information from a source domain to a target domain. It is a mechanism that allows aligning similar casual relations between two systems in scientific reasoning [Gertner, 1983] and transfering source domain information to the target domain [Gentner 1988], [Holyoak 1985] (Figure 1). Thus, analogy is the core of creativity [Koestler 1964] and scientific discovery [Dunbar 1999, 2000].

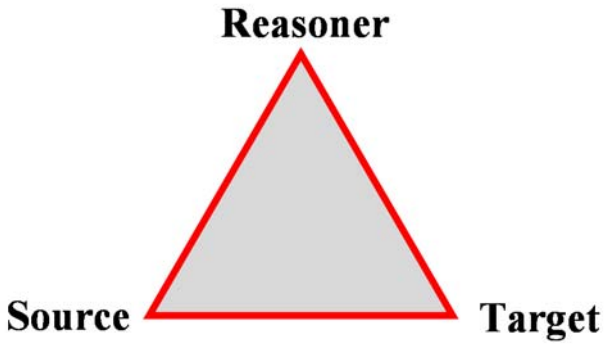

Figure 1. Analogy map of reasoner from a source domain to target domain

This study explores the role of analogy in design processes. It reports the result of an experimental study conducted to better understand the differences among expertise levels in their analogical transfer for a given design task. Compared to other research, a larger group of participants at different expertise levels attended to this experimental research. Additionaly, source domain examples were defined from four different categories according to their distance. Moreover, finer grained analogical relationship categories were used to identify and measure depth of analogical transfers.

2. Analogical reasoning and design

The use of analogy is wide spread by profecionals working at design and engineering companies in the industry. As well as profecionals, novice designers use analogies in common [Bal et al. 2004]. Analogical problem solving has been studied by many researchers according to different perspectives. However, it is not yet fully understood. Some focused on the role of analogy in scientific discovery [Dunbar 1995, 1999], [Gertner 1983], [Hesse 1966], [Holyoak and Thagard 1995], [Nersessian 1988], others focused that in design creativity [Gick and Holyoak 1980, 1983], [Casakin and Goldschmidt 1999], [Ball et al. 2004]. Some studied on visual thinking in problem solving [Beveridge and Parkins 1987], [Novick 1988] and others focused on the importance of the visual information [Bonnardel and Marmèche 2004], [Casakin and Goldschmidt 1999], [Casakin 2010].

Previous researches can be also analyzed and categorized according to the different aspects and use of analogy in creative domains. There is a various findings how and at what levels analogies can be made on different expertise levels and according to distance of source and target. Some have claimed that the more remote the source and target domain is, the more creative the end product is [Koestler 1964], [Dunbar 1999]. More successful analogies are those which are based on deep structure analogies [Gentner and Markman 1997]. Experts tend to establish deep structural analogies whereas novices tend to establish superficial analogies [Celement 1994], [Casakin and Goldschmidt 1999]. Some studies reported that the distance of source domain played an important role in the generation of creative designs [Casakin and Goldschmidt 1999), others claimed expertise was important factor in problem structuring and problem representation and use of analogies [Dreyfus and Dreyfus 1986], [Novick 1988], [Casakin and Goldschmidt 1999].

3. The parameters of analogy mechanism

As seen in prior research, the factors that effect the analogical transfer mainly threefold. These are levels of expertise, distances of analogy, and depth of analogy (Figure 2). Level of expertise play an important role to understand cognitive differences in analogical reasoning process. Second, distance of source domain brings us as the important parameters for defining differences in perceptional category. Third, depth of similarity is an important parameter for revealing the categories of knowledge transfer from source domain to target domain.

