# COGNITIVE STRATEGIES OF ANALOGICAL TRANSFER IN DESIGN: DIFFERENCES BETWEEN EXPERT AND NOVICE DESIGNERS

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**by**
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*varlığı yaşamım boyunca bana verilmiş en büyük ve en özel hediye olan sevgili kızım Melis Ece Özkan'a*

# ABSTRACT


## COGNITIVE STRATEGIES OF ANALOGICAL TRANSFER IN DESIGN: DIFFERENCES BETWEEN EXPERT AND NOVICE DESIGNERS

Analogy is an essential tool of human cognition that enables connecting two systems with casual relations. Previous research in analogy has focused primarily on role of analogy in creative domains. In literature there is lack in understanding the different levels of expertise and the remoteness of source and target domains; how these parameters impact the nature of analogies and stages of analogical transfer in a more holistic view. Thus we aimed to understand analogy mechanism to develop design education for achieving creative solutions transferring interdisciplinary knowledge effectively in the light of cognitive differences of novice and expert designers.

An experimental study is conducted to understand the mechanism of analogy in design. 40 source domains were manipulated in four categories; (1) bus stop, (2) architecture, (3) artifacts, (4) nature. 373 students and 22 expert designers attended to the experiment. The experiment focused on first; the selecting one of the source domain groups and an example from this group, and second; designing a bus stop by analogical reasoning. In this research first we analyzed the relation between expertise levels and distance of source domains. Second, we analyzed the relation between expertise levels and the level of similarity. Third, we analyzed overall relations of these parameters; how local, regional, remote and long-distant analogies influence the level of similarity. Finally, how expert vs. novice retrieval of source domain affected the creative analogy process in design.

Findings lead us to understand relation between expertise, the acquisition of knowledge and creative thought. Results showed that expert designers generally selected local domain which is the less potential source domain for creativity, and novice designers generally selected long-distant domain which is the most potential source domains for creativity. However, in design process analogy and literal similarity increased parallel to the expertise levels contrary to anomaly and mere appearance similarity. Education develops the ability of analogical reasoning. However it conditioned the designers in the selection of source domains.

# ÖZET

## ANALOJİK TRANSFERIN TASARIMDAKİ BİLİŞSEL STRATEJİLERİ: UZMAN VE ÇIRAK TASARIMCILAR ARASINDAKİ FARKLILIKLAR

Bu araştırmanın ana amacı, disiplinlerarası etkili bilgi transferi yaparak yaratıcı düşünme edinimini geliştirmeyi amaçlamış bir tasarım eğitimi için, analoji mekanizmasını bir sistem olarak anlamaya çalışmaktır. Analoji mekanizması kaynak alandan hedef alana bilgi aktarmak amacıyla iki sistem içindeki benzer nedensel ilişkileri eşleştirmeyi sağlayan bir araçtır. Literatürde tasarımcının uzmanlık düzeyinin, kaynak alan uzaklığının ve analoji düzeyinin kristalize edilerek bütünsel bakış ile incelendiği bir araştırmanın eksikliği gözlenmiştir. Bu nedenle, bu araştırma, kaynak alan uzaklıklarının analoji derinliğine etkilerini ve farklı uzmanlık seviyelerindeki bilişsel farkları bütünsel bakış içinde incelemeyi hedeflemektedir.

Tüm bu parametreler ışığında, analojik transferi daha iyi anlamak amacıyla, üç aşamalı bir deney düzenlenmiştir. Deneyde, 4 farklı kategoriden seçilmiş 40 kaynak örnek kullanılmıştır: (1) problem alanından örnekler, (2) mimarlık örnekleri, (3) ürün grubu, (4) doğadan örnekler. Deneye, farklı seviyelerdeki 373 öğrenci tasarımcı ve 22 uzman tasarımcı katılmıştır. Birinci aşama, karışık olarak verilen kaynak alanların değerlendirilmesi, ikinci aşama; bir kaynak alan grubunun seçilmesi, üçüncü aşama; tasarımcının problem çözme sırasındaki aşamalarına ve hedef ürünün analoji seviyesine odaklanır. Analoji düzeyi parametreleri; sadece-görünüm benzerliği, birebir benzerlik, analoji ya da benzemezlik şeklindedir.

Sonuçlar göstermektedir ki, ilk olarak uzmanlık seviyesi ile kaynak alan uzaklığının belirlenmesi arasında anlamlı bir ilişki olduğu görülmüştür. Ayrıca, uzman ve çırak tasarımcıların analojik bilgi aktarım düzeyleri, eğitimin farklı seviyelerinde anlamlı ve lineer bir şekilde gelişmektedir. Ancak, uzmanlıkla birlikte yaratıcı fikir geliştirme potansiyeli olan kaynak alanlardan çok yakın alanlardan bilgi aktarma eğilimi de aynı şekilde artmaktadır. Eğitim bilgiyi kategorize etme, aktarma, geliştirme açısından geliştirdiği, ancak uzmanlığın yaratıcı bakışa ket vuran şartlanmayı da beraberinde getirdiği söylenebilir.

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*"Here and elsewhere we shall not obtain the best insight into things until we actually see them growing from the beginning."*
*Aristotle*

*"Nature delights in transformations."*
*Newton*

*"Thought is: seeking the highest level of abstraction putting finger on essence and bouncing back and forth between actual situation and found essence."*
*Dougles Hotstadfer*

*"It is, as it were, the fundamental principle of cognition that the universal can be perceived only in the particular, while the particular can be thought of only in reference to universal"*
*Ernst Cassirer*

# CHAPTER 1

# INTRODUCTION

## 1.1. Analogy

> Analogy, n., proportion; an agreement or correspondence in certain respects between things otherwise different; likeness. (Gr. Analogia- ana, up to, logos, proportion or relation). Analogism, n., a reasoning up from cause to effect. Analogise, v.t. to explain by analogy. Analogous, adv. similar (Donald, 1867, p.14).

Interdisciplinary analogical knowledge transfer can be characterized as a potential strategy for creativity, originality, and novelty, taking ideas from a field, and altering or seeing alternatives of them to fit new circumstances. Studies in literature revealed that analogies from different fields can foster new insights (Markman, 1999; Bassok and Holyoak, 1989; Catrambone & Holyoak, 1989; Clement, 1988; Dunbar, 1995; Forbus, Gentner, & Law, 1995; Gentner, 1982; Gentner & Gentner, 1983; Gentner, Rattermann, & Forbus, 1993; Gick & Holyoak, 1980,1983 ; Keane, 1988; Novick & Holyoak, 1991 ; Ross, 1987; Spellman & Holyoak, 1993; Thagard, 1992). In this respect, analogy is considered as an essential instrument of creative thought (Koestler, 1964; Hesse, 1966; Dunbar, 1999).

In cognitive science studies, many researchers have focused on analogy as a mechanism to structure problem domains (Gick & Holyoak, 1980; Gentner, 1983, 1989; Clement, 1988; Keane, 1988; Novick, 1988; Gentner, 1993; Holyoak, Gentner & Kokinov, 2001). In addition to the studies in cognitive science, design studies and studies of creativity have further emphasized the role of analogies. These studies underlined that analogical reasoning is often a fundamental cognitive tool for intelligent thought (Reeven, 1938) in scientific discovery (Hesse, 1966; Thagard, 1988; Dunbar, 1995, 1999; 2001; Christensen & Schunn, 2007), in design creativity ((Gero, 1992; Schmitt, 1995; Casakin & Goldschmidt, 1999; Christensen & Schunn, 2007), and specifically for problem solving (Gentner, 1989; Boden, 1990; Kolodner, 1997; Ball, 2004, Goldschmidt, 2001, Casakin, 1999, Casakin and Goldschmidt, 1999, Goal, 1997, Visser, 1996, Cross, 1994; Herstatt & Kalogerakis, 2005).

Analogical reasoning is a central process leading to the emergence of new ideas (Boden, 1990; Kolodner, 1997). For example, Koestler (1964) has identified analogy as the "essence of creativity" and stated:

> The creative act does not create something out of nothing; it uncovers, selects, reshuffles, combines, synthesis already existing facts, ideas, faculties, skills. The more familiar the parts, the more striking the new whole. (Koestler, 1964, p.22)

Perkins (1997) articulated analogy as a mental tool which carries people's cognitive capacity to the possibility of innovations. As an example, in their study on AI models Hofstadter and colleagues (1997) have focused on analogy as an aspect of human thinking with its potential for creativity to extend or reconfigure concepts in new contexts. According to Hofstadter, creativity is based on extension and interrelation of existing concepts (2001). Analogy is a fundamental aspect of thought allowing concepts to slip from their context and constraints to another. Hofstadter describes concepts as fluid and changeable. Conceptual fluidity allows existing concepts' reconfiguration in novel situations and in new ways that respect the constraints of novel contexts (Hofstadter, 1995). In this respect, analogical reasoning process involves new ways of perceiving or describing existing things (Hofstadter et al, 1997). That is why Hofstadter has stated analogy as "core of cognition" (2001).

Design problems can also be formulated or reformulated through analogies based on existing solutions. Analogy is a way of deriving solutions or at least some aspects of solutions from a source domain, highlighting relevant information for a goal (Gero, 1992; Schmitt, 1995; Casakin & Goldschmidt, 1999). By projecting inferences from source domain to the target domain, analogies aid in problem solving process (Gentner, 1989). Analogies involve the modification (mutation) and combination (association) of existing ideas into novel forms since by analogy seemingly disconnected systems are brought together. Creative and innovative potential of analogies are mainly based on the goals and pragmatic casual relations transfer (Holyoak & Thagard, 1995).

## 1.2. Theoretical and Methodological Approach

Analogical problem solving has been studied by many researchers according to different perspectives. However, it is not yet fully understood how and at what levels analogies are effectively used by design students and experts. Broadly speaking, our theoretical stance on cognitive processes involved in analogical reasoning in design is that analogical reasoning is based on pragmatic alignment between source and target domain. Designers are faced with the challenge of how to generate ideas from distant (cross disciplinary) domains in a more pragmatic view, and transfer this “pragmatic” abstract knowledge to problem domain to generate solution. We do not know about the difference between novices in different educational levels and expert cognitive behavior in the retrieval stage and knowledge transfer stage and moreover their relations. The important point of analogical transfer from cross disciplinary domains is based upon understanding cognitive behavior differences in analogical reasoning process. Investigating how designers retrieve source domain(s) in idea generation phase and how they transform relevant information(s) within associative, similarity-based reasoning system in solution generation phase will help enhance creativity and design education.

Prior research seems to paid attention to different aspects of analogy. Some focused on the role of analogy scientific discovery (Dunbar, 1995, 1999, 2001; Gentner, 1983; 1989; 2005; Hesse, 1966; Holyoak and Thagard, 1995; Nersessian, 1988). Some focused that in design creativity (Gick & Holyoak, 1980, 1983; Casakin & Goldschmidt, 1999; Ball, Ormerod & Morley, 2004; Kolodner, 1997). Gertner & Markman (1994), Holyoak & Thagard (1995) researched levels of analogy. Dunbar and Blanchette (1999) have paid much attention to distance of analogy. Some other researcher studied expertise in analogy (Dreyfus & Dreyfus, 1986; Novick, 1988; Casakin & Goldschmidt, 1999; Goldman 1982; Vosniadou 1989). Some focused on visual reasoning in analogical problem solving (Beveridge & Parkins, 1987) and design (Bonnardel & Marmèche, 2004; Casakin & Goldschmidt, 1999), indicating the importance of visual information. Gick and Holyoak (1983), Beveridge & Parkins (1987), Novick (1988), and Craig, Nersessian, & Catrambone (2002) studied the role played by visual representations in the form of diagrams in analogical reasoning. Gick and Holyoak (1983) examined the role of diagrams in analogical problem solving regarding the analogical distance in the form of within and between domain examples.

As seen in prior research, expertise levels, distance of source domain, analogical processing, and analogy levels are the main factors of analogical reasoning. However, there is much to investigate about the interactions of these parameters. They should be analyzed in a more holistic and a systematic way. Moreover, a qualitative and quantitative analysis with finer grained expertise levels and with a larger sample size would be of high value. Thus, this thesis aims at investigating analogical reasoning experimentally with an emphasis on finer grained levels of expertise, finer grained distance of source domain and level of analogical relation. In this respect, this study investigates the analogical reasoning process as a more holistic mechanism inquiring the relationship among these whole parameters.

The aim of the study is to investigate the various contexts in which designers employ analogy to provide and promote understanding. The methodological approach has been influenced by the empirical laboratory investigations of Dunbar and Blanchette (2001), Gentner (1989), by the studies in problem solving (Novick, 1988; Beveridge & Parkins, 1987) and design (Bonnardel & Marmèche, 2004; Casakin & Goldschmidt, 1999; Ball, Ormerod & Morley, 2004), and also by the studies in scientific discovery (Dunbar, 1995, 1999, 2001; Gentner, 1983; 1989; Hesse, 1966; Holyoak and Thagard, 1995; Nersessian, 1988). Overall the objective of the study is to understand the relations among expertise levels, distance of source domain, and levels of analogy.

The questions of this research are as follows:

1. How does the remoteness of source and target domain differ according to expertise levels?

2. How do analogy levels change according to expertise levels?

3. How do the stages of analogy process change according to expertise levels and distance of source domain?

4. What are the overall relationships of expertise level, distance of source domain, type of similarity in the analogy process, and level of similarity of target interact throughout analogical reasoning?

In order to study the questions above an empirical study was conducted. The experiment carried out is described in Chapter 3.

What is shown in the related literature is that the analogical process will be different depending on the designers' level of expertise and the retrieval of near and distant sources. Therefore, it can be proposed that depth of analogical reasoning will differ according to expertise, distance of source domain.

The hypotheses of the study are as follows (Figure 1.1.):

1. Experts will tend to establish more remote domain analogies whereas novices will tend to establish more near domain analogies;

2. Experts will more likely establish deep structural similarities whereas novices will use superficial similarities;

3. Deep structural similarities will result in more original, therefore, creative design solutions;

4. When remote domain analogies are used there will be more stages in the analogy process.

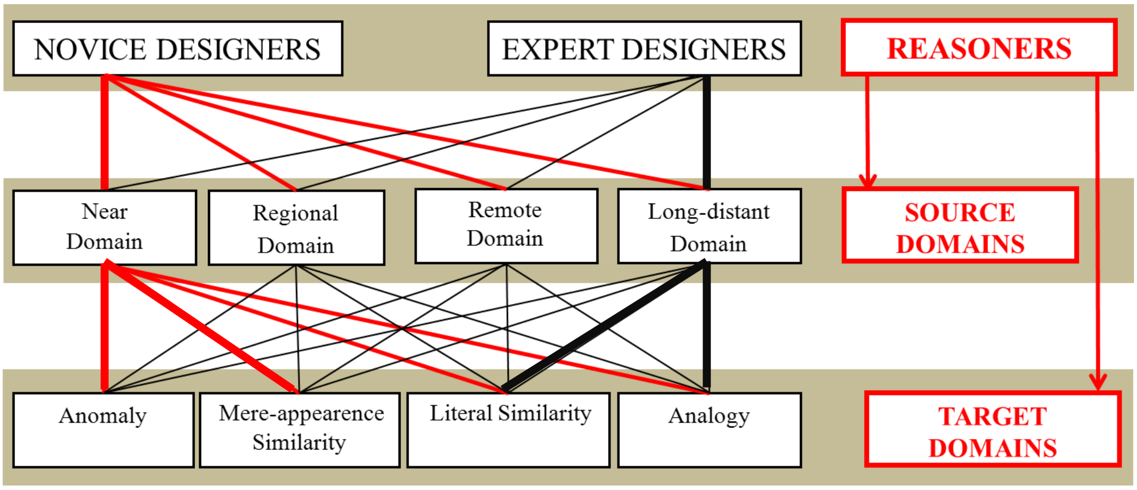



Figure 1.1. Possible paths that novice and expert designers expected to follow

In an attempt to investigate novel research questions in a more holistic view, over reliance on any one method of investigation was avoided. A combination of qualitative and quantitative methods was used to inquire the questions above. The intention is to create a generalization on analogical reasoning mechanism in creativity, innovation, and problem solving. The methods used in the study comprised of an experimental study consisting of four tasks, post-study interviews with participants. Interviews were conducted to see the uniformity between qualitative and quantitative data. The participants of the study were experts and novices from first, second, and fourth year of architectural school. Compared to other similar studies, the number of participants was significantly higher. The inquiry will highlight cognitive changes among architectural students throughout their education with respect to analogical reasoning and how novices are different from and similar to experts.

Studies investigating analogical reasoning have ranged from "naturalistic (field)/in vivo context" and to analysis in "experimental (laboratory) /in vitro context" (Dunbar & Blanchette, 2001). In this study, the "experimental (laboratory) /in vitro" paradigm of research is chosen primarily because of pragmatic reasons. Another methodological issue which determined the scope of the study related to the nature of source examples, i.e., whether they were generated by the participants or given by the experimenter. The former is known as "production paradigm" in which subjects are given a target problem and are asked to generate source analogs as in real world contexts. The latter is known as "reception paradigm" in which subjects are given source and target analogs and are asked to see the relationship between them (Dunbar & Blanchette, 2000). This study followed the premise of the reception paradigm approach.

Broadly speaking, the theoretical assumptions related to the cognitive processes involved in analogical reasoning are as follows. First, expertise of reasoner is one of the main paramaters. Second, source domains and source examples in analogical reasoning play an important inspirational role in the design process. The distance of source domain is an important parameter in defining the familiarity of a source domain for a cognizing agent therefore its likelihood of leading to originality (Johnson-Laird, 1989). Third, the analogy levels between source and target domain play an important role to determine the level of knowledge that novice or expert designers can interpret. Fourth, analogical reasoning consists of an alignment between source and target domains which happens through a series of sub-stages of abstraction and knowledge transfer. The stages of analogy play an important role to determine the retrieval and transfer mechanisms of novice or expert designers.

Factors that impact analogical reasoning are studied in detail in the related literature. In brief, the boundaries of this study was mainly drawn by the theoretical works of Hesse (1966), Hofstadter (1984), and Koestler (1964); the empirical laboratory investigations of Dunbar (1999, 2001); the analogy studies of Gentner (1983), Holyoak and Thagard (1985); and expertise studies of Dreyfus and Dreyfus (1986).

The aim of this study is shaped by two key restrictions:

Restriction 1: The aim of the study is not to exhaustively explain how analogical reasoning works. Rather, it is interested in how designers benefit from analogical reasoning and how their cognitive strategies differ according to expertise and distance.

Restriction 2: The aim of the study is not to make law-like generalizations on analogical reasoning. Rather, the aim is to understand analogical reasoning processes in reference to expertise levels to guide architectural education.

## 1.3. Limitations of the Study

The study has some limitations that need to be addressed. First limitation concerns the sample group with regard to their educational background and sample size. Another limitation is the measurement condition used in this study. The Delphi method was used to determine the consensus among the independent judges and Content Analysis was used for understanding the nature of verbal data. These methods have both strengths and weaknesses. Third limitation concerns the procedure of the study: the use of reception paradigm used in source domain definition, the in-vitro context for the empirical work, and the type of instructions that participants received.

## 1.4. Brief outline of thesis

*Chapter 1* addresses the role of analogy in innovative and creative processes (scientific discovery and problem solving), and briefly structures the research approaches. *Chapter 2* details the rationale behind the methods employed in the study together with a broad coverage of literature review. This chapter provides a rationale for planning, organizing, analyzing and discussing the experiments, materials, limitations and the interpretation of the findings. *Chapter 3* focuses on the experimental setting; provide information on planning, organization procedure, and analysis methods. *Chapter 4* examines the data in macro to micro scale, considering within and between domain and factors interactions in the light of quantitative analyzing models. *Chapter 5* discusses the main finding in the light of the key parameters (factors) and their interactions that influence the analogy mechanism of novice and expert designers. *Chapter 6* contains a summary and conclusions of the whole investigations, their implications, particularly for design education, and the scope for future work.

## 1.5. Summary of Main Findings

As detailed in Chapter 4, the findings of the study indicate that, education is an important factor for not only developing expertise and the acquisition of knowledge, but also framing the creative insight as well. With the development of expertise, deep structural or higher order knowledge transfer, the level of analogical reasoning, and system interpretation increase. Expertise, however, sets limits to creativity as well. Experts are found to focus on similar or near domain sources more than novices, yet, they refrained themselves from copying the source analogues. Instead, they focused on structural similarities of their source analogues. In contrast, first year students generally focus on dissimilar long-distant domain sources which have the most creative potential. First year students, however, were not able to fully appreciate the implications of their selections and failed to see structural similarities between the source and target analogue pairs. They were rather copying the surface features of the selected source analogues. Novice designers seem to require hierarchically related instructions in solution generation process. Briefly, education develops the ability of analogical reasoning. However, it conditions the designers in the selection of source domains. These results were apparent not only in the quantitative outcomes of tasks, but also in the words especially of student designers. Different from first year students and experts, second and fourth year students were focusing more on both surface and structural features of their selected source analogues. They were neither copying the irrelevant surface features as the first year students do nor transferring the structural features as experts do. They were rather literally copying the source analogues.

## 1.6. Implications of Main Findings

What has this research on analogical reasoning revealed and what is to be learned from this investigation? In our perspective, there are several valuable conclusions one can drawn from this research. Moreover, these conclusions have important implications for design education and practice. First, the awareness of cognitive abilities and capabilities of student designers will provide a map in the educational setting. Second, significant relationships exist between the parameters of analogical reasoning and those of expertise. Understanding the nature of analogical reasoning and its relation to creativity will bring greater clarity in using analogy in design more effectively and will fill several knowledge gaps in the literature.