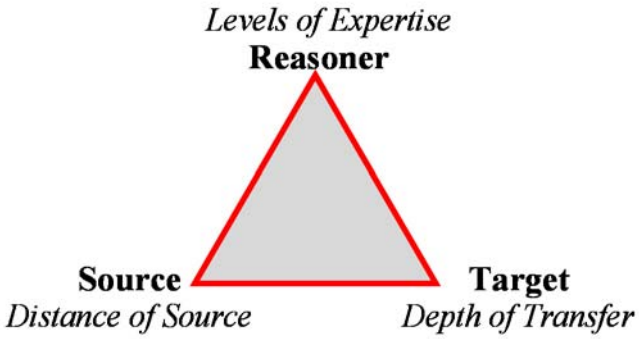

Figure 2. Paramaters of analogical reasoning

Distance of analogy

Distance change depending on whether or not the source and the target domain belong to the same subject domain [Dunbar 1995], [Dunbar and Blanchette 2001]. From the perspective of cognitive science Dunbar classified analogies as (1) local, (2) regional, (3) long distance (Figure 3) [Dunbar 1999]. Researchers stated that distance is a major indication of difficulty in analogical design process [Casakin 2004], [Christensen and Schunn 2007], [Herstatt and Kalogerakis 2005]. For instance, retrieval and transfer of near domain source is much easier [Gertner et al. 1993], while transfer of distant domain need more domain knowledge since they share more superficial characteristics with

the target domain. Ward claimed that apart from knowledge base, goals of the reasoner are the primary determinant of deep structural transfers (1998).

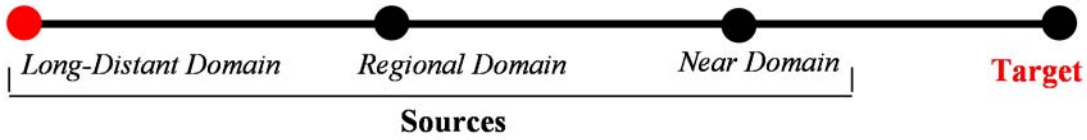

Figure 3. The distances between source and target domain

Depth of transfer

According to analogical relationship between source and target, analogy involves at least two distinct forms of relation. Superficial similarity relates to easily perceivable or superficial common object properties in appearance. Structural similarity on the other hand, involves a resemblance of underlying systems of relations within the source and target domains [Gentner 1983], [Holyoak and Koh 1987], [Rips 1989], [Smith 1990], [Forbus et al. 1995]. Structural similarity exists if the relations between components of source domain match with the relations between components of target domain irrespective of superficial similarities between the objects involved [Forbus et al. 1995]. Because it is a deeper knowledge acquisition, structural similarities have been understood as the most essential characteristic of analogical reasoning [Gentner and Markman 1997].

Depth of analogical relationship can be characterized by matcing source domain to target domain with structural properties, attributial properties, or both. These levels of relations are those mere appearance similarity, analogy, literal similarity and anomaly [Gertner 1983]. In mere-appearance matches, there is merely recognized correspondence between the properties of the objects that are transferred [Keane et al. 1994]. For instance the world is like a ball; that is, they are both spherical. In analogy, only structural and relational predicates are mapped [Gentner 1983], [Holyoak and Koh 1987], [Rips 1989], [Smith 1990], [Forbus et al. 1995], [Novick 1988]. Deep structural properties is based on the kn owledge gathered by analyzing the information from structural to casual relations among the parts and deeper parts of an object. Deeper knowledge depends on how well an object can be understood in its context. The deeper understanding of the casual relations among the information of the parts and the deeper parts create the knowledge base for analogical transfer [Justi and Gilbert 2006]. For example, an atom like the solar system. That is to say, the atom is a central force system like the solar system. This example points out the fact that successful analogies are mainly based on the knowledge of casual relations established in the mind. The access of information on casual relations on deeper levels has strong influences on creativite acts [Koestler 1964], [Hesse 1966]. Moreover, there is literal similarity which includes both attributial and relational predicates. To illustrate, X12 star system in the Andromede Galaxy is like our solar system. Namely, the attributial characteristics of X12 star is like the sun, and relational characteristics, such as being central force system. Finally, in anomaly relation nor attributes is transferred [Gentner and Markman 1997].

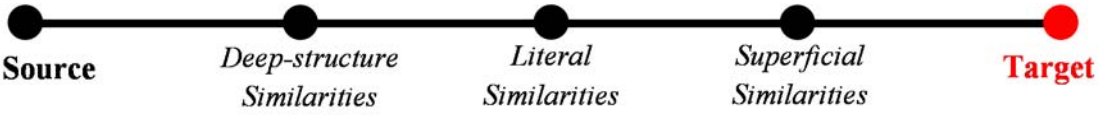

Figure 4. Depth of similarity [Gertner 1983]

Expertise levels

The level of expertise is an important factor in problem structuring, problem representation and use of analogies [Dreyfus and Dreyfus 1986], [Novick 1988], [Casakin and Goldschmidt 1999], [Goldman 1982]. In literature researchers found that novice and expert designers have some differences in the design process. [Dreyfus and Dreyfus 1986] stated that the ability of analogical reasoning is important in developing expertise. Experts tend to establish deep structural analogies whereas novices tend to

establish superficial analogies [Gick and Holyoak 1983], [Novick 1988]. Novices apply specific solution elements, while expert apply generic solutions [Newell and Simon 1972].

The Sub-processes of analogical reasoning mechanism

In cognitive science, there is general consensus that analogical transfer involves different sub-processes. These are retrieval, mapping, transfer and adaptation, evaluation and storage and learning shown in Figure 5

Based on the research presented so far, it appears that these phases are affected by depth of analogy. Retrieval is accessing a source domain and strongly influenced by surface similarity and only weakly influenced by structural similarity [Holyoak and Thagard 1989], [Novick and Holyoak 1991], [Schunn and Dunbar 1996]. Analogical mapping is consists of aligning representational structures to derive the similarities between source and target [Gertner 1983], [Holyoak and Thagard 1989], [Keane et al. 1994]. Transfer and adaptation involves creating new similarities and adapting them to target domain [Holyoak and Koh 1987]. Success of transfer depends critically on the level of structural relation or the relation in causal structure [Holyoak and Koh 1987] or in the principle applied [Novick 1988], [Ross 1984, 1987]. Evaluation is improving the inferences through relational and structural similarites [Forbus and Gertner 1989]. Finally, extracting and storing the principle or model underlying an analogy seems likely to be governed by new systems of relations [Clement 1988], [Gentner 1988], [Holyoak and Thagard 1989], [Keane 1988], [Novick 1988] which structure target domain and the knowledge of reasoner as well.

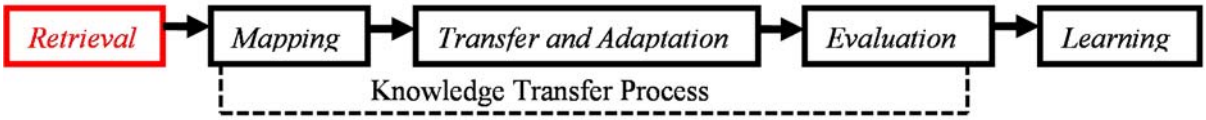

Figure 5. Phases of analogical knowledge transfer

Considering the whole parameters explained above the questions of this research is briefly described below (Figure 6).

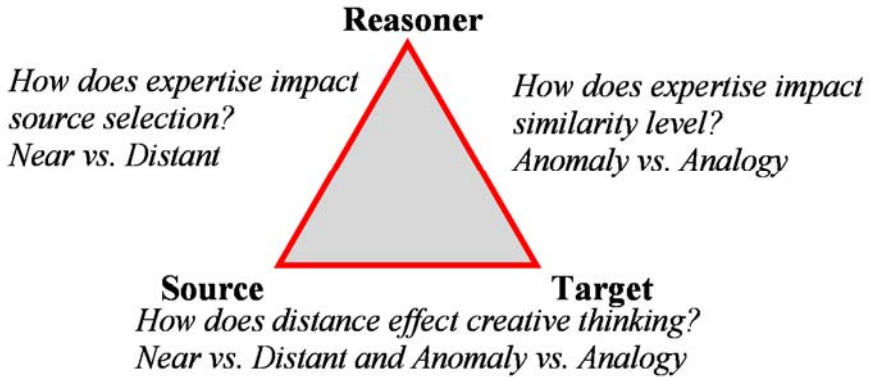

Figure 6. The research questions of each task

4. Research design

Participants

373 students (first level n = 171, second level n = 115, fourth level n = 87) and at least 10 years experienced 22 expert designers participated to the experiment. In the time, first level students were at the beginning of their education which means they had no particular experience in design. We recruited the participants from two seerate scools to minimize the impact of particular context.