What are the implications of these findings for educational research and instructional practice? There are clear implications for educators in being aware of the skills and competencies student designers bring to reasoning tasks. Designers might be informed about how to guide or facilitate the design process better regarding the possibilities, potentials and limitations of near and distant source domains in analogical reasoning.

Design education needs to be reconfigured and expanded with a focus on analogical reasoning which is important for creativity. Analogical reasoning processes facilitate the establishment of a knowledge base. We must focus on discovering new and better ways to uncover and interpret what designers in different levels know and can do analogically in design settings. Also we must move beyond restrictive paradigms of previous debates. The enhancement of analogical reasoning will bring creative insights in idea generation and solution generation.

## 1.7. Implication for Future Research

Findings have implications for development of expertise including practicing designers, educationalists, cognitive scientists and philosophers interested in analogy mechanism. It can be suggested that some in-depth follow-up studies could be carried out by building upon this initial broad-ranging research findings.

# CHAPTER 2

# LITERATURE REVIEW

As discussed in the previous chapter, a wide-ranging literature review of analogy was conducted included studies of scientific discovery and design studies. These explorations provided a broad perspective, theoretically and methodologically, enabling this study to formulate appropriate research questions and choose a suitable methodology.

## 2.1. Two Systems of Reasoning

In the cognitive science literature, two systems have been proposed to describe reasoning (Figure 2.1); the symbolic system and the associative reasoning system (Sloman, 1996). The symbolic one is a rule-based reasoning system which combines rules according to an algorithm. The associative system is similarity-based and invokes analogies in reasoning.

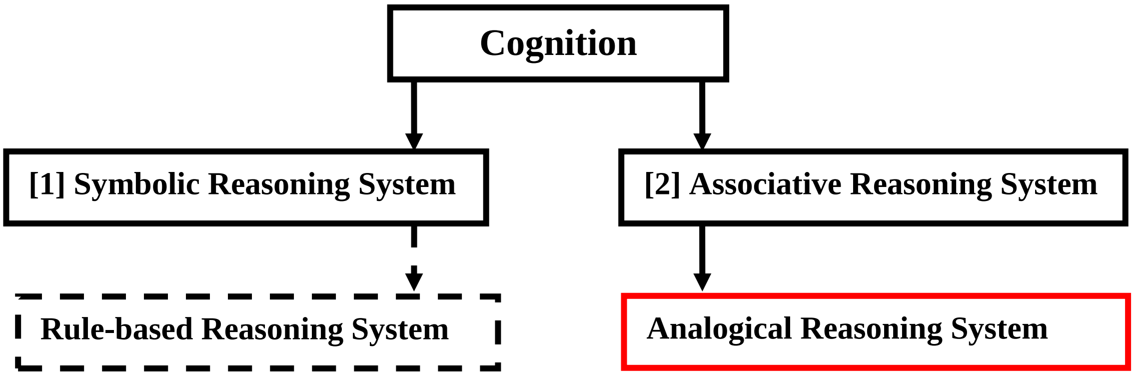



Figure 2.1. The cognitive structure for reasoning through analogies
(Source: Sloman, 1996)

Analogical reasoning is a function of the associative, similarity-based reasoning system. This type of reasoning activates stored schemas based on the identification of connections or similarities between domains (Sloman, 1996). Ball and colleagues (2004) and Cross (1994) stated that analogies serve as associating (corresponding) tools where new information is derived from existing schemas stored in long-term memory.

Analogical reasoning is thus the use of these learned or stored schemas or of knowledge from previous experiences to facilitate understanding a new situation or a new domain.

### 2.1.1. Analogical Reasoning

From cognitive psychology perspective, analogical reasoning has been considered as an important feature of human cognition that involves transfer and apply of knowledge from a familiar domain (*the source or base*) that usually already exists in memory to another less familiar domain (*the target*) to be explained (Gick & Holyoak, 1980; Gentner, Holyoak, & Kokinov, 2001; Holyoak & Thagard, 1997; Vosniadou, 1989). There is general agreement that analogical reasoning involves the transfer of relational information from a source domain to a target domain. Analogical reasoning is a powerful tool that people use for variety of purposes. Ward (1998) makes a distinction between *explanatory* and *inventive* analogy (Figure 2.2). For instance, explanatory analogies could be used for communicative purposes to explain the target domain in reference to a familiar source domain. We see an extensive use of explanatory analogies in science (Gentner and Markman, 1994, 1997; Gentner et al., 1997). Inventive analogies are used primarily to supply solution ideas to the design of novel products. The designers transfer a specific solution principle from a source domain to a target domain (Herstatt and Kalogerakis, 2005). Furthermore, analogical reasoning is a ubiquitous learning mechanism used for a wide range of purposes (Brown, 1989; Vosniadou, 1989).

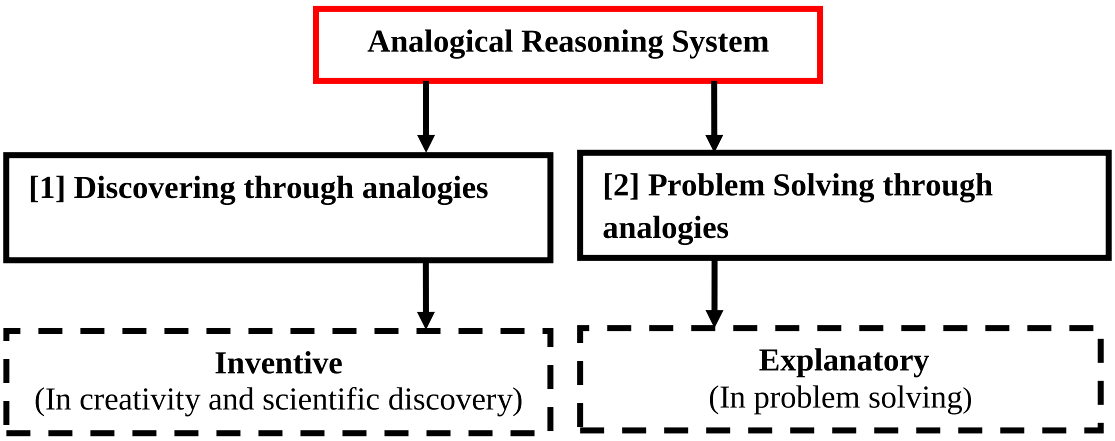



Figure 2.2. Analogical reasoning systems
(Source: Sloman, 1996)

### 2.1.1.1. Two Systems of Analogical Reasoning

Researchers have stated that analogical reasoning can be categorized into two different forms. First is *explanatory* in problem solving and second is *inventive* in creativity and scientific discovery (Ward, 1998).

Explanatory analogies can be used as the integration of different domain abstractions (source domains) into the content of a problem (target domain) (Gentner, 1989; Schmitt, 1995; Casakin & Goldschmidt, 1999; Gero, 1992) in problem solving. In design process, analogical problem solver uses schemas, abstractions (diagrams) or knowledge to reason about, infer, and/or predict information to solve a problem. In other words, analogical abstractions are used to apply the domain general knowledge to a new domain specific problem (Visser, 1996; Keane, 1988; Popovic, 2004).

Inventive analogies can be used to understand structured information of an unfamiliar phenomenon via a familiar one (Hesse, 1963; Koestler, 1964; Hofstadter, 1995; Holyoak & Thagard, 1990; Vosniado, 1989; Ward, 1998) in creativity and scientific discovery.

Reasoner utilizes the existing body of knowledge and experience as possible source domains to solve a target domain. For example, we might explain the structure of the atom by analogy to the more familiar solar system. Electrons orbit the nucleus just like the planets orbit the sun. These are two suitably aligned which has been repeatedly referred to in literature (Gentner, 1983; Gick & Holyoak, 1980, 1983; Holyoak & Thagard, 1995). Else, analogies triggers creativity (Boden, 1992) and scientific discovery (Hesse, 1963; Hoffman, 1995; Dunbar, 2001). Analogical reasoning helps transfer of knowledge from the familiar situation to the new design problem context making relevant alignments with the unfamiliar target situation.

### 2.1.1.2.Parameters of Analogical Reasoning

Analogical reasoning should be considered as a holistic mechanism including source, target and model interaction as shown Figure 2.3.

- “Target” may be an object, an event, a process or an idea that is being modeled.
- “Source” is the familiar entity that is used to represent the target to produce the analogy.

• "Model" is the result of the representation of the relationships. Model is learned by the reasoner.

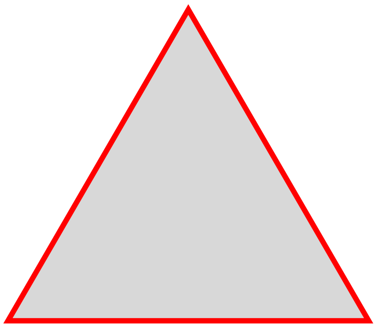



Figure 2.3. Analogical model generation
(Source: Justi & Gilbert 2006)

By analogical reasoning reasoner can create a generic rule, a model that is applicable across many related problems by the establishment of new relationships between them with some aspects (Justin & Gilbert, 2006). The term "model" mentioned here corresponds to the term "schema abstraction" in design experiments.

Analogical reasoning has been studied according to different perspectives (Figure 2.3). These are distance of source domain (Dunbar and Blanchette, 1999), levels of similarity (Gertner & Markman, 1994; Holyoak & Thagard, 1995), and levels of expertise (Dreyfus & Dreyfus, 1986; Novick, 1988; Casakin & Goldschmidt, 1999; Goldman 1982; Vosniadou 1989).

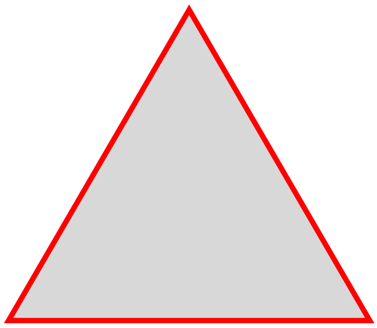



Figure 2.4. Diagram of analogical reasoning

### 2.1.1.3. Distance of Source Domain

Sources of analogy for inspiration play an important role in the design process. In the analogical design process, between inspirational source domain and target problem domain, the 'distance' may change (Dunbar, 1995; Dunbar & Blanchette, 2001; Vosniadou, 1989). Depending on whether or not the source and the target domain belong to the same subject domain, two types of analogy is defined in literature: between-domain or inter-domain analogy (cross-domain analogy) and within-domain analogy or intra-domain analogy (Casakin & Goldschmidt, 1999; Bonnardel, 2000; Bonnardel & Marmeche, 2005). The distance of source domain is one of the important parameters of analogical reasoning. Poincaré described the importance of distance of source domains as follows:

> ... Invention is discernment, choice... Among chosen combinations, the most fertile will often be those formed of elements drawn from domains which are far apart… But certain among them, very rare, are the most fruitful of all. ... The true work of the inventor consists in choosing among these combinations so as to eliminate the useless ones, or rather to avoid the trouble of making them, and the rules which must guide this choice are extremely fine and delicate. (Henri Poincaré cited in Koestler, 1964, p.164).

Different terms have been used to describe the distance between source and target in the literature (Table 2.1).

Table 2.1. The different terminology used in literature

| Terms used to describe the distance between source and target in analogical reasoning | | | | |
|---|---|---|---|---|
| **Year** | **Researcher** | **Distance of Source and Target** | | |
| **1999** | **Dunbar** | Local | Regional | Long-distance |
| **1999** | **Casakin& Goldschmidt** | Within-domain | | Between-domain |
| **2000** | **Malaga** | Close associate | | Remote associate |
| **2002** | **Leclercq & Heylighen** | Direct link | Indirect link | Extra-contextual link |
| **2005** | **Bonnardel & Marmeche** | Intra-domain | Close inter-domain | Far inter-domain |
| **2008** | **Tseng et al.** | Surface similarity | | Structural similarity |
| **2004** | **Ball, et al.** | Domain General Knowledge | | Domain Specific Knowledge |
| **2004** | **Ball, et al.** | Case-driven | | Schema-driven |

Dunbar classified analogies as (1) local, (2) regional, and (3) long distance (Dunbar, 1999). In this research the terminology of Dunbar will be used (Figure 2.5).

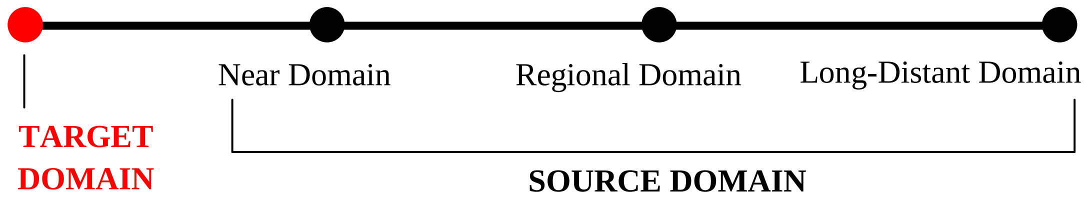



Figure 2.5. Dunbar classification of analogies

Dunbar found that long-distant analogies did not play a significant part in discovery, and were very rare in comparison to local analogies (Table 2.2). However the use of distant domain analogies may be positively related to creativity in design (1999, 2001).

Table 2.2. Dunbar's statements on the forms of analogies used by scientists in different contexts (Source: Dunbar, 1999).

| **Type of Analogy** | **Example** | **As a % of total no. of analogies used.** |
|---|---|---|
| **Local** | An analogy from one gene on the HIV virus to another gene on the HIV virus | ~ 45% |
| **Regional** | An analogy from the Ebola virus to the HIV virus. | ~ 50% |
| **Long-distance** | An analogy to the pop song 'Hotel California'. You can check in but you can't check out. | ~ 2% |

### 2.1.1.4. Similarity Levels of Target Domain

*Superficial and Deep Structural Similarity*

According to similarity level between source and target, analogy involves at least two distinct forms of relation as summarized in Figure 2.6 and Figure 2.7. At one level, there is superficial similarity that involves recognized correspondence and resemblance between the properties of the objects in the source and target domains (Keane, Ledgeway, & Duff, 1994). Superficial similarity relates to easily perceivable or superficial common object properties in appearance. At another level, there is structural similarity that involves a resemblance of underlying systems of relations within the source and target domains (Gentner, 1983, Holyoak & Koh, 1987, Rips, 1989, Smith, 1990, Forbus et al., 1995, Novick, 1988, Vosniadou, 1989). 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, Gentner, & Law, 1995). Because it is a deeper knowledge acquisition, structural similarities have been understood as the most essential characteristic of analogical reasoning (Gentner & Markman, 1997). Structural similarities refer to more central, core properties of source domains which have strong generative characteristics (Justi & Gilbert, 2006). It also has a strong influence on the quality of the solution. Briefly, for analogical reasoning the source and the target must share one or more of the following characteristics: similar surface features, similar goals, and the same underlying systems of higher order relations (e.g., Catrambone & Holyoak, 1989; Gentner, 1989; Holyoak & Koh, 1987; Ross, 1989; Wharton et al., 1994).

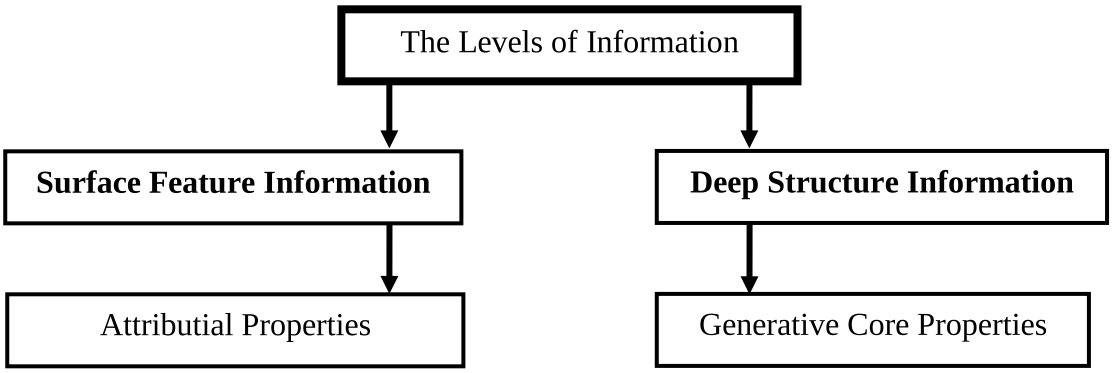



Figure 2.6. General abstraction levels categorized in literature
(Source: Gentner, 1983)

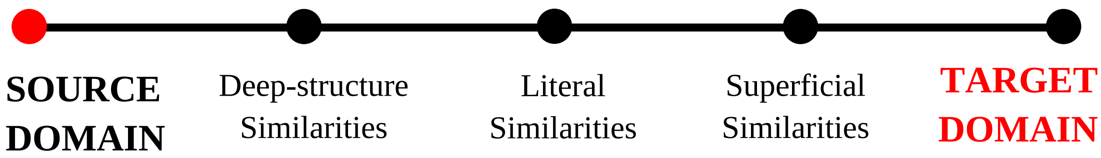



Figure 2.7. The similarity levels between source and target domain

Researchers such as Gentner (1989) and Keane (1988) argued that although superficial similarities are easy to create, under normal circumstances they could not guarantee the transfer of structural relations between source and target. Superficial similarities invoke only descriptive properties of objects like shape, color, size, names, profession, context definition, and kinds of domains. It is likely to be noticed more easily than underlying structural similarities (e.g. Holyoak & Koh, 1986, Vosniadou, 1989). Gentner and Holyoak also argued that local analogies involve more superficial similarity between source and target, contrary to distant analogies. Superficial similarity may make local analogies easier to interpret (Gentner et al., 1993; Holyoak et al., 1987). Both local and distant analogies could involve deeper structural similarity. Distant analogies require an extensive domain knowledge which makes them more difficult in comparison to near analogies (Johnson-Laird, 1989). This is why experts are claimed to be easier at seeing structural similarities (Chi et al., 1981) in comparison to novices (Figure 2.8).

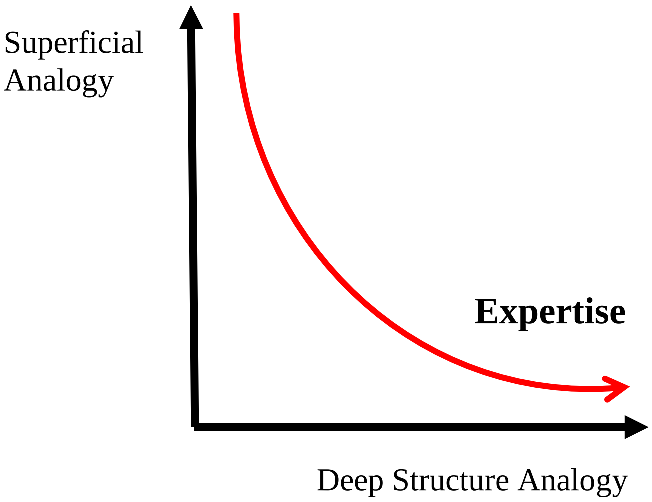



Figure 2.8. Superficial similarity, deep- structure similarity and expertise relation

Structural similarities, on the contrary, combine a system of higher order relations. According to Gentner (1983) the correspondence between a source and a target domain has to be in terms of a complex relational system of similar features, rather than in terms of perceptual similarity. Analogical reasoning requires an analysis of a source domain to its parts to reach its deep structure knowledge and underlying systems of relations. Many researchers have argued that the crucial defining characteristic of an analogy is structural similarity (Gentner & Markman, 1997; Vosniadou, 1989; Holyoak, 1985). A successful, useful analogy depends upon there being some sort of similarities between source and the target domain in deeper levels.

Generally researchers explained that these types of analogies increase creative thinking (Figure 2.9 and Figure 2.10). In literature it is claimed that transfer increases with similarity (Holyoak et al., 1987; Novick, 1988; Ross, 1987; 1989; Simon & Hayes, 1976).

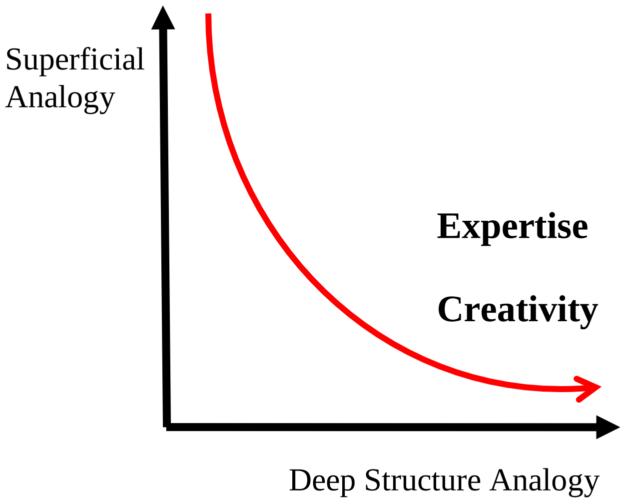



Figure 2.9. Superficial similarity, deep- structure similarity and creativity relation

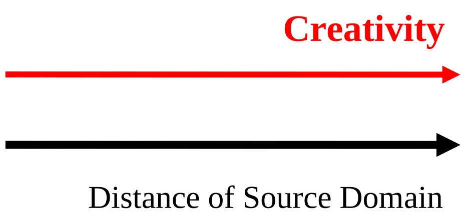



Figure 2.10. Distance of source domain and creativity relation

## 2.1.1.5. Depth of Analogy

Distinguishing between different types of similarity is essential to understand the analogy mechanism in a more holistic view. Gentner and Markman (1997) categorized different levels of relations as mere appearance similarity, analogy, literal similarity and anomaly (Figure 2.11), which refer to similarities at the level of superficial properties, at the level of structural properties, at the level of both superficial and structural, and no similarity respectively.