Materials

An experimental study is conducted to better understand the interactions of these whole parameters explained above. We planned to give a design problem as a target domain to the experimenters. The important point in the selection of problem domain was the simplicity for all levels of expertise. The source domain groups were defined in four different categories; local, regional, remote and long-distance. These are first, bus stop examples, second, examples from architecture, third, examples from artifacts, and fourth, examples from nature respectively. The examples were determined in two phase selection process. In the first phase 320 source examples with 80 examples from each category were identified. Then two authors of the study eliminated them from 80 to 20 examples for each category. For the remaining source examples Delphi protocol implemented and with the %86 agreement, 40 source domains examples were selected unanimously by three independent judges in two round.

Procedure

In order to compare and contrast expert and novices, and to explore whether designers' use of analogy might be influenced by expertise level, the experiment was conducted in three tasks: first, asking participants to rate a randomly shown source examples as source of information for the given design problem; second, selecting a source domain group and explaining the selection criteria, and third, designing a bus stop. In the study, the participants were told to imagine themselves designing a bus stop which is not so complex for all levels of expertise. Then, they were expected to derive some information from the selected source domain, and then apply it to the given design problem.

5. Findings and discussion

In this research for the first task, we analyzed the relation between expertise levels and distance of rated source domains to understand whether distance is the main determinat of analogical reasoning. If the distance were the main factor, then first year students would rate near domain higher, and experts would rate long distant domain higher since experts were much more capable of analogical transfer. For the second task we analyzed the relation between expertise levels and distance of rated source domains to understand how categories impact retrieval process. If the categories were main determinants, selection pattern would chance since the categorization might trigger the top-down processing [see Ripoll et al. 2003]. For the third task, we analyzed the relation between expertise levels and the level of target domain similarity to understand the general approaches in problem solving processes since goals were the main determinant of successful transfers. Finally we analyzed overall relationships of these whole parameters to attain a holistic understanding of analogical transfer.

First task results

In this task we expected from participants to rate randomly ordered 40 source examples (1-poor, 2-fair, 3-average, 4-good, 5-excellent). They rated them without recieving any given information about the categories of source examples. The results for the sum of excellent and good ratings are given Figure 6. Multivariate test (MANOVA) revealed that there was a significant difference among 4 groups in their rating of source examples. Wilks'Λ=0.43, $F(120, 999)=2.7$, $p<.05$ alpha level) (Table 1).

The results showed that expert designers generally gave high scores to near domain examples i.e. the group of bus stop with high scores (good and excellent rating with %59 percentage), inexperienced student designers on the contrary, generally gived high rated long-distant domain examples i.e. the group of nature (good and excellent rating with %59 percentage). Second level student designers rated similar to first levels, and fourth level student designers rated similar to experts. Contrary to our prediction, first level inexperienced student designers, generally focused on the source domains which reserved the most creative information potential. Conversely, expert designers, althougt the expectation was only rating of source domains, generally considered how to use the source examples in the design process and focused on the concept of practicality and design process. They focused on the near domain examples to take to path-of-least resistance. The reasons behind distant domain retrieval may relate to originality (see [Dahl and Moreau 2002]) and mental leaps (see [Ward 1998]).

In contrast, the reason behind near domain retrieval may be cognitive economy (see [Ward 1998]) and time and efford economy (see [Kalegorakis et al. 2010]).

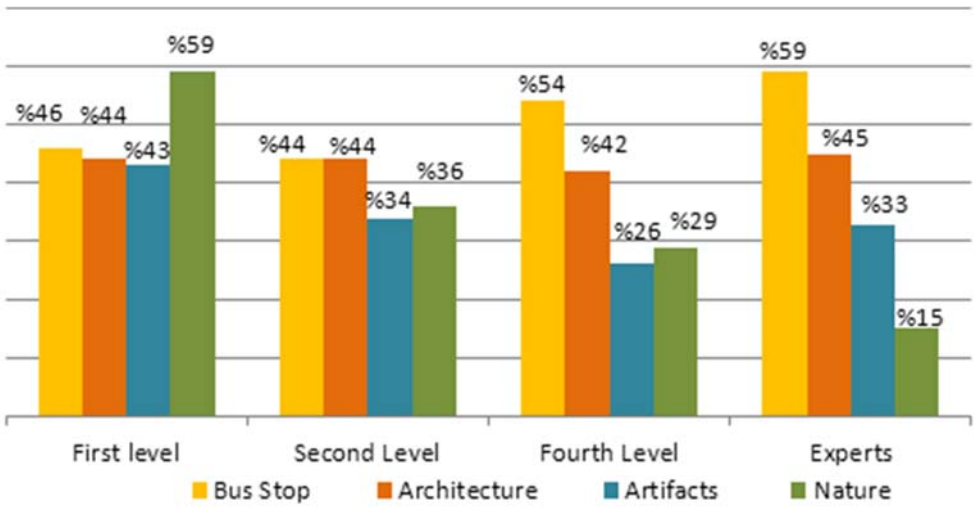

Figure 7. Source domain rating frequency percentage according to expertise

Table 1. Multivariate test (MANOVA) results

		Value	F	Hypothesis df	Error df	Sig.
EXPERTISE LEVEL	Wilks' Lambda	,431	2,696	120,000	998,532	,000

Second task results

In the second task the participants were given the source examples in 4 categories and expected to select one of them (i.e. bus stop, architecture, artifacts and nature). Results are given in Figure 8. Below descriptive graphics revealed the difference between expertise levels and source somain group selection. First level novice designers retrieved the local domain with 40% percentage. Contrary, expert designers retrieved long-distant domain with 52% percentage. The differences in percentags of category selections for second and fourth level students are less pronounced compared to th expert and first level students. Chi-square test (Table 2) results revealed that expertise levels and distance of source domain significantly related factors, x^2 (9, N=389) = 22.97, p=.006.

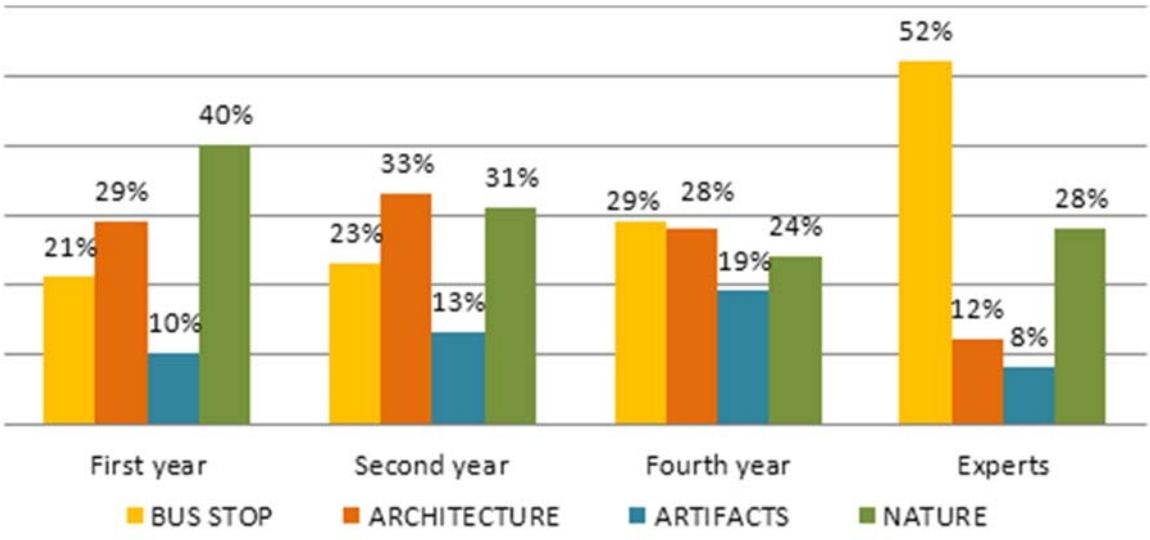

Figure 8. Differences between the expertise levels and source domain selection

Table 2. Chi-square test for expertise levels and distance of source domain relation

Chi Square Test	
	Asymp. Sig. (2-sided)
Pearson Chi-Square	,006

Results from first task and second task together indicate that novice and expert designers rated source domain examples consistently. Second task textual data revealed that inexperienced student designers generally focused on long-distant domains overwhelmingly in the aim of originality, novelty and genious creativity, whereas expert designers generally focused on near domain in the aim of practicality and productivity. On the contrary to our prediction, experts may not always prefer distant domain, although their capabilities.