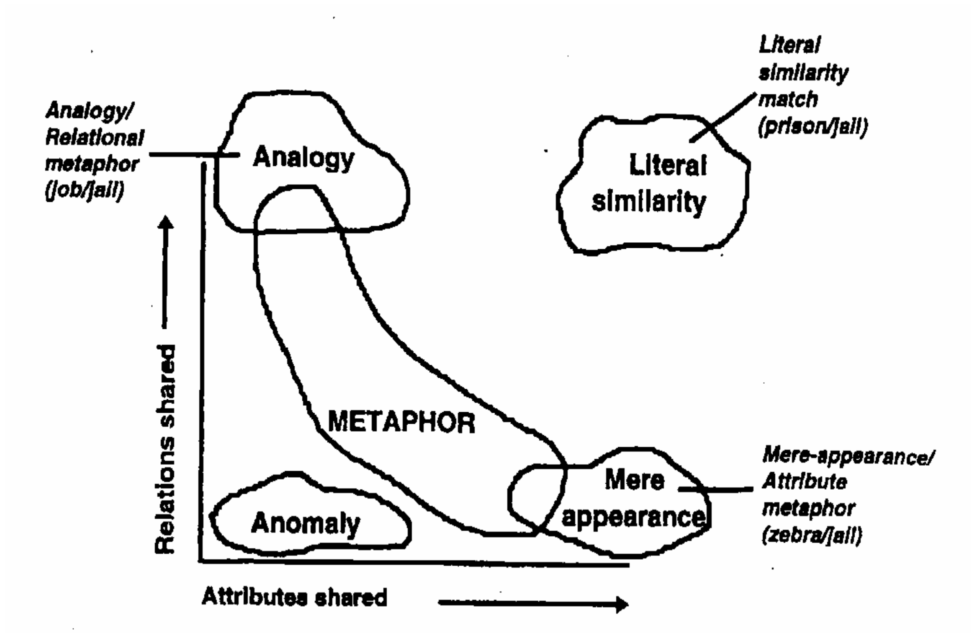



Figure 2.11. Similarity space, showing different levels of relations
(Source: Gentner & Markman, 1997)

In mere-appearance matches, the source domain attributes are the only ones to be transferred. In analogy, only relational properties are mapped. In literal similarity, both relations and source domain attributes are transferred. In anomaly neither relations nor attributes is transferred (Table 2.3 and Table 2.4).

Table 2.3. Kinds of domain comparisons
(Source: Gentner & Markman, 1997).

| | **ATTRIBUTES** | **RELATIONS** | **EXAMPLE** |
|---|---|---|---|
| **Literal Similarity** | Many | Many | Milk is like water |
| **Analogy** | Few | Many | Heat is like water |
| **Anomaly** | Few | Few | Coffee is like the solar system |
| **Mere Appearance** | Many | Few | The glass tabletop gleamed like water |

Table 2.4. Shared relations and attributes comparison

| | SUPERFICIAL SIMILARITY | NO SUPERFICIAL SIMILARITY |
|---|---|---|
| **DEEP-STRUCTURAL SIMILARITY** | LITERAL SIMILARITY | ANALOGY |
| **NO DEEP-STRUCTURAL SIMILARITY** | MERE APPEARANCE SIMILARITY | ANOMALY |

## 2.1.1.5.1. Mere Appearance Similarity

A mere-appearance match is one with overlap in lower-order predicates but not in higher-order relational structure. This type of match involves chiefly object attributes matches. Mere-appearance matches are in a sense the opposite of analogies. Mere appearance transfers fixate on formal characteristics, but use strategies inconsistent with those found in the target domain.

EXAMPLE 1. The world and a ball.

INTERPRETATION: Intended inferences include both object characteristics-e.g., The world is SPHERICAL like a ball.

## 2.1.1.5.2. Literal Similarity

A literal similarity match includes both object-attributes (object descriptions) and relational predicates, such as the systematic causal structure. In a literal similarity comparison, all or most of the relations would be mapped. In brief, surface similarity is merged with deep similarity in literal implementations. The strategy implemented is the same as the source domain, but the same forms carry out the strategy.

EXAMPLE 1. The Xl2 star system in the Andromeda galaxy is like our solar system.

INTERPRETATION: Intended inferences include both object characteristics-e.g., The Xl2 star is YELLOW, MEDIUM-SIZED, etc., like our sun, and relational characteristics, such as the Xl2 planets REVOLVE AROUND the Xl2 star, as in solar system (Gentner, 1983).

### 2.1.1.5.3. Analogy

An analogy is a comparison in which relational predicates or a common relational system, but few or no object attributes, can be mapped from base to target. Analogy is quite satisfied whether the source domain differs from the target domain in size, shape, color, and substance (Gentner, 1989). Analogies implement strategies found in the target domain without transferring the forms. In brief, analogy is based on deep structural similarities with relational abstractions. The target domain contains only abstract principles of source domains. There are no concrete properties of objects to be transferred.

Gentner (1983) clarified the distinction between literal similarities and analogies by referring how the objects are structured as schema. Objects are literally similar when the particular characteristics of the objects are the same. They are analogous when the relational structures are similar, but the particular characteristics of each object are not the same.

EXAMPLE 2. The hydrogen atom is like our solar system. The atom is a central force system like solar system.

INTERPRETATION: The relational structure: the electron REVOLVES AROUND the nucleus, just as the planets REVOLVE AROUND the sun, but not the common properties. The fact that the nucleus ATTRACTS the electron CAUSES the electron to REVOLVE around the nucleus from the fact that the sun ATTRACTS the planets CAUSES the planets to REVOLVE AROUND the sun (Gentner, 1983).

### 2.1.1.5.4. Anomaly

Anomaly occurs when there is no similarity or relation between source and target domain. An anomaly does not involve any apparent similarity between the concept and the source domain on which the concept is based. In this type of relations, the analogical reasoning strategy is unclear due to misinterpretation of the source domain that leads to extraction of incorrect strategies.

According to Gentner, mere appearance similarity, literal similarity and analogy have a continuum relation, not dichotomic (1989). Although adequate for prediction, literal similarity matches stated as probably less useful and limited than analogies for purposes of extracting causal principles (Forbus & Gentner, 1983; Ross, 1989).

### 2.1.1.6. Phases of Analogical Reasoning Mechanism

In cognitive science, there is general consensus that analogical transfer involves different sub-processes. These are shown in Figure 2.12.

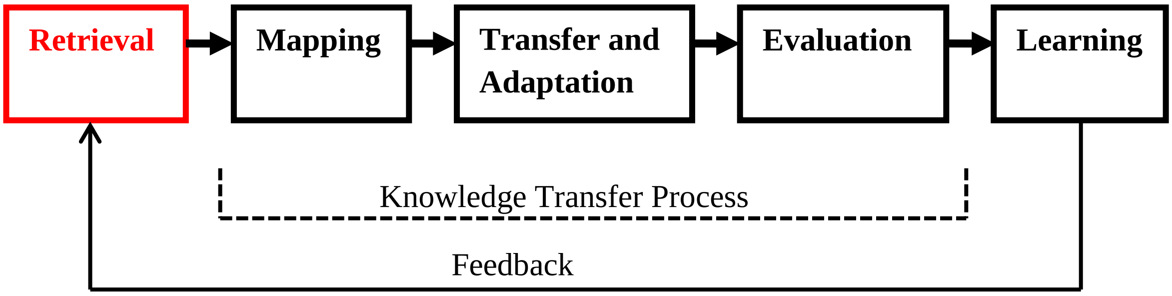



Figure 2.12. Phases of analogical knowledge transfer

Based on the research presented so far, it appears that different sub-processes are affected by different kinds of similarity. In analogy, there is a relational shift in processing analogy and similarity from surface to structural commonalities. Retrieval is strongly influenced by surface similarity and only weakly influenced by structural similarity (Holyoak & Thagard, 1989; Novick & Holyoak, 1991; Schunn & Dunbar, 1996; Hesse, 1991). Analogical mapping is strongly influenced by structural similarity, including shared systematicity; it may also be weakly influenced by surface similarity (Gentner, 1983; Holyoak & Thagard, 1989; Keane, Ledgeway & Duff, 1994). Transfer and adaptation involves creating new similarities and adapting them to target domain (Holyoak & Koh, 1987). Evaluation is chiefly influenced by structural similarity and systematicity. Finally, extracting and storing the principle underlying an analogy seems likely to be governed by structural similarity and systematicity (Clement, 1986; Gentner, 1988; Holyoak & Thagard, 1989; Keane, 1988; Novick, 1988).

#### 2.1.1.6.1. Retrieval

Retrieval refers to accessing a source domain (Figure 2.13). Surface similarity seems to be an important determinant of retrieval (Gentner & Landers, 1985; Gentner, Rattermann, & Forbus, 1993; Holyoak & Koh, 1986; Holyoak et al., 1987; Keane, 1987; Ross, 1987; Novick, 1988). Many studies found that retrieval is particularly difficult when surface similarity is unperceivable. During the retrieval stage, existing knowledge is used to retrieve source analogues that are similar either superficially or structurally (Gick & Holyoak, 1980; Gick & Holyoak, 1983; Anolli et al., 2001). Mapping on the other hand, has been found to be closely related to structural similarity (Gentner et al., 1993; Holyoak & Koh, 1987; Ross, 1987; Novick, 1988). The reason behind this is that people often fail to access structurally relevant knowledge of a source domain, even when they have this knowledge in their in long-term memory (Gick & Holyoak, 1980). Generally specific content knowledge or some pragmatic information is used to guide the analogical retrieval, rather than structural principles like systematicity (Hofstadter, 1984; Hofstadter, Mitchell, & French 1987).

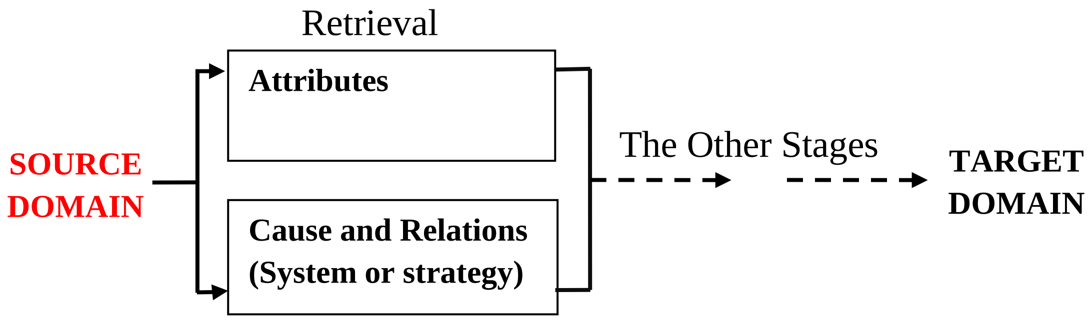



Figure 2.13. Surface feature and deep-structural similarity retrieval

Since objects from near domains share more superficial similarity than objects from remote domains and superficial similarity is an important factor of retrieval, some researches maintain that near domain sources will enhance within-domain analogies (Ward, 1998). In other words, the presence of local domain sources may make it hard for people to break away from local analogies, since superficial similarity dominates retrieval and distant domain sources will be more difficult to access.

### 2.1.1.6.2. Mapping

Research has been carried out to understand the cognitive processes people use for creating and understanding analogies (Falkenhainer et al., 1989; Gentner & Markman, 1997; Gentner et al., 2001; Hummel & Holyoak, 1997). Mapping is the core process in analogical design. Mapping consists of aligning representational structures to derive the similarities between source and target. In general it consists of matching two corresponding structures. In an analogical mapping process, a source domain is matched with a target domain. In analogical mapping the source domain is used as a model for making inferences about the target problem (Gentner, 1983; Holyoak & Thagard, 1989; Keane, Ledgeway & Duff, 1994). After finding the corresponding source object, reasoner tries to map the target domain, taking the object's relations as constraints in the mapping. Thus, finding the correspondences and projecting inferences are a crucial part of the mapping process.

In literature there are two different types of mapping defined. These are structure-driven and goal-driven mapping.

***Structure Mapping***

According to Gentner's structure-mapping theory (1983), analogical mapping involves setting up correspondences between source and target domains. It is a syntactic approach and relies on structural/relational commonalities. This model is not goal oriented and disregards content-context relationships. Structure mapping conveys a system of relations from the source domains to the target domains. Gentner (1983) emphasized that analogy is guided by structural constraints, and that analogical inferences will follow from mappings based on higher order relations (*the systematicity principle*) rather than surface attributes in the mapping process (Figure 2.14). Falkenhainer and colleagues (1989) proposed also that one-to-one correspondence should be unique and mapped syntactically.

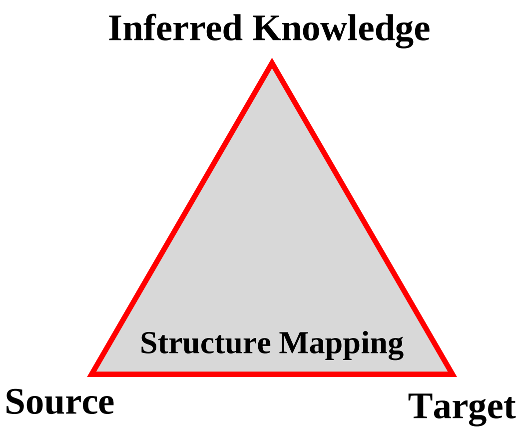



Figure 2.14. Structure mapping
(Source: Gentner, 1983)

*Analogical Constraint Mapping*

According to Holyoak's pragmatic approach (1985), constraint mapping involves setting up correspondences between source and target domains with respect to a goal and context of any case. In pragmatics goals and context guide the interpretation of an analogy (Figure 2.15). All stages of analogy are based on these goal states. Holyoak and Thagard (1989, 1990) combined this pragmatic focus with the assumption of structural consistency.

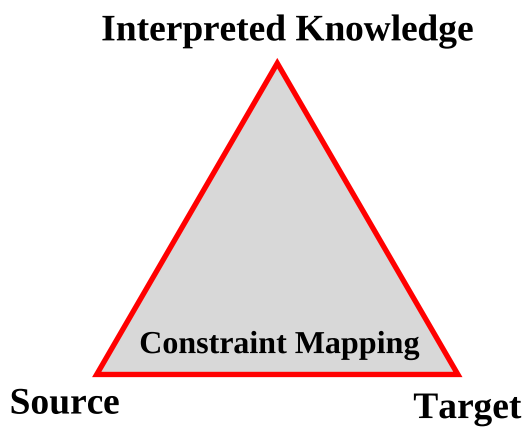



Figure 2.15. Analogical constraint mapping
(Source: Holyoak, 1985)

The main difference between their theory and Gentner's theory of analogy is the causal relations between the corresponding elements (higher order relations). In Holyoak and Thagard's theory, causal relations depend on and change with the context. Gentner's theory is based on one-to-one mappings and structural consistency which is based on syntactic relationship and is rigid with respect to contextual changes. In contrast, Holyoak's multi-constraint mapping (1985) reveals the various relations with respect to a goal and context in a more flexible manner. This approach allows the construction of a new schema based on inferences and predictions through the interaction of structural parallelism and pragmatic factors. In the pragmatic account, the distinction between structural commonalties and surface commonalties is based solely on relevance with respect to problem solving goals.

### 2.1.1.6.3. Transfer and Adaptation

According to Keane and his colleagues (1994) during the mapping stage one need to adapt the transferred knowledge to the target domain. In their study, they found that the process of adaptation act as a constraint on the retrieval stage. In this stage a possible inference can be modified to fit the target (Keane, 1996, Novick & Holyoak, 1991). In analogical design problem solving, this stage is executed by the generation of new knowledge using the established mappings. For each mapping the analogy creates new knowledge. Then, using the mappings between the source and the target domain, designers transfer knowledge from the source domain to the target. This transfer may happen in two ways: first there is a superficial transfer and second deep structural transfer. In the superficial transfer object attributes are transferred. In the second one causal relations are mapped across domains. Success of transfer depends critically on the level of structural relation (Holyoak & Koh, 1987) or in the principle applied (Novick, 1988; Ross, 1984, 1987). One transfers and adapts some of the knowledge derived from the source domain to the target domain. Adaptation and transfer often requires abstraction.

### 2.1.1.6.4. Evaluation

Once the common similarity and the candidate inferences have been discovered, the analogy is evaluated according to structural consistency with factual correctness of a source domain. In this stage inferences and analogy are improved (Forbus & Gentner, 1989).

### 2.1.1.6.5. Storage or Learning

Once the generic abstraction or the domain general knowledge has been discovered, it is extracted (as a model) for later use (Clement, 1986; Gentner, 1988; Hall, 1989; Holyoak & Thagard, 1989; Keane, 1988; Kedar-Cabelli, 1988; Novick, 1988; Thagard, 1988, Falkenhainer, Forbus et al., 1989; Holyoak and Thagard, 1995).

## 2.1.2. An Example from Design

One example from product design will help us understand how analogies used in design. Philip Stark’s design process for his famous lemon squeezer illustrates how a creative designer managed to transfer ideas from a biological source domain to product design (Figure 2.16) (Lloyd & Snelders, 2003).


Figure 2.16. Philippe Starck’s original sketches for the Juicy Salif lemon squeezer

Philippe Starck, while thinking about the design of a new lemon juicer, first retrieved the near source domains, i.e., conventional lemon squeezers, from his memory. He was not satisfied with the near source domains, however, and he quickly jumped to distant source domains. In his mind the squid fascinated him as a source potentially original source domain. The squid that he retrieved was a remote intra source domain and triggered a creative process. He recognized it from the mere appearance similarity. Then he started to adapt the squid to the problem in his hand and evaluated the lemon squeezer design. Philippe Starck’s analogy process is an example of a designer’s inspiration from a remote domain to generate a novel design idea. Including many stages the design process ended with a novel design object (Figure 2.17).


Figure 2.17. A photograph for Philippe Starck Juicy Stalif in 1989 (copyright Alessi)

Another example from architectural design is Santiago Calatrava's The Milwaukee Art Museum (Figure 2.18). Calatrava inspired by dynamism and movement of natural forms; especially by wings. His analogical transfer existed as kinetic architectural structure (Tzonis, 2004).

Figure 2.18. Bird drawing of Clatarava in 1987 and The Milwaukee Art Museum

## 2.1.3. Expertise and Analogical Reasoning Mechanism

Often the relationship to be established between a source and a target is mediated through level of expertise (Figure 2.19). The level of expertise is an important factor in problem structuring and problem representation and use of analogies (Dreyfus & Dreyfus, 1986; Novick, 1988; Casakin & Goldschmidt, 1999; Goldman 1982; Vosniadou 1989). Researchers found that novice and expert designers have some differences in the design process.

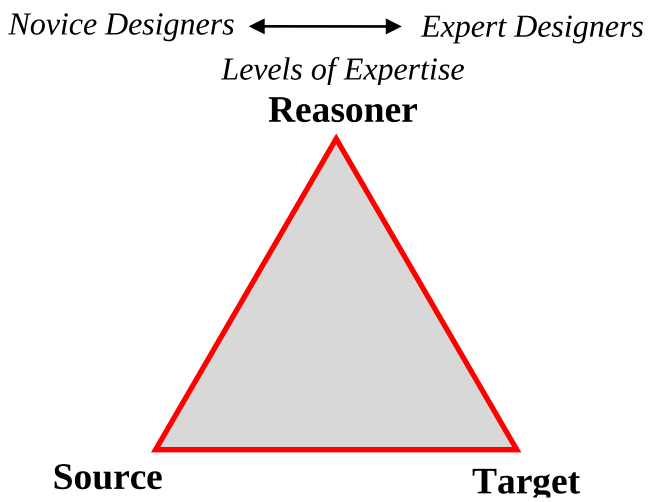



Figure 2.19. Expertise and analogical reasoning mechanism

Dreyfus and Dreyfus (1986) stated that the ability of analogical reasoning is important in developing expertise. They categorized five stages in the linear progression from novice to expert. One of the components Dreyfus and Dreyfus (1986) saw as a distinguishing mark of proficiency in performance was the ability to recognize new situations as similar to remembered situations (i.e., the ability to use visual analogies). They characterized novices as analyzers detaching the whole into little pieces while experts as experienced synthesizer, connecting and unifying the pieces into wholes.

Experts develop a conceptual understanding of the underlying nature of domain specific problems, which then enables them to recognize similar problems. Experts not only engage in schema-driven analogizing, but also spontaneous analogizing (Linden et. al, 2004). When an expert encounters a problem, an appropriate schema that is analogically related to the problem is automatically accessed (Gick & Holyoak, 1983). Novices, however, have not had the opportunity to develop a repertoire of analogically related schema because of their narrow knowledge base. Novices apply specific solution elements from prior design problems to current problems. Experts tend to establish deep structural analogies whereas novices tend to establish superficial analogies (Gick & Holyoak, 1983; Novick, 1988). They generally focus on common object properties or irrelevant features (Anderson, 1990; Newell & Simon, 1972). Ball et al. (2004) found that experts and novices alike use this method when experts encounter non-routine engineering design problems. Experts are capable of realizing larger and meaningful chunks of knowledge based on established connections between different domains

(Chase & Simon, 1972; Chi, Feltovich & Glasser, 1973; Chi et. al., 1982; Mayer, 1983). They are aware of relevant knowledge types that might be useful for problem solving because of their larger knowledge base (Ericson & Staszewski, 1989; Medin & Ross, 1989). The results of a number of developmental and expert/novice studies also showed that experts categorized problems differently from novices (Chi, Feltovich, & Glaser, 1981).