Third task results

In the fourt task, we asked participants their design solutions by analogy to the source example they selected in the second task. Their designs were categorized by three independent judges in Delphi protocol in terms of mere appearance similarity, literal similarity, analogy and anomaly. The descriptive analysis of the analogy levels of target domain are given in Figure 9. Results revealed that first level student designers generally transferred mere-appearence information and focused on the attributial characteristics (%52) opposed to structural transfer (%6). Many of them transferred nether attributial properties, nor structural characteristics (26%). On the contrary expert designers generally transferred deep-structure knowledge and were able to make analogies (56%). Second level and fourth level generally made literal similarities (%39). This result indicate that with training and expertise, reasoner transfer deep structural similarities yet they can not them to a new solution. Chi-square test results revealed that there is a significiant relationship between expertise level and depth of analogical transfer; x^2 (9, N=375) = 89,39, p=.000, p<0.05 (Table 3). The descriptive analysis revealed that this relationship between expertise and similarity level of source and target domain is a linearly changing.

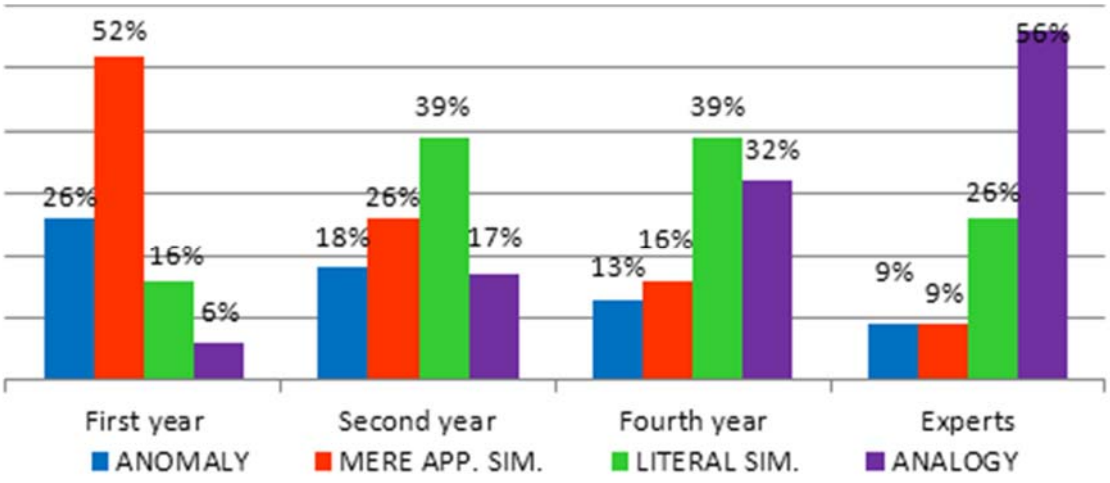

Figure 9. The changes of levels of analogy in different expertise levels

Table 3. Chi-square test for the relation between analogy levels and group selections

Chi Square Test	
	Asymp. Sig. (2-sided)
Pearson Chi-Square	,000

Third task visual data analysis revealed that, inexperienced student designers were better in creative idea generation from long-distant domains, whereas expert designers were better in productive analogical solution generation from near domains. By the increasing expertise, analogical relationships between source and target domain gradually and linearly increased. On the contrary, mere appearence similarity and anomaly linearly decreased.

Descriptive analysis in Figure 9revealed the relation between depth and distance of analogy of designers. The frequencies seems as randomly distributed. Chi-square test results revealed that there is no significiant relations between depth of analogy and distance of source domain parameters; x^2 (9, N=371) =9,39, p=.402, p < 0.05 (Table 4).

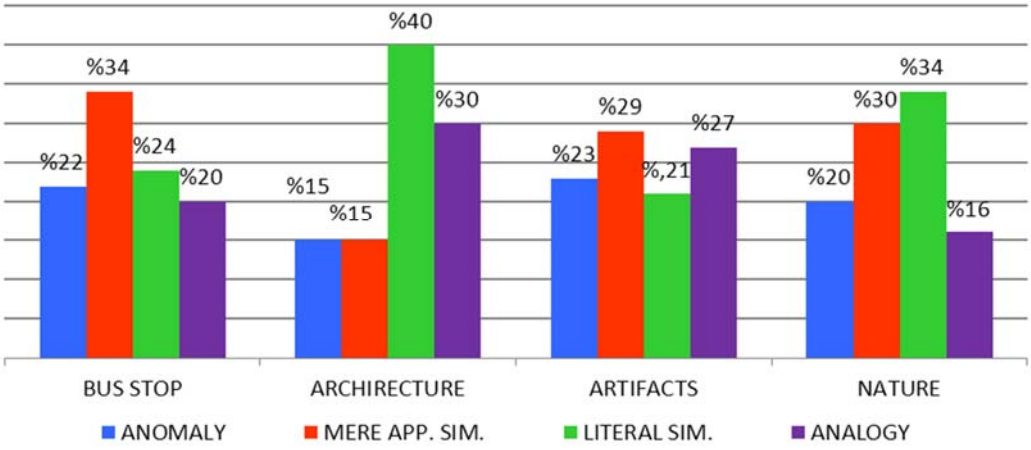

Figure 10. The difference of the analogy level of target domain according to group selection

These analysis reveals that it is not the distance of source domain that effect the level of analogical transfer, but level of expertise. Source domain selection criteria are mainly based on the goal of the reasoner.

In their explation often first year students expressed that the bus stop to be designed should be unique and different, i.e., original, novel, eye catching, pleasing to the eye and easthethic. They offered nature as a primary source offers more unique design opportunities. However they mainly focused formal characteristics. Experts on the other hand were more concerned about strategizing the design process, i.e., effective design process, productivity, efficiency. Compared to other groups, they are more concerned about how their selections will shape the design process and expected quality of the end product. They generally stated that using near domain examples would ensure the success of the end product since it was closer to the problem in hand.

Table 4. Chi-square test for the relation between expertise levels and analogy levels

Chi Square Test	
	Asymp. Sig. (2-sided)
Pearson Chi-Square	,402

6. Discussion

When the results from all the tasks are considered together, we see that present results are inconsistent with the predictions of this study. First year students generally focused on distant source domains in the expense of achieving originality (see [Dahl and Moreau 2002]) and genuine creativity. On the contrary, experts generally focused on the nearest (the most tried out) source domain in the thought of practicality, time, and efficiency [Kalegorakis 2010], and cognitive economy [Ward 1998]. Experts were satisfied with "mental hops" (see [Ward 1998]) on account of using their knowledge base. The reason behind the experts' preference for nearest domain was that these types of source analogues impose very similar constraints. The most quick and practical solution in the case of designing a bus stop would be to transfer what is known from the best understandable local source domain information. Ward [1994] identifies this preference as path-of-least resistance. Novices, on the other hand, were generally interested in the long-distant domains. They generally selected long-distant domains for the reason that they see distant domains as highly novel and original, which could lead to "mental leaps". (see [Holyoak and Thagard 1995]). Selecting a distant domain source analogue would be helpful to expand the search laterally (see [Goel 1995]). However knowledge transfer is cognitively more demanding endeavor. That is why first level students generally transferred merely the

information that were given in the design task. Second and fourth year students, who were neither completely after originality neither practicality; generally focused on regional or distant domains during idea generation phase. They were probably aware that it needs more effort and knowledgebility to transfer long-distant domain information to a target domain. In addition, they were insufficient to transfer deep structural similarities avoiding the surface feature characteristics. Instead they literally transferred source domain information in the solution generation phase [Gentner 1983]. The second and fourth year students seem to lack the abstraction skills which would have helped them avoid literally copying the source examples. They seem to focus and transfer, rather, domain specific knowledge from the sources [Ward 1994, 1998]. The explanatory graphic (Figure 11) shows the relation observed among expertise, distance of source, and levels of analogy.