### 2.1.3.1. Visual Reasoning

Analogy often involves visual reasoning (Holyoak and Thagard, 1997). Some studies on visual analogy by Beveride and Parkins (1987) and Gick and Holyoak (1980) investigated the role of visual diagrams in ill-defined analogical problem-solving. Gick and Holyoak concluded that there is no relation between visual representations and problem-solving process. However, Beveride and Parkins (1987) and Novick (1988) demonstrated that the type of visual representation has an impact on the problem solving process. Thus the way problems are represented is considered a critical element of success or failure in analogical reasoning. Beveridge and Parkins (1987) pointed that the goal-driven abstraction (casual knowledge) is an important part of design process to find associations between source and problem domain and transfer of knowledge to the target domain.

### 2.1.3.2. Visual Perceptual Ability and Design Expertise

There is few research on the role of visual displays in design problem solving. Some examples are Goldschmidt (1995), Casakin and Goldschmidt (1999), and Casakin, (2010). Casakin and Goldschmidt investigated the role of visual displays in analogical reasoning in design. Casakin (2005) and Goldschmidt and Smolkov (2006), who studied the effect of visual displays on design performance, highlighted the importance of visual representations in design.

Even though visual analogy is a well-recognized method for design, few experiments exist focusing on visual analogy in design. Notable results from these experiments include the work of Casakin and Goldschmidt (1999), Ball, et al. (2004), and Kolodner (1997). This last found that visual analogies can improve design problem solving for both novice and expert architects. Visual analogy had a greater impact for novices as compared to experts (Gross & Do, 1995). Collins and Bustein (1989) found that effective problem solving with analogies depends on expertise, skills, and the use of visual analogy.

Other researchers have differentiated between the type of analogical reasoning used by experts and novices. Ball et al. (2004), for example, concluded that expert engineering designers use more schema-driven analogies while novice engineering designers use more case-driven local analogies. Schema-driven analogizing is the application of abstract knowledge to familiar problem types, which is cognitively more economical. Ball et al. (2004) concluded that experts store numerous models (design problem schemata) because they are exposed to and learn from many underlying systems of any domains.

According to the experimental study of Casakin (2004) both novices and experts transferred more between-domain than within-domain knowledge in visual analogy in design problem-solving. However, Casakin did not report the creative solutions of these studies. The experimental studies with visual analogies indicate that distant analogies are common in analogical design process. These studies also reported that the distance of source domain also played an important role in the generation of creative designs. However, Clement exerted that to project the inferences of distant domains, abstractions facilitate the analogical reasoning, therefore, are difficult to form without expertise (1994). Novices, as they are not sufficient to realize the relevant features, generally fail to transfer abstractions (Casakin & Goldschmidt, 1999).

#### 2.1.3.3. Abstraction Ability and Analogical Reasoning

Abstraction not only serves as a visual aid to store and retrieve conceptualizations, but as a medium of analogical reasoning to facilitate more ideas. Gick and Holyoak (1983), Beveridge and Parkins (1987), and Novick (1988) studied the role of visual representations and abstractions in analogical reasoning. The studies found that problem domain representation alter according to expertise levels. Daehler and Chen (1993) claimed that expertise is bounded to the way subjects represent knowledge and expertise develops the ability of forming abstract problem representations and structural mappings from source to target.

Abstractions in analogy serve as idea and solution generation tools which include both symbolic and in-detail knowledge. They facilitate transfer of knowledge and features derived from source domain to the target domain. Domain general or domain specific knowledge of source domain is brought together with target domain by these visual instruments.

#### 2.1.3.4. The Level of Inert Knowledge

The ability to access to a remote domain with deep structural similarity is based on the level of knowledge. By the development of knowledge base, the ability of seeing the structural relationships between superficially unrelated systems, and mapping more complex structures increase. Vosniadou (1989) stated that although critically limited by the information included in the knowledge base, analogical reasoning can act as a mechanism for enriching, modifying, and restructuring the knowledge base itself.

## 2.2. Summary

There is a wide range of findings regarding the relationship between analogical reasoning and expertise, distance of source and target, and type of similarity. In this thesis, analogical reasoning in design will be investigated through the interaction of these three factors (Figure 2.20). With regard to expertise, novices' and experts' analogical reasoning performances will be compared. With regard to the distance of source and target, the impact of four categories of source domains, ranging from local, regional, remote, and long-distant, on analogical reasoning will be compared. With regard to levels of similarity, four types of similarity, i.e., literal similarity, surface similarity, analogy, and anomaly, will be discussed in reference to designers' performance.

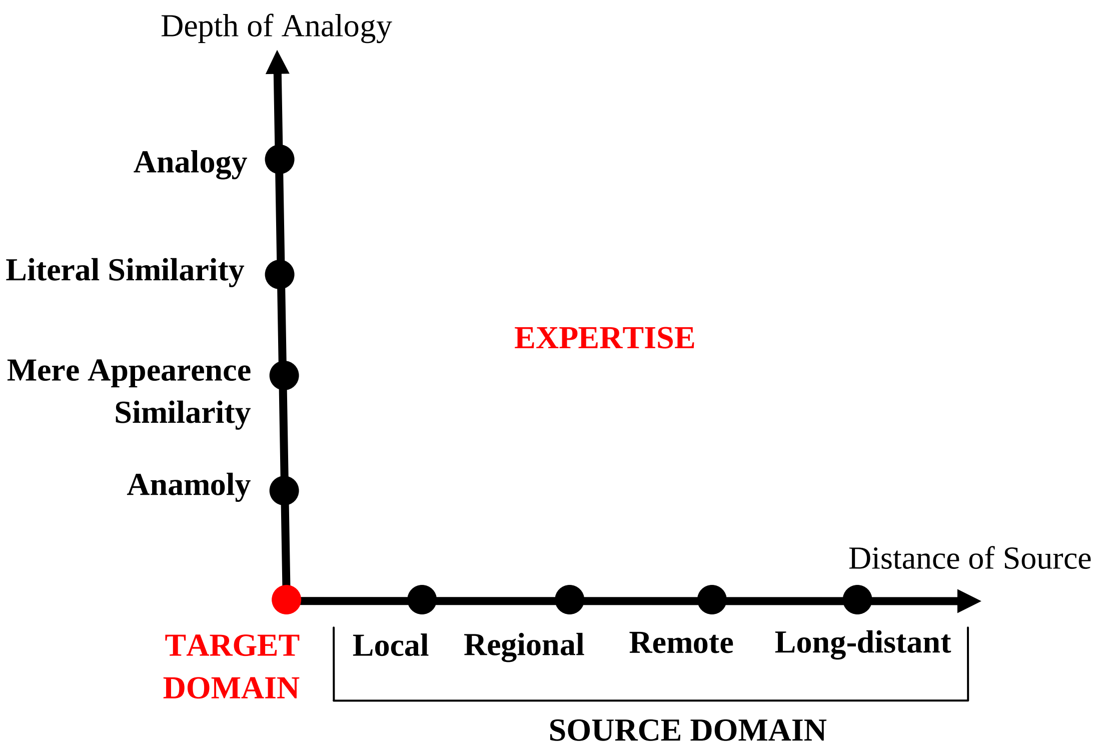



Figure 2.20. Distance of source domain, levels of similarity and expertise relation

Briefly, the main factors of analogical transfer should be relationally defined. The matrix of these parameters will reveal whether there is a linear relationship among distance of source, depth of transfer, and expertise.

# CHAPTER 3

# DEFINITION OF THE EXPERIMENT

An experimental study is conducted to better understand the mechanism of analogy in design. In the study, the distance of source domain to the target domain is manipulated to inquire whether there is a difference between different levels student designers (novice) and expert designers in their use of analogy. In the study, a number of issues were investigated in detail. First, how the participants rated randomly given source domain was explored. Second, a source domain group and an analogue selection and the reasons of source analogue selections of participants were inquired. Third, what they do with these selections was investigated. Fourth, their reasoning processes in the way they evaluated the utility of these sources with regard to the design problem to be solved were studied in detail.

## 3.1. Problem (Target) Domain

The novice and expert designers have different level and structure of knowledge. The complexity of the problem (*routine* versus *non-routine*) also affects the way reasoner creates a strategy (Gero and Maher, 1993). In this respect design situations may pose routine and non-routine problems according to the level and type of knowledge they will require. In order to make the *instructions* and *formulations* of the study equally accessible to both novices and experienced participants, a general, familiar, and easy design problem was given to the participants of the study. Moreover, it is well known that the design process may take over a long *time* and a designer may not be continuously thinking about a design problem. Therefore, the design task was defined within the boundaries of a very routine problem (bus stop design problem) in order to lessen as much as possible the adverse effects of the artificial context.

## 3.2. Source Domains

The assumption of the study is that the relevance of sources of inspiration and their distance to the target domain will be appreciated differently according to the level of expertise in design. In this respect, analogue sources were selected from four different source domains. These examples were drawn from bus stops, architecture, usual design objects, and nature, corresponding to local, regional, remote, and long-distant source domains. Initially, the examples were selected by consulting graduate students of architecture. To collect the visual data, the categories were searched on the web. First 320 examples of source analogues were identified. Selected 320 source examples were then reduced to 80. Then, three independent judges, who were expert designers, rated the set of 80 source analogues.

The first source domain group included images that are closely related to the design problem given; that is the group of bus stop examples. The second group included images that are removed from the design problem given, but related to the field of the design task: that is the domain of architecture. The third one included images that are farther removed from the problem of bus stop design task: that is the group of artifacts. Finally, the forth included images that is distant from, and unrelated to, the field of the design task: that is the group of nature (see the Appendix for a description of the experiment texts). Thus, the source example categories were defined as bus stops, architecture, artifacts, and nature. The goal was to understand how different kinds of source analogues serve as useful stimuli for different expertise levels (i.e., that enhance creativity) in design idea generation and whether there was a significant difference among different levels of expertise in their retrieval of source analogues.

### *Delphi Method*

For the selection of appropriate source domain examples from the collected data, Delphi method was used. Delphi method is a systematic process for obtaining proficient designers' views and seeking a large scale consensus among them on categorization in an expert panel. Secondly, it is based on expert opinion, especially preferred to avoid the drawbacks associated with the other methods of opinion gathering. Other reason to prefer this method was that the selection of the source domain examples was not amenable to analytical techniques, but could be drawn from a proficient group judgment. At the beginning of the panel to decrease subjective approach categories were explained by the information derived from literature. In the survey's first phase, we asked a series of images randomly presenting them by power point slight show. Each proficient designer attended to the Delphi Categorization Panel individually to avoid group-think. It was also open to controversial and disagreements amongst experts. In this respect, to reach a consensus through an iterative feedback, the participants were asked to respond to structured and scaled categories. Additionally, the item clarity was expected to prevent the invalid results in this limited time procedure. For the convergence of categorization, iterations realized through e-mail procedure to avoid pressure towards convergence. The method was effective since a large scale consensus was reached in two rounds.

The judging procedure is presented in Table 3.1. The judges were provided with the set of 80 (20 images from each group) source objects presented as one mixed group. The source domains were rated by a scale of 1 to 5: 1 (poor), 2 (fair), 3 (average), 4 (good), 5 (excellent). Euclid method was used to analyze the results of the ratings. In two rounds of rating, full agreement was reached among the judges. For the first round of rating, all scores with a standard deviation less than one was considered equal. In the first round, there was agreement on 69 out of 80 source analogues. In the second round of rating, there was a full consensus among the judges for the remaining 11 source analogues.

Table 3.1. The steps of the Delphi method

| *Delphi Method:* | |
|---|---|
| (1) | Step 1: Selection of 80 different source domains |
| (2) | Step 2: Selection of experts |
| (3) | Step 3: Rating 80 images (1 to 5) |
| (4) | Step 4: Analyze the answers to the first round ratings-standard deviation SD<1 |
| (5) | Step 5: Second round rating for SD>1 for each expert without showing the results |
| (6) | Step 6: Summarize the results |

The information obtained through Delphi method was used as input to first task and second task as source domain examples.

## 3.3. The Structure of the Experiment

This study was designed to inquire about the analogical connections between the source and target domains that novice and expert designers establish. In the study, the participants were expected to derive some knowledge from the selected source domain, and then apply it to the design in hand. The important point here is to understand how and why novice and expert designers will retrieve and convey specific ideas and concepts from the selected source domain and transfer it to the design task.

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 for the given design problem; second, selecting a source domain group and explaining the selection criteria, and third, designing a bus stop.

### 3.3.1. First Task

The first task was conducted to analyze whether there is a difference among participants in their source example ratings. Participants were asked to rate randomly given 40 source domains using a scale of 1-to-5: 1(Poor), 2(Fair), 3(Average), 4(Good), and 5(Excellent). For this task, the category information for the source analogues was not provided. Participants were allowed to look the source examples once and limited with 15 seconds for each images. In first task, the images were presented in power point slight show presentation.

### 3.3.2. Second Task

The second task consisted of two sub-tasks. One focused on the selection of the source domain, other focused on the reasons of selections.

### 3.3.2.1. Task A

The first task was oriented toward analyzing whether there is a difference among participants in their source domain selections. Different from the first task, the category information for the source analogues was provided in the second task. Specifically, participants were asked to select one of the four source domain groups and a specific source example from within this group. Participants were allowed to look the source examples as long as they wanted in Task 2 and Task 3. In Task 2, the source examples were presented in a frame that was approximately vertically 5 centimeters and horizontally 6 centimeters. The photos of the examples were presented once and approximately in similar frames.

### 3.3.2.2. Task B

As a follow-up to the previous task, here participants were asked to state the reasons for their selections. The first aim was to determine the goals behind the participants' selections. Participants were expected to explain what aspects of the selected source domains they considered as relevant for dealing with the design problem at hand. They explained the utility of the sources they selected with regard to the design problem. The second aim was to determine whether there is a relationship between expertise level and the stated reasons.

***Content Analysis***

Textual data were analyzed by a purely descriptive, systematic content analysis method. Content analysis is appropriate for analyzing the textual material systematically to enlist the source domain selection reasons of the participants. It consists of word counts. The first aim of the content analysis is not to reveal the underlying motives for the observed pattern of data, but to understand the nature of the textual data according to categorical variables which is derived from literature and organized as a coding manual according to research strategy of the study. The words were defined according to literature review and used as items of content analysis. The second aim was to reveal the correspondences between the results of the analysis of numerical and categorical data. The method may have some theoretical and procedural limitations. The analysis is limited by textual data gathered from 396 participants. The coding was made disregarding the laboratory context that the text produced. The coding scheme may be inherently reductive. However it is useful to understand the parallel connectivity of textual, numerical and categorical data. The analysis was backed up by a table and statistical summaries.

### 3.3.3. Third Task

The third task was conducted to analyze whether there is a relationships between expertise and what they do with the selected source analogue. In this task, participants were told to design a bus stop. They were required to use analogy in their designs.

***Delphi Method***

Delphi method was used in this categorization procedure. The categorization of the target domain outputs were not amenable to analytical techniques, but could be drawn from a proficient group judgment. To reach a consensus through an iterative feedback, the participants were asked to respond to scaled structured detailed categories. The designs were categorized according to the level of analogy parameters: 1 (Anomaly), 2 (Mere Appearance Similarity), 3 (Literal Similarity), 4 (Analogy). The respondents were three judges, who were proficient designers. They were provided with the set of 378 design solutions presented as one mixed group. For the convergence of categorization, iterations were conducted through e-mail procedure to avoid pressure towards convergence. The item clarity was expected to prevent the invalid results in this procedure. Euclid method was used to analyze the results of the categorizations. In three rounds of categorizations, there was full agreement among the judges. In the first round, there was 84% agreement, while in the second there was full agreement for all the remaining design solutions, except three, which were categorized again in the third round (Table 3.2).

Table 3.2. The steps of the Delphi Method

| *Delphi Method:* |
|---|
| Step 1: Categorization of 378 different target domains (1 to 4). |
| Step 2: Analyze the categorizations that respondents did not get agreement on. |
| Step 3: Categorization of 59 disagreed different target domains. The respondents were not asked the fourth category that they eliminated in the 1. Step categorization. |
| Step 4: Analyze the categorizations that respondents did not get agreement on again. |
| Step 5: Categorization of 3 disagreed different target domains. The respondents were not asked the fourth category that they eliminated in the 2. Step categorization again. |
| Step 6: Analyze the categorizations that respondents agreed on again. Minimum 2 agreements were enough for categorization of target domains. |

In task 3 the input obtained from Delphi method were used as numeric data to investigate the frequencies of analogy levels.

## 3.4. Time

In this research the main point was to understand the perception of information level in the suggested time limits. Two pilot studies were conducted to better organize the procedure of the experiments and to finalize the time allotments. The time limits were accurately determined and extended well beyond required for the participants after the pilot experiment. In the first task, each visual display was presented for 15 seconds in the thought that in a very short space of time, generally reasoner focuses on the main points of the problem. It took in total six minutes to complete these tasks. Task 2 and Task 3 took maximum 40 minutes in total.

## 3.5. Participants

The research design was planned considering these differences (e.g. educational and experiential differences, demographic and age differences). Participants in this study were either novice or experienced designers (Figure 3.1). Participants as novice designers in this study were recruited from two sources: students from Dokuz Eylül University (DEU) and from Izmir Institute of Technology (IYTE) majoring in architectural design.

Experts were proficient architectural designers with at least 10 years of experience. They were experienced on both practice, and design education. ‘‘Novice’’ designers were first year students who had no particular experience in design, second year, and fourth year bachelor students in architecture (Figure 3.1). Of the 394 participants, 374 were novice designers from different levels ($n$ = 171 first year; $n$ = 115 second year; and $n$ = 88 fourth year) and 22 were experts. From 374 novice designers participated to the study 68 first year students were from IYTE and 104 were from DEU, 68 second year students were from IYTE and 60 were from DEU, 44 fourth year students were from IYTE and 44 were from DEU. 254 designers were female (64 %), 142 designers were male (36%) with an average of 21 years old. The students enrolled in the research as part of their course.

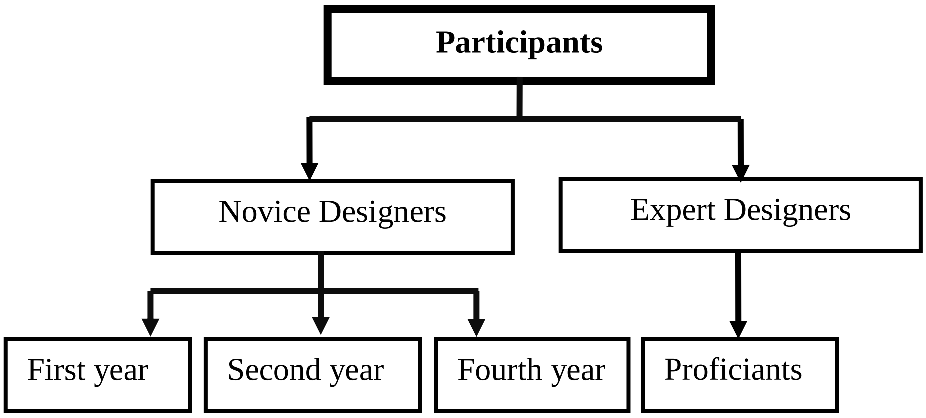



Figure 3.1. The considered expertise levels for the study

## 3.6. Procedure of the Experiment

Throughout the design process participants were expected first to generate bus stop design, and second to write down the knowledge they interpreted from the source domain they retrieved. Participants were also instructed to use words and/or sketches to describe their ideas. They were asked not to discuss the experiments with their classmates until the experiment was completed. Participants were given a one-page introduction for the first task including rating table of 40 mixed images. The introduction told participants about the general goals of the study and the bus stop design problem. Then they received a presentation of analogical reasoning and architectural design examples. The presented architectural design examples were local, regional, remote and long-distant analogies. They were told that they were expected to rate the given 40 source examples imagining that they would design a bus stop in analogy to the given examples. 15 second were given to rate each image. The overall time limit was 6 minutes to complete Task 1. They were also informed about analogy and how distance of source and target relationship might impact the creative potentials of a design.

All groups were provided with the same instructional conditions. They were provided with power point presentation that had visual and verbal instructions on what an analogy is and the examples of different source domain analogies. Participants did not receive any instructions which could lead them in a specific direction. Rather they received a definitive and explanatory instruction at the beginning of the experiment. For example, the words that were thought to be used in content analysis were not highlighted in the instruction procedure. Rather, the information about analogical reasoning was told.

Novice designers attended the experiment in seminar rooms. Expert designers attended the experiment in their own office rooms. They were asked not to discuss the experiments with other participants until all the experiments were completed.

## 3.7. Material

In Task 1 participants were given one A4-size page to rate the source examples. After explaining the analogy and the experiment, they were shown 40 images through a Power Point presentation. In Task 2, they were given seven A4-size pages: one-page for source group selections, four pages for four different source domain groups, one-page for explaining the selection criteria, and one page for the design tasks. They were told that they were expected to retrieve one source group and one example from this group that they want to use in their analogical design process. They were also told that they expected to explain their selection of source domain and the knowledge(s) they gathered to use in their idea generation process. They were expected to make some abstractions using diagrams and text. Novices were provided with the same schedule of conditions as the one provided for experts.

## 3.8. The Quantitative Analysis of Data

The data gathered consisted of textual, pictorial, verbal and quantitative data. The following analyses were conducted to study the different types of data.

1. Reliability Analysis for the Source Domain Items
2. Analysis of the Within Domain and Between Domain Differences according to Factor(s); Univariate and Multivariate Analysis of Variance-ANOVA and MANOVA (Factorial Design) and K-Independent Samples Procedure: The Kruskal-Wallis Test
3. Analysis of the Relations of Factors; Chi-Square Test
4. Descriptive Analysis

*Why these statistical tests are conducted?*

The item analyses (*Reliability Analysis*) was conducted to decide which items (Question) to include or to exclude from a scale. The experiment was determined with a set of hidden categorical variables. Multivariate analysis of variance (MANOVA) was conducted to determine the effect of the four level of expertise (first year, second year, fourth year, and experts) on the 40 dependent variables (Question1G2 to Question40G4) test scores. The Kruskal Wallis test was used to measure one independent variable with four expertise levels and with four question group levels as an ordinal and nominal dependent variable. Chi-square test was conducted to assess whether there is a relationship between two categorical variables, i.e., group selection and expertise level.

### 3.8.1. First Task

The experiment was conducted in which more than one dependent variable is measured. The design of the study was based on analysis of questions' (variance) ratings. An analytic procedure that comes very naturally is multivariate analysis, matrix of factors and dependent variables. Because, more than one dependent variable (variance) provides the basis for understanding the necessity of multivariate analysis (Hease & Ellis, 1987) with inter-correlation among the dependent variables. The experiment is determined with a set of hidden categorical variables to explain the variability again in a set of continuous categorical variables. 40 different dependent variables defined which all measure different aspects of four cohesive theme groups (bus stop, architecture, artifacts, nature) according to the four level of expertise (first year, second year, fourth year, and experts). The independent or grouping variable (the factor of expertise levels) divides individuals into more than one or two groups. Multivariate analysis of variance (MANOVA) was conducted to determine the effect of level of expertise on source examples (Question1G2 to Question40G4) test scores.

In this research the aim to use the factorial MANOVA test is to measure whether independent variable creates difference. Also the Kruskal Wallis test was used to measure one independent variable with four expertise levels and with four source domain groups as an ordinal and nominal dependent variable. In other words, it is the non-parametric version of ANOVA since it permits the analysis of two groups. The Kruskal Wallis test was used to measure which independent variable creates difference.

### 3.8.2. Second Task

#### 3.8.2.1. Task A: Numeric Data Analysis

For the first part of the second task, Chi square test was used to determine whether retention frequencies were significantly related. This test is conducted to assess whether there is a relationship between two categorical variables group selection and expertise level. SPSS database used to obtain the test statistic and its associated p-value.

#### 3.8.2.2. Task B: Textual Data Analysis

For the second part of the second task, the data were analyzed according to the design categories below (Table 3.3). They are based on the superficial to deep-structural information and whole and parts, parts and parts relations. The important point here is in which level the experimenters made interpretations and derived knowledge from source domains.

Table 3.3. Possible design parameters designers expected to consider

| | First year | Second year | Fourth year | Experts |
|---|---|---|---|---|
| Mere Appearance-Formal | | | | |
| Function | | | | |
| Structural Relation | | | | |
| Casual Relation | | | | |
| Originality | | | | |
| Design Process | | | | |

### 3.8.3. Third Task: Visual Data

For the last task, the designs were categorized by three independent judges who were experts in the field of design. All judges were designers and design instructors who did not know the participants. Categorization is made according to level of similarity type to understand to what extent novice and expert designers generate original analogies in their design and what forms of analogy they use.

To analyze the experimental data expertise levels, distance of source, analogy levels, and analogy process are compared and correlated according to their sub-parameter. Table 3.4, Table 3.5, Table 3.6, and Table 3.7 demonstrate how the comparison of analogical reasoning mechanism parameters was organized. Table 3.8, Table 3.9, and Table 3.10 display how the cognitive behaviors of novice and expert designers in analogical reasoning process was studied.

Table 3.4 demonstrates how the selection of source domain changed according to levels of expertise. The matrix of these parameters will reveal the relationship between expertise and distance of transfer.

Table 3.4. Correlations among distance of domain and levels of expertise

| | First year | Second year | Fourth year | Experts |
|---|---|---|---|---|
| Local | | | | |
| Regional | | | | |
| Remote | | | | |
| Long-distance | | | | |

Table 3.5 demonstrates how the analogy levels of target domain changed according to levels of expertise. The matrix of these parameters will reveal the relationship between expertise and distance of transfer.

Table 3.5. Correlations among level of analogy and levels of expertise

| | First year | Second year | Fourth year | Experts |
|---|---|---|---|---|
| Mere Appearance Similarity | | | | |
| Literal Similarity | | | | |
| Analogy | | | | |
| Anomaly | | | | |

Table 3.6 demonstrates how analogy levels of generated target domain changed according to distance of source domain selected. The matrix of these parameters will reveal the relationship between expertise and depths of transfer.

Table 3.6. Correlations among distance of source and level of analogy

| | Local | Regional | Remote | Long-distant |
|---|---|---|---|---|
| Literal Similarity | | | | |
| Analogy | | | | |
| Mere Appearance Similarity | | | | |
| Anomaly | | | | |

Table 3.7 demonstrates how analogical reasoning process differed according to levels of expertise. The matrix of these parameters will reveal the relationship between distance of source and depths of transfer.

Table 3.7. Correlations among expertise levels and analogy process

| | Retrieval | Mapping | Adaptation | Evaluation | Storage |
|---|---|---|---|---|---|
| Novice | | | | | |
| Expert | | | | | |

Table 3.8 demonstrates source domain selection or rejection criteria according to levels of expertise.

Table 3.8. Novice and expert textual and audial data analysis

| Level of Expertise | Source Domain | Reasons for Considering | Reasons for Rejecting |
|---|---|---|---|
| | | | |
| | | | |

Table 3.9 demonstrates mostly considered design parameters in source domain and an example selection stage.

Table 3.9. Design parameters that expert and novice designers considered

| **Parameters** | **Novice Designers** | **Expert Designers** |
|---|---|---|
| | | |
| | | |

Table 3.10 demonstrates how cognitive behaviors diverged in analogical reasoning process. Differences between novice and expert designers will be summarized considering below parameters.

Table 3.10. Differences between novice and expert designers

| **Common Behaviors** | **Novice Designers** | **Expert Designers** |
|---|---|---|
| Distance of Source and Target | | |
| The Level of Similarity | | |
| Similarity Type | | |
| Level of Knowledge | | |
| Idea Generation | | |
| Solution Generation | | |
| Reasoning Type | | |
| Goals | | |

### 3.8.4. The question asked in the interview

At the end of the study, the participants were asked to discuss the following questions to determine further the reasons for their ratings, selections, explanations, and designs. The answers to the questions tape recorded. The audial data were analyzed to investigate the cognitive behaviors and differences among expertise levels. The questions asked in the interview were:

- What do you think about analogy and analogical reasoning? And what did you think about this study?
- While searching an example for a source domain what do you consider most? Do you generally focus on near domain examples or examples from the other domains?
- In the scope of this study, which one of the source domains did you focus? Why?
- Which type of information do you first consider?

The answer of these questions will reveal the reasons behind the cognitive behaviors of participants.

# CHAPTER 4

# RESULTS OF THE EXPERIMENT

## 4.1. Questions of the Research

Before getting into reporting and discussing the results, it will be useful to remind the research questions of each task Figure 4.1.

*First Task:*

Whether there is a difference among *participants with different expertise level* in their *source example rating*.

*Second Task:*

Whether there is a difference between participants with different expertise level in their source domain group selection, when the category information is disclosed.

*Task A*:

What are the differences among participants in their stated reasons about the selection of source domains?

*Task B*:

Whether there is a relationship between expertise level and level of similarity they establish with the source domain.

*Third Task:*

What are overall relations among level of expertise, distance of source and level of analogy?

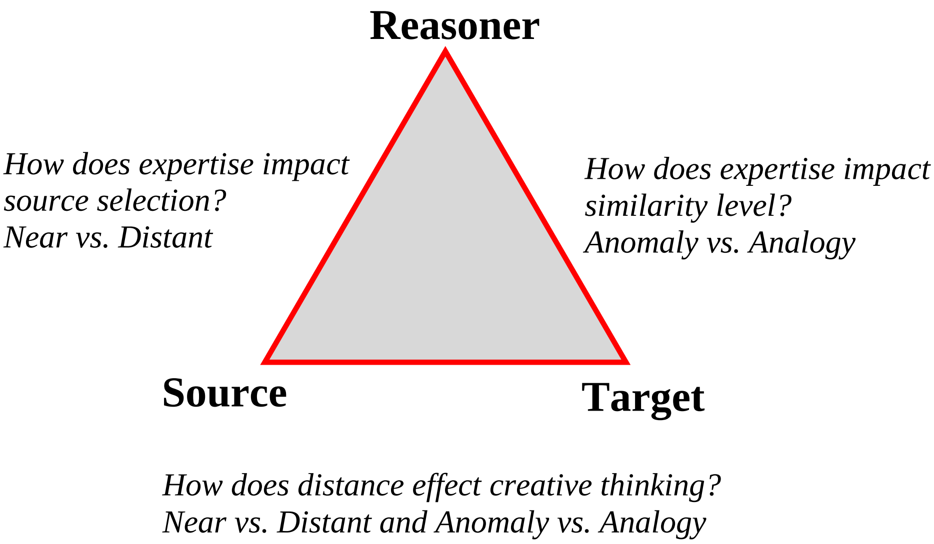



Figure 4.1. The research questions of each task

## 4.2. Reliability Analysis of Source Domains

A reliability analysis is conducted to determine which of the source examples shown in the study should be included or excluded from the experiment. The objective of reliability analysis in this research is to select a set of source examples that yields a summed score that is more strongly related to the construct of interest than any other possible set of source examples.

Based on SPSS analysis results it appears that no source example was different from the rest of the source examples. Accordingly, none of the source examples was eliminated (Table 4.1 and Table 4.2).

Table 4.1. Reliability Test

| **Reliability Test** | | |
|---|---|---|
| **Cronbach's Alpha** | **Cronbach's Alpha Based on Standardized Items** | **N of Items** |
| ,831 | ,834 | 40 |

Table 4.2. Item-Total Test for source domain examples

| **Item-Total Test** | | | |
|---|---|---|---|
| **ITEMS: Questions (Source Domains)** | **Cronbach's Alpha if Item Deleted** | **ITEMS: Questions (Source Domains)** | **Cronbach's Alpha if Item Deleted** |
| Question1G2 | ,829 | Question21G1 | ,826 |
| Question2G4 | ,829 | Question22G4 | ,827 |
| Question3G3 | ,830 | Question23G1 | ,829 |
| Question4G4 | ,829 | Question24G3 | ,831 |
| Question5G2 | ,828 | Question25G3 | ,831 |
| Question6G1 | ,835 | Question26G4 | ,826 |
| Question7G1 | ,831 | Question27G4 | ,821 |
| Question8G1 | ,831 | Question28G3 | ,827 |
| Question9G4 | ,830 | Question29G3 | ,827 |
| Question10G1 | ,828 | Question30G1 | ,826 |
| Question11G3 | ,825 | Question31G3 | ,824 |
| Question12G4 | ,825 | Question32G2 | ,824 |
| Question13G4 | ,825 | Question33G3 | ,830 |
| Question14G2 | ,829 | Question34G1 | ,828 |
| Question15G1 | ,831 | Question35G2 | ,825 |
| Question16G4 | ,827 | Question36G2 | ,829 |
| Question17G2 | ,828 | Question37G1 | ,830 |
| Question18G3 | ,828 | Question38G2 | ,823 |
| Question19G2 | ,826 | Question39G2 | ,827 |
| Question20G3 | ,829 | Question40G4 | ,827 |

### 4.2.1. Results of First Task

With this task, the relationship between the cognizing agent and the source domain is investigated (Figure 4.2).

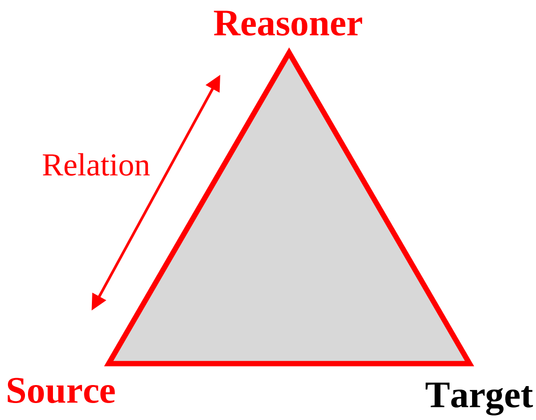


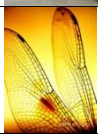

Figure 4.2. Interaction between the designer and source domains

A multivariate analysis of variance (MANOVA) was conducted to determine the effect of the four levels of expertise (first year, second year, fourth year, and experts) on the *40 source examples'* rating scores. Significant differences were found among the four expertise level on the dependent measures, Wilks'$\Lambda$=0.43, $F(120,999)=2.7$, $p<.05$ alpha level (Table 4.3). Table 4.4 contains the means and the standard deviations on the *40 source domains* for the four expertise level groups. A univariate analysis of variances (ANOVA) on each source domain was conducted as follow up test to the MANOVA. A Kruskal-Wallis Test also was conducted to evaluate and control differences among the expertise levels on the 40 source domains rating scores.

Table 4.3. Source domain rating difference between expertise levels

| **Multivariate Test** | | | | | | |
|---|---|---|---|---|---|---|
| | | **Value** | **F** | **Hypothesis df** | **Error df** | **Sig.** |
| Expertise level | Wilks' Lambda | ,431 | 2,696 | 120,000 | 998,532 | ,000 |

Table 4.4. Comparison between Kruskal-Wallis and Univariate Test

| **Comparison between Kruskal-Wallis and Univariate Test and Mean Differences** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Mean** | | | | | | |
| **Source Domain No** | **First year** | **Second year** | **Fourth year** | **Experts** | **Kruskal Wallis Asymp. Sig.** | **Univariate Tests Sig.** | **The Visual Representation of Source Domain** |
| **Question 1G2** | 3,41 | 3,17 | 3,37 | 3,32 | **,228** | **,374** |  |
| **Question 2G4** | 3,24 | 3.00 | 2,72 | 3.00 | **,007** | **,013** |  |
| **Question 3G3** | 3,30 | 3,20 | 3,11 | 2,68 | **,078** | **,115** |  |
| **Question 4G4** | 3,34 | 3,22 | 3,26 | 3,14 | **,489** | **,794** |  |
| **Question 5G2** | 3,88 | 3,81 | 3,84 | 3,91 | **,972** | **,958** |  |
| **Question 6G1** | 2,87 | 2,96 | 2,80 | 3,73 | **,026** | **,025** |  |
| **Question 7G1** | 3,88 | 3,86 | 3,70 | 4,09 | **,397** | **,467** |  |
| **Question 8G1** | 2,41 | 2,71 | 3,01 | 3,91 | **,000** | **,000** |  |
| **Question 9G4** | 2,49 | 2,29 | 2,14 | 2,64 | **,091** | **,081** |  |
| **Question 10G1** | 3,03 | 3,06 | 3,03 | 3,50 | **,306** | **,291** |  |
| **Question 11G3** | 2,74 | 2,56 | 2,06 | 3,27 | **,000** | **,000** |  |
| **Question 12G4** | 3,37 | 3,16 | 2,86 | 3,09 | **,007** | **,024** |  |

**(cont. on next page)**

Table 4.4. (cont.)

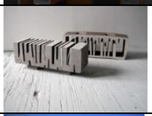
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Question 13G4** | 3,72 | 3,33 | 3,20 | 3,46 | **,001** | **,002** |  |
| **Question 14G2** | 3,26 | 2,87 | 3,14 | 2,64 | **,019** | **,014** |  |
| **Question 15G1** | 3,32 | 3,13 | 3,24 | 3,64 | **,274** | **,211** |  |
| **Question 16G4** | 3,69 | 3,48 | 2,98 | 3,14 | **,000** | **,000** |  |
| **Question 17G2** | 4,33 | 4,03 | 3,64 | 3,68 | **,000** | **,000** |  |
| **Question 18G3** | 2,90 | 2,86 | 2,20 | 2,50 | **,001** | **,000** |  |
| **Question 19G2** | 3,47 | 3,36 | 3,36 | 3,59 | **,638** | **,645** |  |
| **Question 20G3** | 3,25 | 3,41 | 3,30 | 3,00 | **,405** | **,490** |  |
| **Question 21G1** | 3,39 | 3,19 | 3,37 | 3,55 | **,324** | **,383** |  |
| **Question 22G4** | 3,29 | 2,62 | 2,33 | 2,64 | **,000** | **,000** |  |
| **Question 23G1** | 3,42 | 3,26 | 3,14 | 3,46 | **,252** | **,238** |  |
| **Question 24G3** | 2,55 | 2,68 | 2,93 | 3,14 | **,038** | **,025** |  |
| **Question 25G3** | 2,69 | 2,76 | 3,11 | 2,86 | **,062** | **,082** |  |
| **Question 26G4** | 2,98 | 2,63 | 2,25 | 2,32 | **,000** | **,000** |  |
| **Question 27G4** | 3,59 | 3,17 | 2,85 | 3,23 | **,000** | **,000** |  |
| **Question 28G3** | 2,93 | 2,55 | 2,26 | 2,41 | **,001** | **,000** |  |

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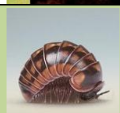
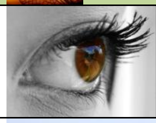
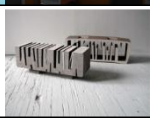
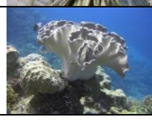
Table 4.4. (cont.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Question 29G3** | 2,56 | 2,09 | 2,16 | 2,32 | **,018** | **,004** |  |
| **Question 30G1** | 3,52 | 3,18 | 2,88 | 3,10 | **,001** | **,001** |  |
| **Question 31G3** | 3,60 | 3,27 | 2,69 | 3,27 | **,000** | **,000** |  |
| **Question 32G2** | 3,45 | 3,09 | 2,84 | 3,32 | **,001** | **,000** |  |
| **Question 33G1** | 3,20 | 3,26 | 3,50 | 4,09 | **,006** | **,007** |  |
| **Question 34G1** | 3,82 | 4,04 | 4,00 | 4,09 | **,238** | **,252** |  |
| **Question 35G2** | 3,75 | 3,29 | 3,14 | 3,14 | **,000** | **,000** |  |
| **Question 36G2** | 3,76 | 3,52 | 3,41 | 3,50 | **,015** | **,049** |  |
| **Question 37G1** | 3,39 | 3,26 | 3,06 | 3,86 | **,008** | **,017** |  |
| **Question 38G2** | 3,28 | 2,83 | 2,46 | 3,05 | **,000** | **,000** |  |
| **Question 39G2** | 2,97 | 2,73 | 2,54 | 2,91 | **,028** | **,019** |  |
| **Question 40G4** | 3,03 | 3,12 | 2,53 | 2,59 | **,006** | **,009** |  |

Both Univariate test and Kruskal-Wallis test results were indicating a fairly strong relationship on the nearly same source examples among the participants on the dependent measures, $p<.05$ alpha level. In the univariate test, participants rated significantly differently 26 source domains were. 14 source examples were nonsignificant. After eliminating 14 source examples (outliers) the MANOVA test was repeated. A fairly strong difference among participants was found in the second step of the test. These 26 examples created the significant difference.

The procedure indicated that rating of source domain significantly differed according to the expertise levels as shown in Table 4.5.

Table 4.5. Source domain groups rating differences

| **SOURCE DOMAIN GROUPS** | **BUS STOP** | **ARCHITECTURE** | **ARTIFACTS** | **NATURE** |
|---|---|---|---|---|
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |
| 4 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |
| 7 |  |  |  |  |
| 8 |  |  |  |  |
| 9 |  |  |  |  |
| 10 |  |  |  |  |
| **Nonsignificant results** | **6 nonsignificant** | **3 nonsignificant 1 marginally sig.** | **3 nonsignificant** | **2 nonsignificant** |

In the univariate test nonsignificant differences were obtained from all four source domain groups (Table 4.5). There were six nonsignificant examples from the group of bus stop, three nonsignificant and one marginally significant from the group of architecture, two nonsignificant and one marginally significant from the group of artifacts, and two nonsignificant source example from the group of nature.

In this analysis, statistical results revealed that generally participants rated differently the nature source examples (long-distant domain). All the participants most likely lacked deep-structural knowledge about the examples of nature. Their ratings must be based on surface features of these examples. In contrast to examples from nature, participants did not rate differently local domains. Both surface and deep features of bus stop examples were relatively easier to perceive in this analogical design experiment. The difficulty in perceiving deeper structural features increased with the distance of the source domains to the target domain. Architecture examples were difficult to perceive. Artifacts, which were remote domain examples, were even more difficult.

Below descriptive graphics revealed how randomly given *source domain* rating differs according to expertise levels question (Table 4.6). Expert designers rated bus stop examples (local domain) with higher scores than distant domains. However novice designers rated long-distant domains with higher scores than local domains. The graphics of mean differences shown in Table 4.6 revealed the consistency in the expertise levels. Experimenters generally rated the whole set of examples consistently.

A MANOVA analysis results (Table 4.7) revealed that four expertise levels were significantly different in their rating of 40 source examples (Wilks'Λ=0.43, F(120,000)=2.7, p<.05).