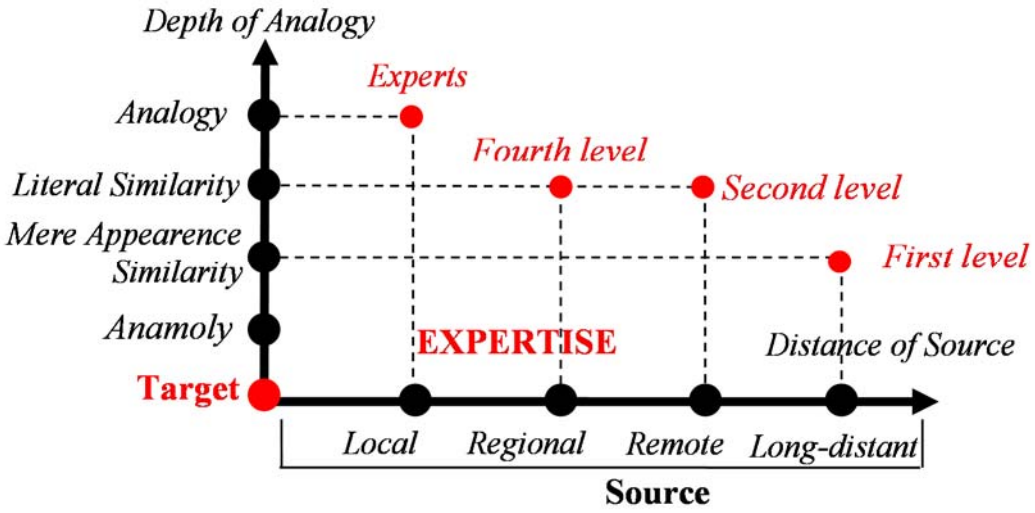

Figure 11. The relations among distance of source, depth of analogy and expertise

The analysis of sketches indicate that in the solution generation stage novice designers transfer from source domain in a single step processing mode [Hummel and Holyoak 1997], although they generally aimed at originality and behaved as a creative thinker in the retrieval stage. Single step processing mode is a very limiting superficial strategy. Expert designers behaved less as a radical creative thinker; retrieving the local sources, but more as a modest creative problem solver; mapping, transferring, adapting and evaluating target domain. Experts were more qualified in transferring information and planning the design process regarding the time, material, and representation usage than novice designers. They were able to construct the solution generation process with more related multiple sub-steps and work systematically. They were able to coherently integrated problem domain with the source domain. Second and fourth year students, in comparison to first year students and experts, established a one-to-one correspondence adapting the source domain to the target domain almost literally. They seem to aim neither originality nor practicality simultaneously. They generally made literal transfers.

Experiment results showed that inexperienced student designers are able to produce creative ideas and tried to achieve "mental leaps" more than the expert designers. However they generally focused on the given representation of source domain and inferred and transferred information in pictorial, attributial, or superficial level. Expert designers on the other hand generally focused on the source examples, connected them with the target domain in convergent "mental hops". Intermediate student designers were in between these two cognitive behaviors. They were generally insufficient to perceive higher-level casual relations and probably aware of the difficulty of "mental leaps".

7. Conclusion

To summarize, participants significantly differ in the way they take advantage of source domains. By the increasing expertise, deeper-structure information transfer and knowledgeability increased. Education develops the ability of analogical reasoning. However it generally conditions the designers

in the selection of source domains. In the light of these findings we can conclude that novice designers need more systematic thinking support whereas expert designers need more novice thinking mood. In a holistic looking to design processes, we can say that collaboration is must for associating creative idea generation and effective solution generation processes. Effective use of analogy will be base of creative developments in organization of information, design processes, collaboration, and spatial requirements as relational systems which serve to a main purpose. Interdisciplinary information transfers from distant domains are more likely to be potential for extraordinary creative analogies. Knowledging on the micro and macro levels of information categories through casual relations will lead creative analogies. Creative outputs are possible by thinking as novice designers with creative "mental leaps" in the idea generation process and reasoning as expert designers with creative "mental hops" in solution generation process.

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Ms. Özgü Özkan
Research Assistant
Izmir The Institute of Technology
Gülbahce Kampüsü
35430 Urla/Izmir, Turkey
Telephone: +90 2327507070
Telefax: +90 2327506015
Email: ozguozkan@iyte.edu.tr