Table 4.6. Ratings mean difference among different expertise levels

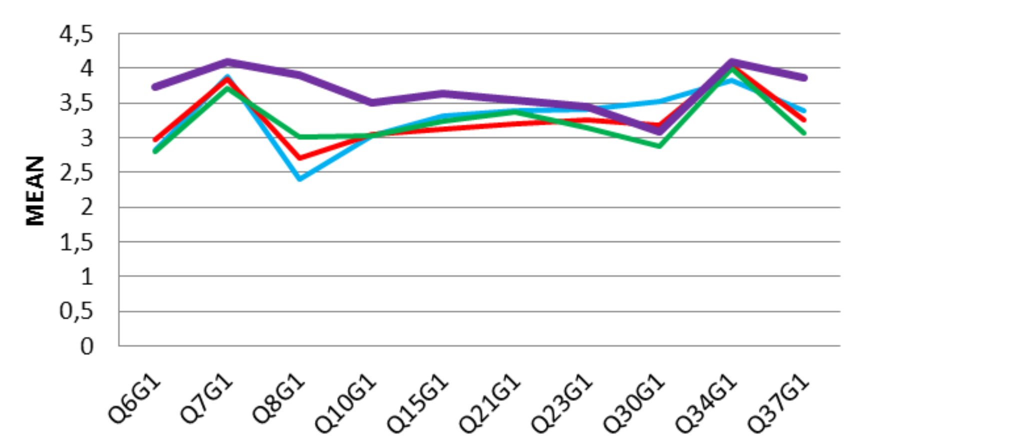
| | |
|---|---|
| **BUS STOP** |  |

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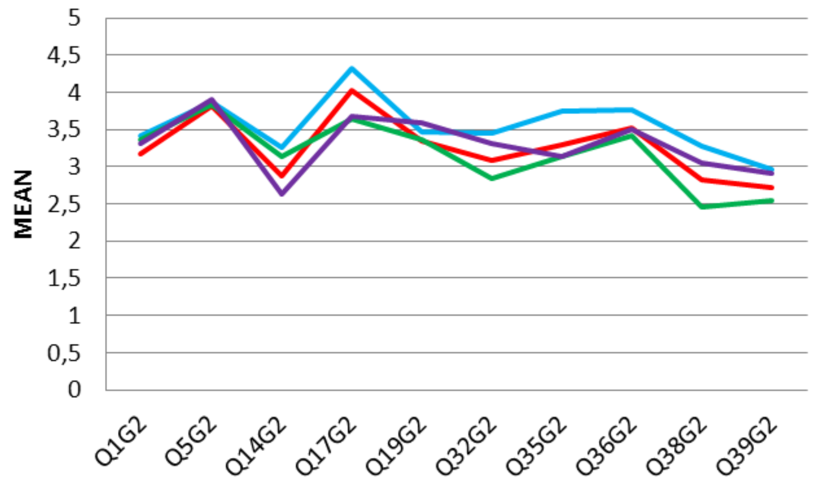
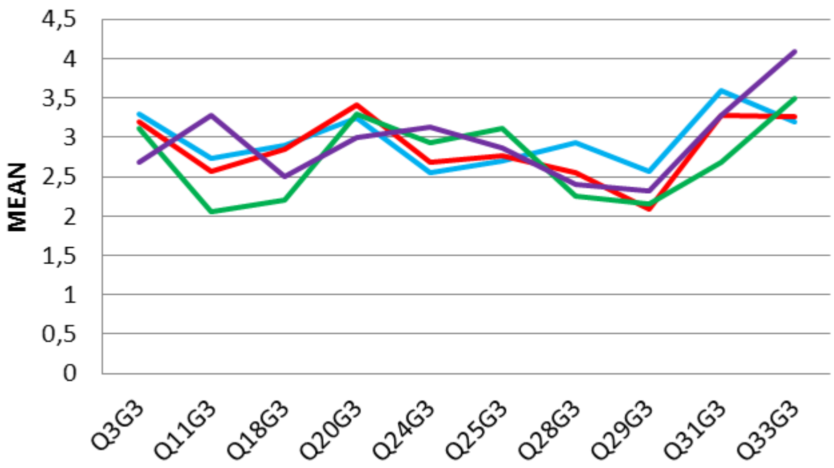
Table 4.6. (cont.)

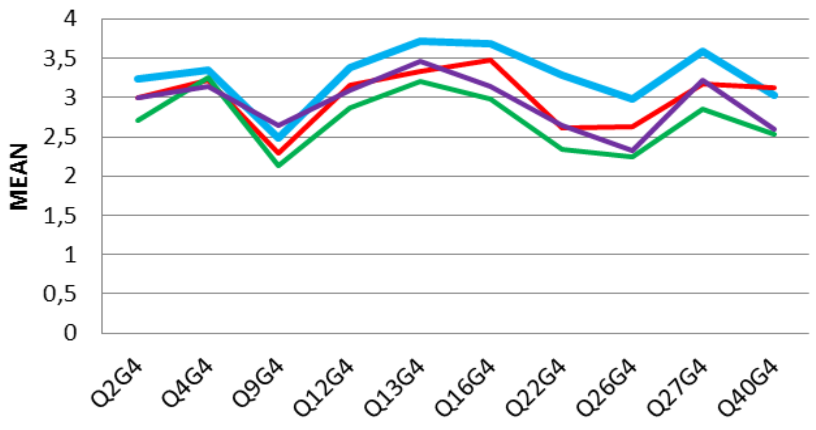
ARCHITECTURE




ARTIFACTS




NATURE




First year Second year Fourth year Experts

Table 4.7. Comparison of expertise levels for source examples rating

| **Pairwise Comparison of Significances among Expertise Levels** | | | | | |
|---|---|---|---|---|---|
| | **Sig.** | | | | |
| | | **First year** | **Second year** | **Fourth year** | **Experts** |
| | **First year** | 1 | ,000 | ,000 | ,000 |
| | **Second year** | ,000 | 1 | ,000 | ,015 |
| | **Fourth year** | ,000 | ,000 | 1 | ,126 |
| **Sig.** | **Experts** | ,000 | ,015 | ,126 | 1 |

The results in Table 4.8 show that expert designers generally rated near domain examples, i.e., the group of bus stop (good and excellent rating with %59 percentage) and the group of architecture (good and excellent rating with %45 percentage) higher. First year students rated long-distant domain examples, i.e., the group of nature (good and excellent rating with %59 percentage) and the group of artifacts (good and excellent rating with % 43 percentages) higher. Second and fourth year students rated all the groups nearly homogenously. Textual data revealed that novice designer generally focused on originality, novelty, aesthetics and form. On the contrary to the prediction of the study, expert designers generally considered how to use the source examples in the design process and focused on practicality. First year students generally focused on the source domains which reserved the most creative potential.

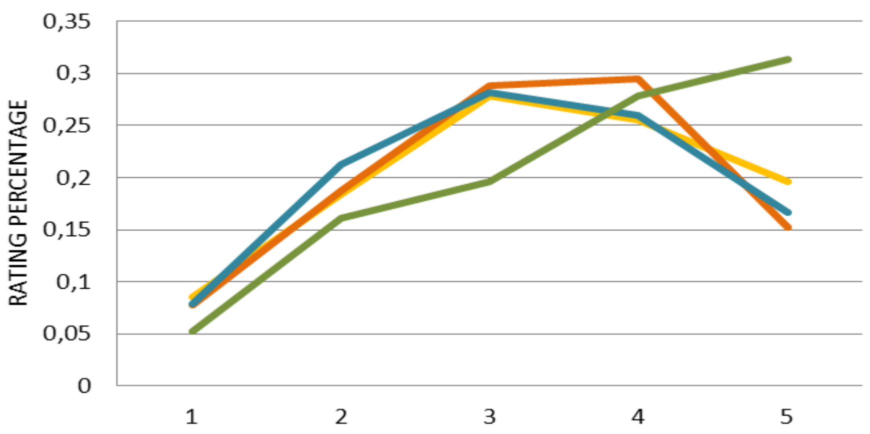
Table 4.8. Source domain rating frequency percentage according to expertise (1-poor, 2-fair, 3-average, 4-good, 5-excellent)

| | **BUS STOP** | | | | **ARCHITECTURE** | | | | **ARTIFACTS** | | | | **NATURE** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **First year** | **Second year** | **Fourth year** | **Experts** | **First year** | **Second year** | **Fourth year** | **Experts** | **First year** | **Second year** | **Fourth year** | **Experts** | **First year** | **Second year** | **Fourth year** | **Experts** |
| 1 | 0.09 | 0.08 | 0.08 | 0.05 | 0.08 | 0.05 | 0.08 | 0.07 | 0.08 | 0.15 | 0.20 | 0.10 | 0.05 | 0.12 | 0.20 | 0.13 |
| 2 | 0.18 | 0.19 | 0.21 | 0.16 | 0.19 | 0.21 | 0.21 | 0.20 | 0.21 | 0.25 | 0.30 | 0.28 | 0.16 | 0.25 | 0.26 | 0.23 |
| **sum** | **0.27** | **0.27** | **0.29** | **0.21** | **0.27** | **0.26** | **0.29** | **0.27** | **0.29** | **0.40** | **0.50** | **0.38** | **0.21** | **0.37** | **0.46** | **0.36** |
| 3 | 0.28 | 0.29 | 0.28 | 0.20 | 0.29 | 0.30 | 0.29 | 0.29 | 0.28 | 0.27 | 0.23 | 0.28 | 0.20 | 0.26 | 0.24 | 0.29 |
| | | | | | | | | | | | | | | | | |
| 4 | 0.26 | 0.29 | 0.26 | 0.28 | 0.29 | 0.29 | 0.29 | 0.31 | 0.26 | 0.25 | 0.19 | 0.22 | 0.28 | 0.25 | 0.22 | 0.07 |
| 5 | 0.20 | 0.15 | 0.28 | 0.31 | 0.15 | 0.15 | 0.13 | 0.14 | 0.17 | 0.09 | 0.07 | 0.11 | 0.31 | 0.11 | 0.07 | 0.08 |
| **sum** | **0.46** | **0.44** | **0.54** | **0.59** | **0.44** | **0.44** | **0.42** | **0.45** | **0.43** | **0.34** | **0.26** | **0.33** | **0.59** | **0.36** | **0.29** | **0.15** |

Descriptive statistics' graphics below reveal how randomly given source domain rating differs according to expertise levels (Table 4.9). The results show that differences between expert and novice designers' ratings increase in parallel to increase in expertise. Furthermore, with increase in expertise, the variance within each participant group increases as well. The increased knowledge and specialty could be a factor for this variance in the way participants perceived the source domains. Novices perceived the source examples with superficial pictorial characteristics in similar way. They were mostly dependent solely on the visual representation of the source domain shown during the study.

Table 4.9. Within subject source domain rating frequency percentage

**FIRST YEAR**




**SECOND YEAR**

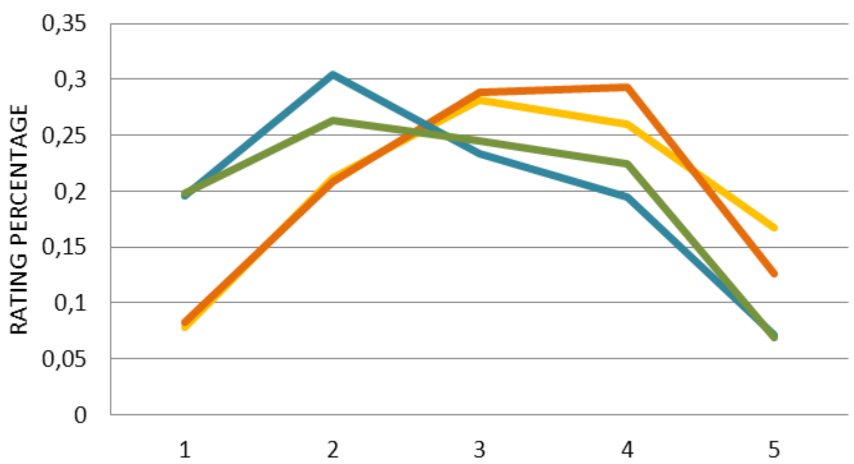



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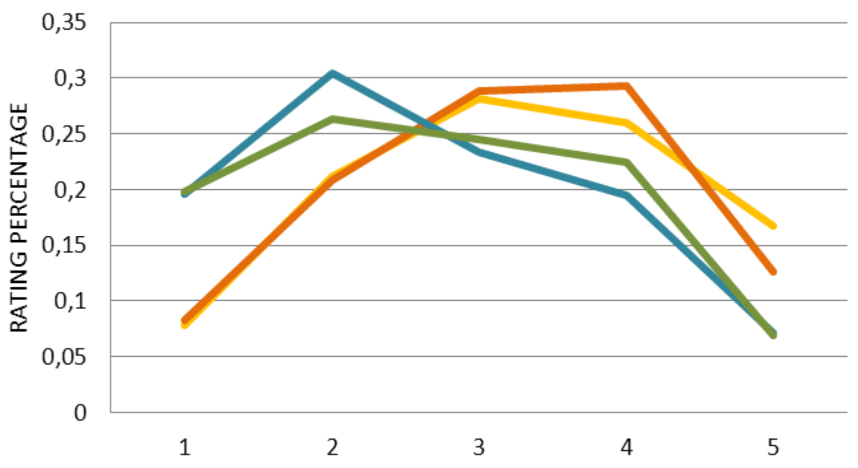
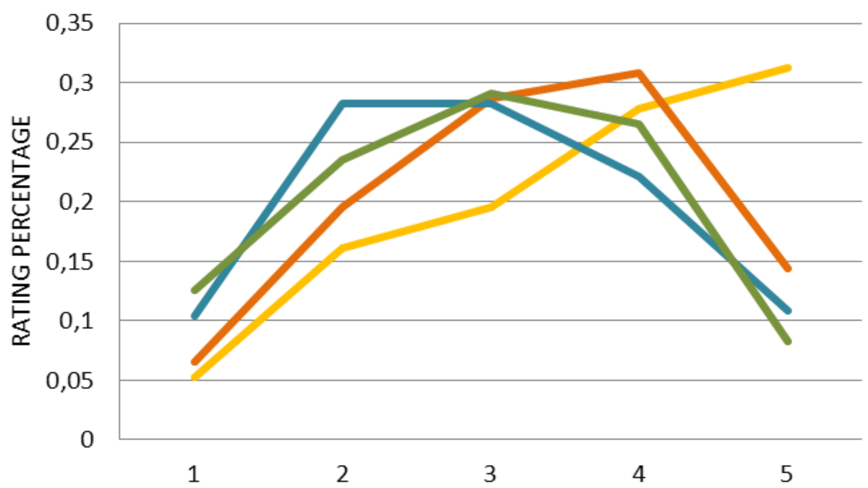
Table 4.9. (cont.)

| | |
|---|---|
| **FOURTH YEAR** |  |
| **EXPERTS** |  |
| | Bus stop, Architecture, Artifact, Nature |

The multivariate tests showed that rating difference increases according to expertise level (Table 4.10). This may be the result of increasing specialty in direct proportion to expertise. The cognitive parameters that affected the analogical reasoning process or source domain and reasoner interaction will be discussed in Chapter 5.

Table 4.10. Source domain rating difference according to expertise level

| **Multivariate Tests** | | | | |
|---|---|---|---|---|
| | **First year** | **Second year** | **Fourth year** | **Experts** |
| Pillai's trace | ,107 | ,251 | ,054 | ,008 |

### 4.2.2. Results of Second Task

With this task, the relationship between the cognizing agent and the source domain is investigated further (Figure 4.3). Different from the previous task, however, the source domain categories were disclosed to the participants and they were asked to select one of the four source domain as the most potentially useful source domain for the design of a bus stop.

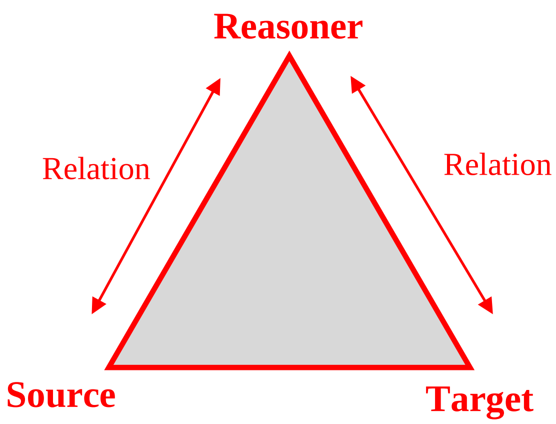



Figure 4.3. Interaction between the designer and source domains

#### 4.2.2.1. Task A

Below in Figure 4.4 descriptive graphics show the differences in the source domain group selections of participants.

Descriptive statistics' results (Table 4.11) reveal that differences among participants increases linearly with education. These results indicate that there is a statistically significant difference between expert designers and first year students and also between fourth year students and first year students at the alpha level. In reference to across group chi-square comparisons (Table 4.11), experts and first year students were most significantly different ($X^2$ (3, N = 389) = 2,625, p= .022, ($p < 0.05$)); first and fourth year students were second most significantly different ($X^2$ (3, N = 389) = 2,625, p= .044).

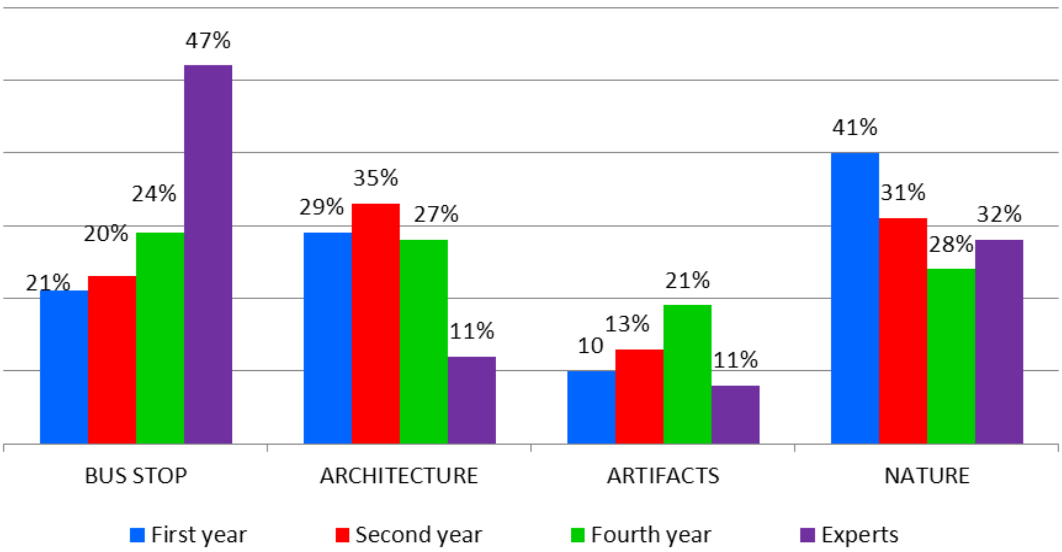



Figure 4.4. Source domain group selection according to expertise levels

Table 4.11. Comparison of expertise levels for source domain group selection

| **Comparison of Significances among Expertise Levels** | | | | | |
|---|---|---|---|---|---|
| | **Sig.** | | | | |
| | | **First year** | **Second year** | **Fourth year** | **Experts** |
| **Sig.** | **First year** | 1 | ,218 | ,044 | ,022 |
| | **Second year** | ,218 | 1 | ,422 | ,115 |
| | **Fourth year** | ,044 | ,422 | 1 | ,289 |
| | **Experts** | ,022 | ,115 | ,289 | 1 |

The descriptive graphics below indicate the difference between expertise levels and source domain group selection in terms of percentages (Figure 4.5). 40% of all first year students retrieved the local domain. On the contrary, 52% of all expert designers retrieved the long-distant domain.

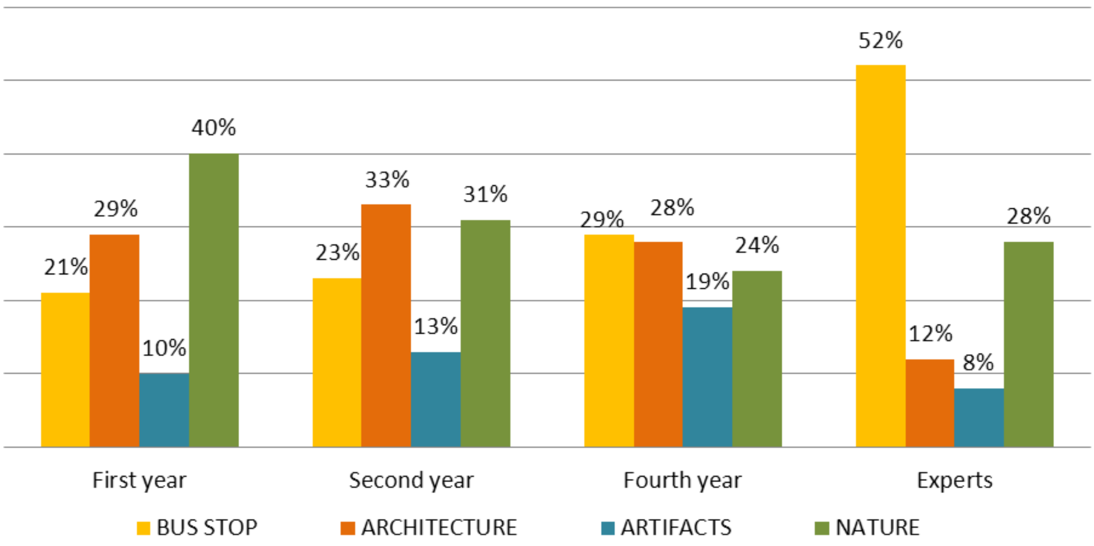



Figure 4.5. Differences between the expertise levels and group selection

Univariate test results (Table 4.12) brought out that there is a marginally significant difference between expertise levels in their source domain group selection ($X^2$ (3, N=385) = 2,63  p=.050, $p < 0.05$).

Table 4.12. Univariate test for expertise levels according to distance of source

| **Univariate Tests** | | | |
|---|---|---|---|
| | **df** | **F** | **Sig.** |
| **Contrast** | 3 | 2,625 | ,050 |
| **Error** | 385 | | |

A chi-square test was performed for source domain group selection task to determine which source domain groups were equally preferred (Table 4.13 and Table 4.14). The analysis revealed the significant relation between expertise levels and distance of source domain parameters.

Table 4.13. Frequency of group selection according to expertise level

**Expertise level * Group selection cross tabulation**

| | | BUS STOP | ARCHITECTURE | ARTIFACTS | NATURE | TOTAL |
|---|---|---|---|---|---|---|
| **First year** | Count | 35 | 49 | 17 | 69 | 170 |
| | Expected Count | 42,4 | 48,5 | 22,3 | 56,8 | 170,0 |
| **Second year** | Count | 25 | 36 | 15 | 34 | 110 |
| | Expected Count | 27,4 | 31,4 | 14,4 | 36,8 | 110,0 |
| **Fourth year** | Count | 25 | 24 | 17 | 21 | 87 |
| | Expected Count | 21,7 | 24,8 | 11,4 | 29,1 | 87,0 |
| **Experts** | Count | 12 | 2 | 2 | 6 | 22 |
| | Expected Count | 5,5 | 6,3 | 2,9 | 7,4 | 22,0 |
| **Total** | Count | 97 | 111 | 51 | 130 | 389 |
| | Expected Count | 97,0 | 111,0 | 51,0 | 130,0 | 389,0 |

Table 4.14. Chi-square test for expertise levels and distance of source relation

| **Chi Square Test** | | | | |
|---|---|---|---|---|
| | Pearson Chi-Square | N | df | Asymp. Sig. (2-sided) |
| **Value** | 22,973 | 389 | 9 | ,006 |

These results indicate that there is a statistically significant relationship between source domain group selection and expertise level ($p < 0.05$). The results of the test were significant, $x^2(9, N=389) = 22.97$, $p=.006$. Group selection and expertise levels are significantly related factors. Preference for the four source domain groups was not equally distributed in different participant groups. In the overall, the proportion of expertise levels differ significantly from each other $x^2(9, N=389)=22.97$, $p=.006$, $p<0.05$. First year students were more likely to show an interest in retrieving the group of nature than were experts. On the contrary, experts were more likely to show interest in retrieving the group of bus stop than were other participants. Second year and fourth year students were more homogenously distributed.

The percentage of first year students (P=20.59%) for the group of bus stop retrieval was less than the hypothesized proportion of 24.94%, while the percentage of experts (P=54,55%) was much greater than the hypothesized proportion of 25,00%. The percentage of first year students (P=40,59%) for the group of nature retrieval was more than the hypothesized percentage of 33,41%, while the percentage of experts (P=27,27%) was greater than the hypothesized percentage of 33,64. Overall, these results suggest that novice designers generally selected distant domain more than expert designers. Second year and fourth year students were in between these two cognitive behavior. The cognitive parameters that affect the analogical reasoning process will be discussed in Chapter 5.

#### 4.2.2.2. Task 2.2.

This task was a follow-up to the previous one and asked participants to explain the reasons for their source domain selections. The items of content analysis were *mere appearance (formal) characteristics*, *function*, *structural relation*, *casual relation*, *originality* and *design process*. Approximately 396 answers of Task 2.2 question and approximately 20,000 words of relevant excerpts were transcribed and keywords (e.g.) were color-coded during transcription to facilitate subsequent analysis and collation.

The results are given in frequencies of parameters mentioned as a reason for source domain group selection (Table 4.15).

Table 4.15. Parameters generally considered for source domain group selection

| | **First year** | **Second year** | **Fourth year** | **Experts** |
|---|---|---|---|---|
| **Mere Appearance-Formal** | 0,98 | 0,91 | 0,85 | 0,68 |
| **Function** | 0,73 | 0,74 | 0,81 | 0,59 |
| **Structural Relation** | 0,07 | 0,30 | 0,56 | 0,50 |
| **Casual Relation** | 0,02 | 0,14 | 0,20 | 0,45 |
| **Originality** | 0,41 | 0,10 | 0,08 | 0,09 |
| **Design Process** | 0,06 | 0,11 | 0,24 | 0,45 |

Content analysis of participants stated explanations show that first year students generally focused on originality, novelty, and creativity in their selection (Table 4.15). Whereas, expert designers generally considered productivity and practicality. The explanation of an expert designer highlights the aim of practicality: 'To solve the design problem, it seems that it is more appropriate to look at precedents which work. I think it is better to use tried and worked out solution in problem solving. One has to be critical looking at precedents, yet, the material selections and form explorations would feed in the end design directly since it is closer to the problem in hand. Perhaps, one would have been more open-minded by looking at other category examples (such as artifacts, nature, etc…), but I personally think that we should focus on concrete architectural solutions since design is about providing a concrete and working product.' A first year student who selected near domain made similar statement 'improving source examples is an easier way to solve a design problem.  This category makes the solution process rational and practical.'

Whereas expert designers were oriented towards optimizing the analogical process generation from near domains, first year students' selections and goals were oriented to creative idea generation from long-distant domains. First year students who selected long-distant domain offered nature as the source of original thoughts. One statement is 'nature makes me feel freer and more comfortable about the bus stop ideas that are forming in my mind but not finalized yet' and other one is 'nature is source of excellent examples and full of various types and choice for selecting according to our imagination.'

Second and fourth year students, on the other hand, considered originality and productivity to a certain extent, and were neither like experts nor first students. They made generally literal similarity from regional domains in the thought that literal transfer from long-distant domain would not be the solution to the problem, and literal transfer of near domain would yield plagiarism. A second year student who selected artifact declared 'the reason why I did not select bus stop group is I do not want to create a similar one. It needs broader view to transfer knowledge from nature. Artifacts are original and easy to understand.' A fourth year student who selected architecture wrote 'the reason that I picked architecture is it s being functional and easthetic. These two property is important for design." Another one stated 'it is easier to transform it to a novel design changing the functions of its form."

In the four subsequent tables given below explained the most frequently mentioned reasons for each source example (Table 4.16, Table 4.17, Table 4.18, Table 4.19).

Table 4.16. Parameters generally considered for bus stop

| **SOURCE DOMAIN GROUPS** | **BUS STOP** | **Source Selection** | **PARAMETERS** |
|---|---|---|---|
| **1** |  | 5 | Basic geometry, open to different directions, safety, modularity, sub-units, holistic, spatial properties, functionality, material properties, covering |
| **2** |  | 18 | Material, holistic, aesthetical, color, geometry, stable, curved corners, space defining, covering, basic geometry, basic form, relation to context, parts and whole relation, function |
| **3** |  | 1 | Form, basic geometry |
| **4** |  | 1 | Structure |
| **5** |  | 7 | Basic geometry, protecting, planar elements, open to variations, compact, simple |
| **6** |  | 7 | Fluid form, color, function, holistic form, easy to understand, purpose, |
| **7** |  | 12 | Protecting, material, basic geometry, linear, modular, space defining, orientation, structure, |
| **8** |  | 3 | Basic geometry, like an animal and analogized according to purpose, covering, space defining, plain geometry |
| **9** |  | 19 | Ergonomics, pattern, different sections, transparency, sub-functions, ergonomics, space, |
| **10** |  | 6 | Basic geometry, a good start to design, covering, sub-function, protecting, material |
| **Easy to use as a design idea, but copying risk, because very specified ideas. Ready to use knowledge. Construction, material, scale, is easy to observe. Generic function is the same, less complexity. Public Space. Easier to predicate relations. Relations to environment are more like to the problem defined. The nearest solutions to the problem, no originality for analogy, Easy to design.** | | | |

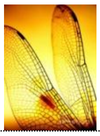
Table 4.17. Parameters generally considered for architecture

| SOURCE DOMAIN GROUPS | ARCHITECTURE | Source Selection | |
|---|---|---|---|
| **1** |  | 10 | Structure, originality, color and design balance, aesthetic |
| **2** |  | 15 | Use of different type of geometry, flexibility |
| **3** |  | 2 | Structure, originality, color and design |
| **4** |  | 39 | Originality, organic form, permeability, protecting form, fauns, different aura, experience, social space, art space |
| **5** |  | 1 | |
| **6** |  | 2 | Function, transparent shelter, individualism |
| **7** |  | 9 | Form, direction, undulation |
| **8** |  | 17 | Contrast use of material, different direction, geometry, alternative space, rational, rooms, form |
| **9** |  | 2 | |
| **10** |  | 3 | Form, permeability, transparency |
| **Specific solutions, different generic functions-different purposes, different type of spaces, different scale, material complexity, increasing details, visibility of space, relations to environment is not like the problem, adaptation needs. Stimulating the individual characteristics.** | | | |

Table 4.18. Parameters generally considered for artifacts

| **SOURCE DOMAIN GROUPS** | **ARTIFACTS** | **Source Selection** | |
|---|---|---|---|
| **1** |  | 0 | |
| **2** |  | 11 | Sub-functions, structure |
| **3** |  | 6 | Metaphoric meaning, protecting, connotation, formal properties |
| **4** |  | 15 | Aesthetical form, protecting, structure, continuity, fluidity, a different approach, originality, |
| **5** |  | 7 | Movement, creating different forms, design idea, open and close, mechanism |
| **6** |  | 8 | A porous form, permeable outer surface, protector layers, grouping and differentiation inside, solid-void, ergonomic |
| **7** |  | 3 | Originality |
| **8** |  | 0 | |
| **9** |  | 3 | Movement, protection, open and close, mechanism |
| **10** |  | 4 | Transparency, continuity, structure, human interaction, modular parts, permeability |
| **Creativity, abstract ideas, formal properties, meanings, iconic, no relation to environmental context, dynamic, transportable. Object. Easy to observe details and materials. Metaphoric. Mechanism.** | | | |

Table 4.19. Parameters generally considered for nature

| SOURCE DOMAIN GROUPS | NATURE | Source Selection | |
|---|---|---|---|
| **1** |  | 5 | Pattern, color, material, movement, open to new ideas, originality |
| **2** |  | 30 | Structure, covering, protection, rhythm, sequence, continuity, dynamic form, gathering mechanism, skin, covering, interesting |
| **3** |  | 2 | Transparency, structure, organic, light weight structure, different geometries |
| **4** |  | 21 | Protecting, aesthetical, symbolic, interesting, originality, beauty |
| **5** |  | 16 | Structure, weight bearing, material and structure relation, spatial potential, aura-dynamic property, spatial dynamism, horizontal position, movement, large perspectival view, steel structure, originality |
| **6** |  | 23 | Pattern, material, geometry, rhythm, adaptability to environment, parts and whole relation, context relations among the parts, relation to context, covering, golden ratio, structure, shelter |
| **7** |  | 7 | Transparency, centrality, public space, fractal geometry |
| **8** |  | 1 | Protecting, aesthetical |
| **9** |  | 9 | Shelter, material, color, aesthetic form |
| **10** |  | 7 | Anatomy, geometry, curve, mechanics, joints, symmetry, balance, optimum material usage, space creation, structure system, protecting, robustness, open to new ideas |
| **Open to new ideas, origin, interesting, free to new ideas, full of concrete ideas, full of information according to level of knowledge, freedom. Generic function is ecological life in dynamism. Original, interesting. Origin of design. Too complex. Source of form and structure information.** | | | |

### 4.2.3. Results of Third Task

With this task, the relationship between the target and the source domain is investigated with regard to the type of similarity the participants established between the two (Figure 4.6).

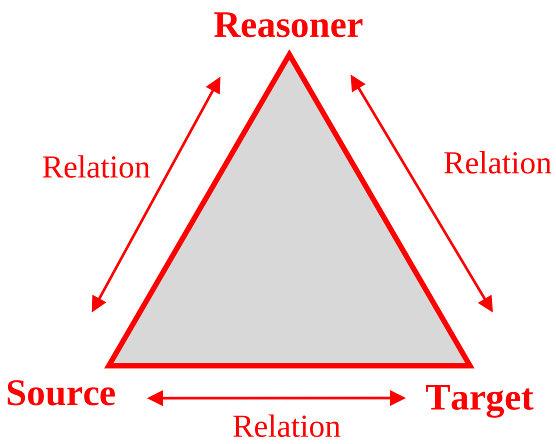



Figure 4.6. Interaction between the designer, source domains and target domain

Descriptive statistical results indicate that there is a difference among participants in the way they establish analogies (Figure 4.7).

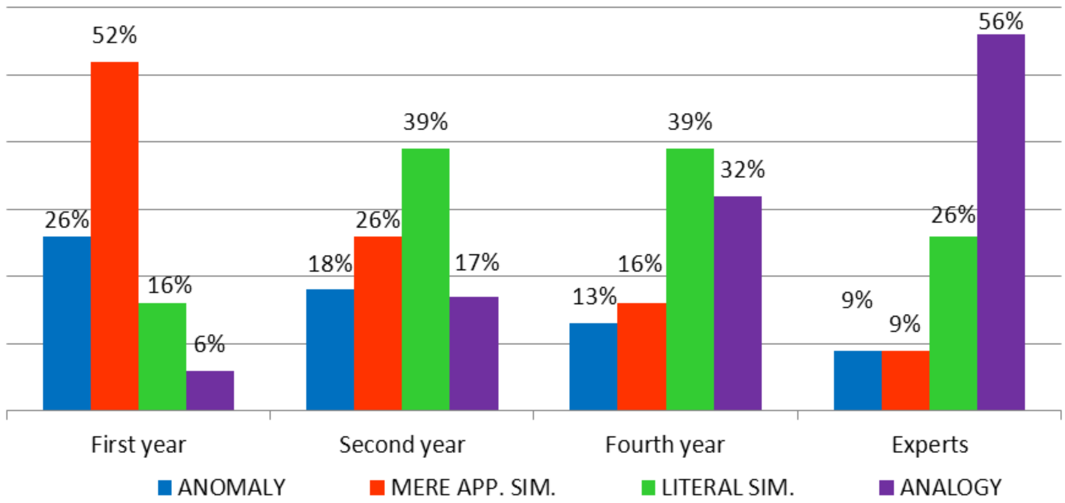



Figure 4.7. Expertise levels according to the levels of analogy

Results reveal that first year student generally transferred surface features of the source examples and focused on their form and object attributes. They could not make any analogical connection between source and target. The frequency percentage of mere-appearance similarities for first year students is 52% which is the highest result in this category. The percentage of anomaly is 26% for first year. On the contrary, expert designers generally transferred deep-structure knowledge and were able to establish analogies (56%). Second and fourth year students generally made literal similarity with the source examples. The percentage of mere appearance similarity is 26% for second year students and the percentage of analogy is 32% for fourth year. The percentage of literal similarity is 26% for expert designers. As others have suggested expert designers are more successful in perceiving and transferring deep-structural knowledge. By education student designers gain the ability of reasoning with analogical relations. This means that expertise has a strong effect on the ability of analogical reasoning.

With the increase in expertise, analogical relationships between source and target domains increase gradually. On the contrary, mere appearance similarity decreases linearly. The descriptive analysis results indicate that there is a linear relationship between expertise and similarity level of source and target domain.

Univariate test results show that there is a statistically significant difference between expertise levels in the type of relation they establish between source and target ($X^2$ (9, N=371)=23,94 p=.000, $p < 0.05$) (Table 4.20).

Table 4.20. Univariate test for levels of analogy according to expertise levels

| **Univariate Tests** | | | |
|---|---|---|---|
| | **df** | **F** | **Sig.** |
| **Contrast** | 3 | 23,964 | ,000 |
| **Error** | 371 | | |

Chi-square test results indicate that there is a significant relationship between expertise level and the type of relation they establish between source and target ($X^2$ (9, N=375) = 89.39, p=.000, $p < 0.05$) (Table 4.21).

Table 4.21. Chi-square test for expertise level and levels of analogy relation

| **Chi Square Test** | | | | |
|---|---|---|---|---|
| | **Pearson Chi-Square** | **N** | **df** | **Asymp. Sig. (2-sided)** |
| **Value** | 89,392a | 375 | 9 | ,000 |

Table 4.22 shows that by the expertise increase anomaly and mere appearance similarity decrease and analogies increase linearly.

Table 4.22. (Linearity Table) Analogical reasoning development of expertise levels

| **Frequency Percentage Table** | | | | |
|---|---|---|---|---|
| | **First year** | **Second year** | **Fourth year** | **Experts** |
| Anomaly | 26 | 18 | 13 | 9 |
| | → | | | |
| Mere appearance similarity | 52 | 26 | 16 | 9 |
| | → | | | |
| Literal similarity | 16 | 39 | 39 | 29 |
| | ↔ | | | |
| Analogy | 6 | 17 | 32 | 56 |
| | ← | | | |
| | 100 | 100 | 100 | 100 |

Descriptive statistics' results (Table 4.8) show the relation between depth of analogy and distance of source domain.

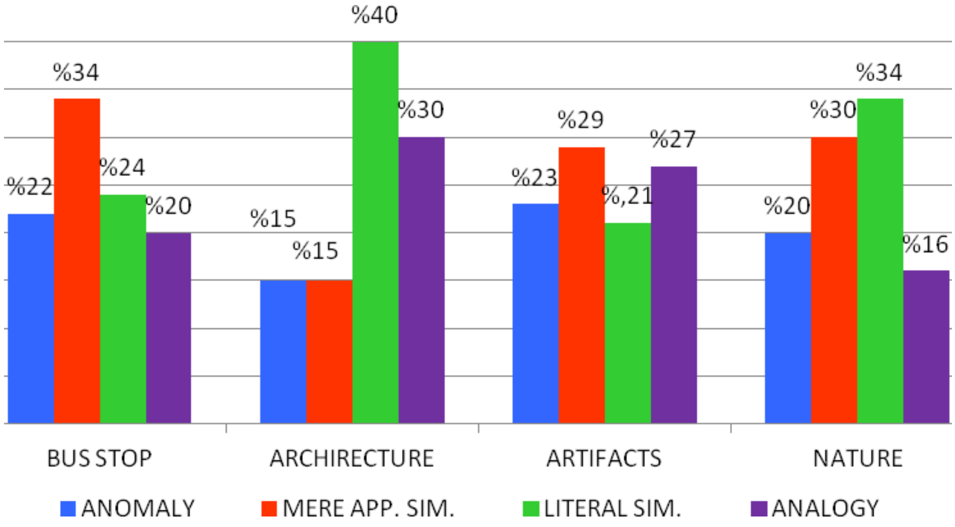



Figure 4.8. Distance of source and levels of analogy relation

According to this analysis knowledge transfer is generally based on mere appearance similarity in the group of bus stop (%34). Analogy is less observed (%20) in this group. Knowledge transfer from the groups of architecture (%40) and nature (%34) are generally based on literal similarity. Analogy is less observed (%16) in the group of Nature. In the group of architecture designers established more analogy (%30) in comparison to the other groups. Knowledge transfer from the groups of architecture (%40) and nature (%34) is generally based on literal similarity. In the group of artifacts, there is a homogeneously distributed frequency of the levels of analogy.

Univariate test results revealed that there is no significant difference between the levels of analogy according to source domain group selection; $X^2$ (3, N=364) = 0.55 p=.647, $p < 0.05$ (Table 4.23).

Table 4.23. Univariate test for levels of analogy according to distance of source

| **Univariate Tests** | | | |
|---|---|---|---|
| | **df** | **F** | **Sig.** |
| **Contrast** | **3** | **0,552** | **,647** |
| **Error** | **364** | | |

Chi-square test results revealed that there is no significant relations between the levels of analogy and distance of source domain parameters; $x^2$ (9, N=371) =9,39, p=.402, $p<0.05$ (Table 4.24).

Table 4.24. Chi-square test for expertise levels and levels of analogy relation

| **Chi Square Test** | | | | |
|---|---|---|---|---|
| | **Pearson Chi-Square** | **N** | **df** | **Asymp. Sig. (2-sided)** |
| **Value** | 9,391 | 368 | 9 | ,402 |

Univariate test results revealed that there is no significant difference between the levels of analogy according to source domain group selection and expertise levels factors together; $x^2$(9, N=352) = 0,764, p=.650, $p < 0.05$ (Table 4.25).

Table 4.25. Univariate test for levels of analogy according to expertise levels and distance of source

| **Univariate Tests** | | | |
|---|---|---|---|
| | **df** | **F** | **Sig.** |
| **Contrast** | 9 | 0,764 | ,650 |
| **Error** | 352 | | |

Table 4.26 shows that by the expertise increase analogical transfer from all source domains improves gradually.

Table 4.26. (Linearity Table) Analogical reasoning development of expertise levels

| | Bus Stop | Architecture | Artifacts | Nature |
|---|---|---|---|---|
| First year | Mere App. Similarity | Mere App. Similarity | Mere App. Similarity | Mere App. Similarity |
| Second year | Mere App. Similarity | Literal Similarity | Literal Similarity | Literal Similarity |
| Fourth year | Literal Similarity | Literal Similarity | Literal Similarity | Analogy |
| Experts | Analogy | Analogy | Analogy | Analogy |

The cognitive mechanism of analogical reasoning with overall interaction of source domain, target domain and reasoner interaction will be discussed in Chapter 5.

# CHAPTER 5

# DISCUSSION

In this research analogical reasoning mechanism is explored for the purpose of understanding knowledge transfer in design. In this chapter, the quantitative and qualitative findings of the study are going to be discussed. The findings will be interpreted in reference results of studies from the literature. Moreover, the limitations of the study and the implications for further research will be discussed. The main aim of the study was to investigate the influence of the expertise levels on the source and target domain selection (retrieval stage) and the levels of analogical knowledge transfer (transfer, adaptation and evaluation stages). The important relational parameters inquired in the study are represented in Figure 5.1.

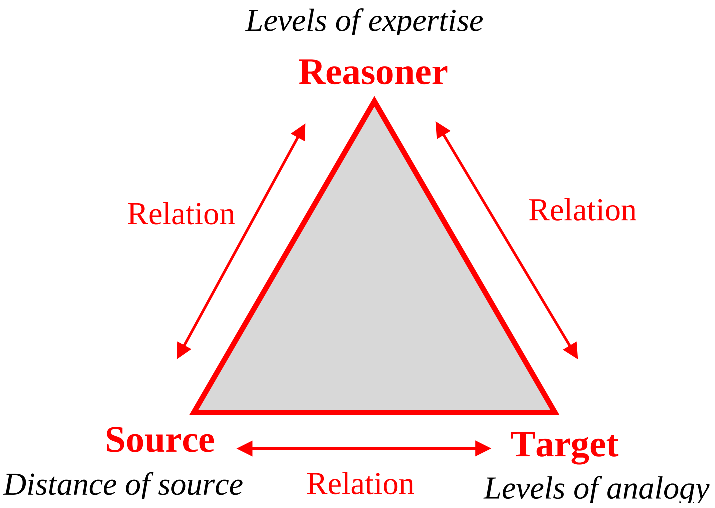



Figure 5.1. The level of information derived is very important an analogy process.

## 5.1. The Idea Generation Process

### 5.1.1. Expertise-Distance of Source Domain-Level of Similarity

Analogical reasoning has long been proposed by cognitive scientists as a vital part of *inventive* and *explanatory* reasoning processes (Ward, 1998) that fosters *creativity*, *discovery*, *comprehension*, and *problem solving* supporting several distinct cognitive tasks. Interdisciplinary knowledge transfers from distant domains are more likely to lead to extraordinary creative analogies (Ward, 1998). Thus retrieval is seen as an important starting point of analogical design (Forbus et.al., 1994, 1996; Holyoak & Koh, 1986; Holyoak et al., 1987; Keane, 1987; Ross, 1987; Novick, 1988) for the reasons related to efficiency and creativity. Some researchers revealed that superficial similarity is perceived as an analogical trigger during retrieval (Getner, et al., 1993; Holyoak & Koh, 1987). This type of similarity, rather than deep-structural similarity, is shown to dominate primarily the retrieval stage (Catrambone, 2002; Gentner et al., 1993; Gick & Holyoak, 1980, 1983; 1985; Ross, 1987). Superficial similarity generally comes into prominence in local domain sources and in this respect Bonnardel (2004) claimed that designers with different levels of experience spontaneously evoked more local domain sources than distant domain sources. Johnson-Laird (1989) stated that the selection of a source analog is largely dependent on the distance between the source and the target domain. Distant domain sources are more difficult to access (Gick & Holyoak, 1980, 1983; Ross, 1987, 1989; Reeves & Weisberg, 1994; Ward, 1998; Holyoak and Koh, 1987; Casakin, 2004), especially because they lack surface similar features with a target problem (Keane, 1987; Gentner et al., 1993; Holyoak & Koh, 1987; Novick, 1988). Novices are insufficient to access structural relations between source and target (Gick and Holyoak, 1980; Novick, 1988; Phye, 1989; Clement, 1994; Holyoak and Koh, 1987; Casakin, 2004). Generally, it is considered that experts are better at retrieving and using analogies. Dahl and Moreau (2002) stated that in design the use of distant analogies is positively related to originality and novelty. In microbiology studies, Dunbar (1995, 1997, 2000) found that distant analogies were very rare and did not play a significant part in discovery in comparison to local and regional analogies. In his experiment Casakin (2004) generalized the use of distant analogies which is much more prevalent in design than in natural sciences.

This study was developed the hypothesis in the light of the studies in literature. The present results are inconsistent with the predictions of this study (Figure 5.2). First year students generally focused on distant source domains in the thought of *originality* (see Dahl and Moreau, 2002). 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). 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 knowledge. 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" (Holyoak & Thagard, 1995). Selecting a distant domain source analogue would be helpful to expand the search laterally (see Goel, 1995). However it is cognitively more demanding endeavor. 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 to transfer long-distant domain knowledge to a target domain. The important point here is they were insufficient in practically transferring source domain knowledge to target domain. They instead literally transferred source domain knowledge 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 transfer, rather, *specific knowledge* from the sources (Ward, 1994; 1998).

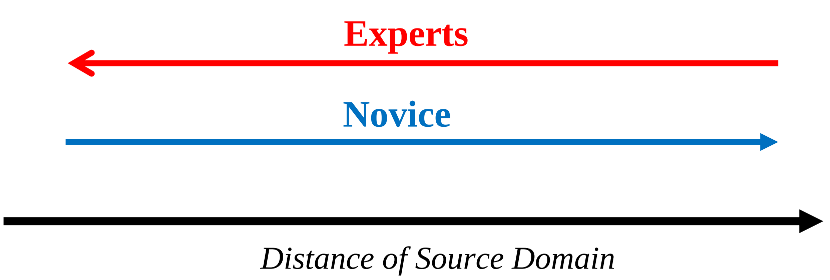



Figure 5.2. Distance of source and target domain and expertise relation

Distant domains entail non-obvious analogies which are critical for developing new ideas with *"heuristic search"* (e.g. Simon, 1973, 1986). First year students designers generated multiple, often unconventional possibilities in a *divergent sense*. Heuristic search is presumed to be a basic property of *divergent thinking* (Guilford, 1968; Gabora & Saab, 2011). In the idea generation stage of creative thinking, first year students thought in multiple directions and generated potentials of multiple alternatives from the long-distant domains being aware of the creative potential of source domains. Contrary to novices, expert designers selected the local domain with the primary objective of practicality knowing that distant domain analogies require further and detailed processing to become viable. Expert designers considered the problem solving process as well as the idea generation process even during the rating task, although they were not expected to solve the given design problem. Expert designers were also conscious of the necessity to combine and relate different pieces of knowledge for solution process. Experts' behavior can be presumed to be a basic property of *convergent thinking* (Guilford, 1968; Gabora & Saab, 2011). Thus, precisely, novices were looking at long-distant domain in a *creative idea generation mood.* Experts were looking at near domain in a *creative solution generation mood.* A creative process involves first *the selection* of a suitable source analogue and *generating ideas* based on this selection and second analyzing and relating multiple selected properties of source domains and *generating solutions*. In the *holistic* consideration of the *idea generation* and *solution generation processes*, experts tried to understand the source domain better to use it in the whole process. Briefly, the degree of difficulty in accessing and selecting a source analog were not only dependent on the distance between the source and the target domain (cf. Johnson-Laird 1989), but also, it significantly related to the level of expertise, to the goal of the reasoner and to the ability of holistic evaluation of the whole analogical process.

### 5.1.2. Categorical Thinking

Second task results of category selection were similar to the first task. The results from the first and second tasks were almost identical, which means that when category membership of each source analogue is disclosed the participants' preferences do not change. Even, when categories were not revealed, it seems that designers decided as if they knew the source categories. The type of *representation* played a stronger role than *typicality* (Ward et al., 1996). The finding differentiated with that of Ward et al. who found that selection is guided by categories so that category consistent intrusions can occur (1996), and category influence the form of the new ideas that people create (e.g., Ward, 1994). According to analysis of the experimental tasks rather than the categories, the goal of the reasoner is the most important factor in analogical reasoning process.

The selection of source domain examples served the particular goals set by the designer. For novices the dominant goal seems to be originality whereas for experts it is practicality. Participants of the study seem to make what Markman called *"category based induction"* (1999). However it seems that induction is fundamentally based on *"goal driven nature of human thought"* (Hofstadter, 2001). Briefly the findings indicate that novices were able to make categorization of the source examples just like experts. In the goal-driven thinking mood, novice designers spontaneously made *perceptual categorization* (Clancey, 1997), whereas expert designers made *conceptual categorization* (Clancey, 1997).

Retrieval is closely related with the main purpose or strategic thinking of the reasoner. Thus expertise emerges as the most important factor that effect the goal of the reasoner and thinking strategy. Local analogies involve greater object attribute similarity between the source and the target, as compared with distant analogies (Gentner et al., 1993; Holyoak et al., 1987; Gentner, Rattermann, & Forbus, 1993; Holyoak & Koh, 1987). The types of similarity match with the goal of the reasoner as it is in the analogical idea generation stage. Novice designers intuitionally selected long-distant source domain recognizing the superficial characteristics in the aim of *originality*. Experts deliberately selected near source domain recognizing the deep-structural similarities in the aim of *productivity* and *efficiency*.

*Strong* versus *weak problem* solving methods (Ericsson & Smith, 1991) may create the difference in selection or the retrieval of the source domain and in categorical thinking. Strong problems may yield more local domain retrieval. Weak problems, on the other hand, may lead distant domain retrieval.

## 5.2. Solution Generation Process

### 5.2.1. Expertise, Distance of Source Domain and Level of Analogy

The ability of transferring relational knowledge with analogy between different domains is very important in human cognition (Gentner, 1983; Holyoak, Gentner & Kokinov, 2001). Some researches stated that in spite of their *creative* and *innovative* potential; it may be difficult to successfully transfer knowledge from distant domains (Johnson-Laird, 1989). Distant source domains involve different bodies of knowledge and different sub-structures. In-vivo studies of analogical reasoning indicate that in their daily occupations, people are better at successfully transferring knowledge from long-distant domains (Blanchette & Dunbar, 2000, 2001), Using a *reception paradigm* methodology (cf. Blanchette & Dunbar, 2000; Dunbar, 2001), participants were expected to select previously defined source examples in a limited *in vitro* laboratory context. The experimental set-up aimed to constrain subjects' abilities of analogical thinking in the solution generation process. In the solution generation process, first year students generally focused on *the domain specific knowledge* (Popovic, 2004) in *perceptual category* (Clancey, 1997). They generally failed to transfer knowledge of causal relationships to new situations. Expert designers on the contrary generally focused on *the domain general knowledge* (Popovic, 2004) in different *conceptual categories* of source domains in the solution generation process. Second and fourth years students, in contrast to the other two groups of participants, were able to see the significance of domain general knowledge, however failed to refrain themselves from using domain specific knowledge.

Success of transfer depends critically on the level of *structural relation* or *the relations of the principles* applied (Holyoak & Koh, 1987; Novick, 1988; Ross, 1987; 1989). Gentner and her colleagues (Gentner, Rattermann, & Forbus, 1993) stated that some degree of spontaneous relational access and transfer was influenced from both surface similarity and structural similarity, but the ability to successfully perform the analogical mapping was influenced only by structural similarity. In this study, successful transfer increased with the expertise given that experts' primary objective in the analogical reasoning was practicality. The perception of deep-structural similarity increased the alignments of inference and spontaneous transfer (Catrambone, 2002;

Gentner, Rattermann, & Forbus, 1993; Gick & Holyoak, 1980; Catrambone, 2002; Gentner, et al., 1993; Holyoak & Koh, 1987; Novick, 1988; Ross, 1989) through prior exposure (Gick & Holyoak, 1980; Reeves & Weisberg, 1993) parallel to expertise.

The explanatory graphic (Figure 5.3) shows the relation observed among expertise, distance of source, and levels of analogy.

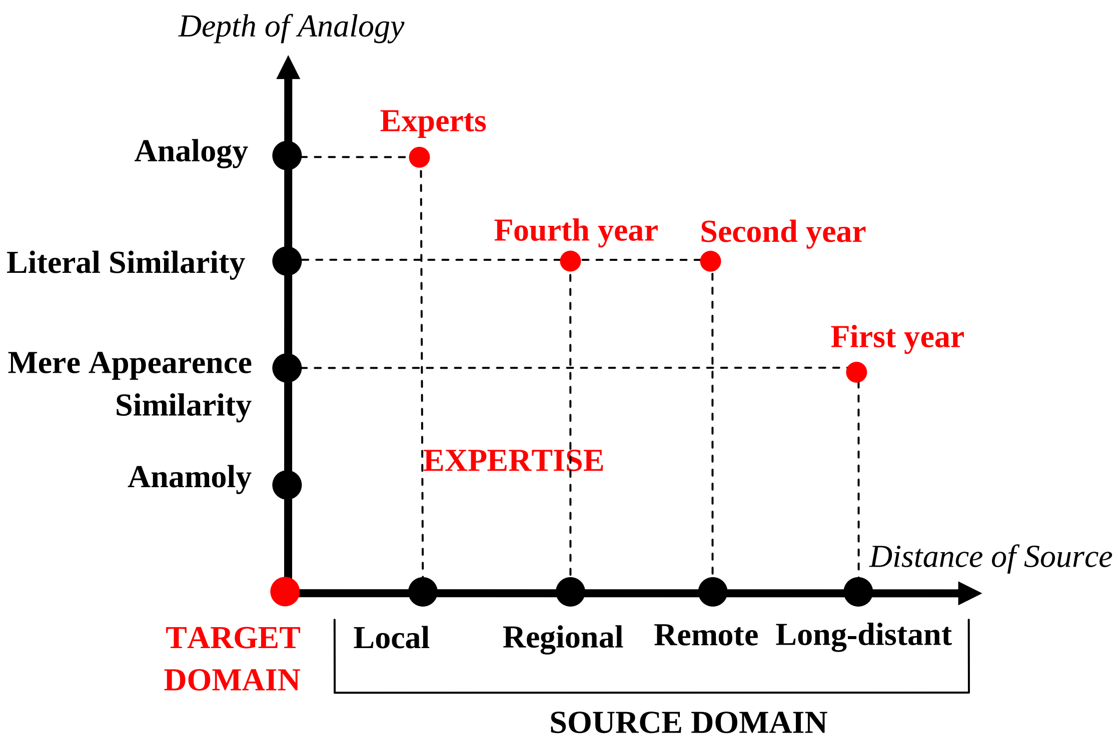



Figure 5.3. The relations among distance of source, depth of analogy and expertise

Expert designers generally transferred knowledge to new situations that share same causal principles, with reference to *general principle inference* (Simon&Hayes, 1976), *rule-based coherence* (Duncker, 1935; Gentner, 1983; Gentner & Gentner, 1983; Gick & Holyoak, 1980, 1983), and *goal-directed thinking* (Holyoak, 1985) because of the structure of their knowledge. *Domain expertise* at the same time constrained their selections. The reason behind experts' preference for the best known local and regional source domains might be because of their ability of easily recognize deep-structural knowledge in different *conceptual categories*. This ability is described as *local-to-global approach* (Ripoll et. al., 2003). The reason behind their near domain selection might related to the reception paradigm in vitro context. Experts were aware that they had a limited time and distant analogies needed many analogical stages. They also received limited source domain examples to make relevant inferences.

The findings indicate that expert designers were better in combining the problem structures with the solution ideas than novices. Novice designers focused more on formal aspects of the problem while expert designers focused simultaneously on problem and solution. Expert designers' thinking process was based on *"experiential memory"* (cf. Lawson, 2001) and *"large body of knowledge and procedural skills"* (cf. Chi, Glaser and Rees 1982) trying out solutions through abstract representations. Novice designers thinking process was based on *"theoretic memory"* (cf. Lawson, 2001) trying out solutions through pictorial representations.

Table 5.1. Comments from novice designers related to source example

| **Textual Data** | | |
|---|---|---|
| **The Level of Expertise** | **Source Domain** | **Some Comments from Student Designers** |
| DEU1-009 Long-distant Domain |  | "Novelty is very important for me. Design is searching new abstract ideas, rather than transferring concrete ones." |
| DEU1-074 Long-distant Domain | | "Inspiring from nature yields original and aesthetic solutions. Rather than seeing usual buildings, it would be better to see natural forms and patterns in our environment. The color and pattern of this source model inspired me." |
| IYTE2-014 Long-distant Domain |  | "The designs are more aesthetical when inspired from nature. Also nature is full of appropriate design ideas for organic design. The source example that I have chosen has a relevant form appropriate to a bus stop." |
| IYTE2-058 Long-distant Domain |  | "Design should be inspired from raw ideas. Inspiring from architecture or artifacts can yield copied solutions. May be because I experienced only basic design education it is not an efficient view. But for now I think nature is the best source for creative ideas." |
| DEU1-023 Long-distant Domain | | "Nature is excellent and full of divergent ideas. Too many alternatives in there. It is better to select the most relevant idea to my imagination among these alternatives." |

Table 5.2. Comments from expert designers related to source example

| **Textual Data** | | |
|---|---|---|
| **The Level of Expertise** | **Source Domain** | **Comments from Expert Designers** |
| EXPERT 11 Local Domain |  | "Since the problem was bus stop design, I looked at to the existing solutions. Thus, I could be able to understand formal and structural ways to approach to the problem. This is the most efficient way to reach a solution. It is better to develop or shift the available solutions practically. It is also easier to understand the system of the source example from the structural, functional point of view. Practice and mobility is other parameters to thin in the design process." |
| EXPERT 12 Local Domain |  | "Designed examples are the best mentor for a productive problem solving process. It is organic form characteristics can yield ergonomic solutions. Its changing surface can be adaptive to different functions of design. Also on the perceptional category it seems like a natural form." |
| EXPERT 6 Local Domain |  | "To solve any design problem, concrete examples are the better sources of information. Both because they are produced and experienced examples, it will be efficient to look these examples. Their form and material characteristics are near to the problem domain. These examples are more deterministic for solution generation. Actually other source domains are stimulating the design process for productivity. Nevertheless it is the best way to look at the local domain sources." |

When novices' (Table 5.1) and experts' (Table 5.2) explanations of their source domain selections were compared, we see that expert designers considered the design problem, main function and its sub-functions relation, and the whole design process planning. Novices, on the contrary, generally focused on the formal issues and pictorial characteristics of the selected source examples. They explained their ideas in considering different directions but not in relation to each other and to a main goal. As stated by others as well (Casakin and Kreitler, 2006; Casakin, 2003, 2010; Çubukçu and Çetintahra 2010), the visual displays played an important role in analogical reasoning and knowledge transfer process in this study.

To further investigate the rationale behind the participants' preferences, a number of questions were asked to them in the setting of an un-structured interview. In the interview first year styudents highlighted that the reason behind their selection of long distant domain was originality. They stated that nature was the source of novel ideas. Among them a small group selected architecture. They stated that architectural examples are easier for abstact thought. Other small group who selected artifacts offered that artifacts were the appropriate transfer different meanings by transforming them to the new context. The group who selected bus stop said that bus stop is near to the functions and sub function of problem domain and served an easier path to for target domain. Others claimed that near domain carried the plugarism risk. Second year students stated that architecture served a knowledge of structure which is ready to use and easy to understand. They explained that the difficulty is thinking and transferring in different scales. They also declared that transferring both formal information and structural information will yield an original solution. Other important reason to selection of arcitecture was their analytical way of seeing things. These explanations also reveal that they tried to transfer information literally but in the demand of generating original solutions. Fourth level students generally selected architecture and artifacts and stated the main reason was their way of thinking. They tried to understand source domain with generic to specific abstractions. Function is the main concept for their abstract thought combining with spatial characteristics. Expert designers pointed out the more effective way to solve such a problem is to look at near domain. Near domain examples are full of detailed informations: technical, material, space use excetera. Expert designers claimed that they can able to transfer other domain knowledge spontenously using their experience without looking source domain examples. For lon-distant domain examples, participants found difficult to perceive the geometrical and contextual relations and make connections in detail. Thus design process needs many design stage and operational procedure to transfer knowledge and attain a solution. Novice designers explained that they need more information about source domain examples. They also mentioned that while reasoning with remote and long-distant domain examples, the information of different functions came into prominence. They saw these domain examples as the sources of many ideas. However the complexity and unfamiliarity of distant domain examples creates difficulty.

Some novice designers generally offered that analogy may be a limited way of thinking. Others stated that systematically understanding and using analogy will be more useful for problem solving processes.

Analyzing the participants' designs, novices were found to establish mainly mere-appearance similarity, second and fourth year students literal similarity, and experts analogical similarity. Mere-appearance similarity is based on superficial object attribute similarity whereas analogy is based on deep-structural knowledge transfer. Some examples are presented below (Table 5.3 and Table 5.4). Novice designers perceived the *shallow characteristics* and mainly reasoned based on *domain specific knowledge* (Bonnardel, 2000; Popovic 2004). By implication they are insufficient in connecting the source and target domain in the final solution. Expert designers, on the other hand, were able to make relevant connections using their *domain general knowledge base* (Bonnardel, 2000; Popovic 2004) with a more holistic view.

Table 5.3. Examples for superficial transfer

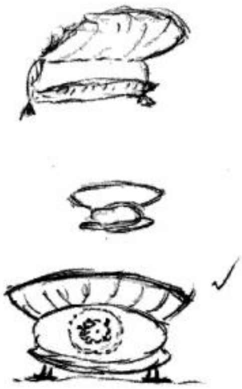
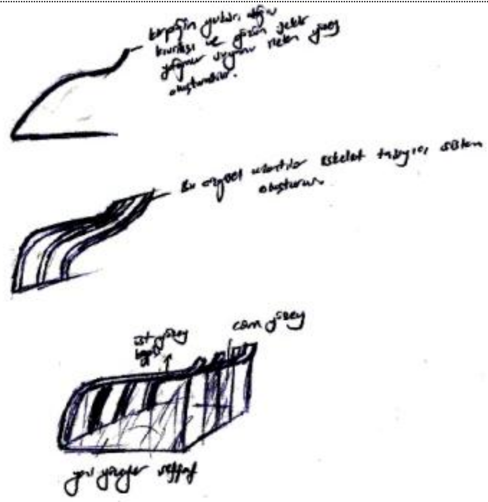
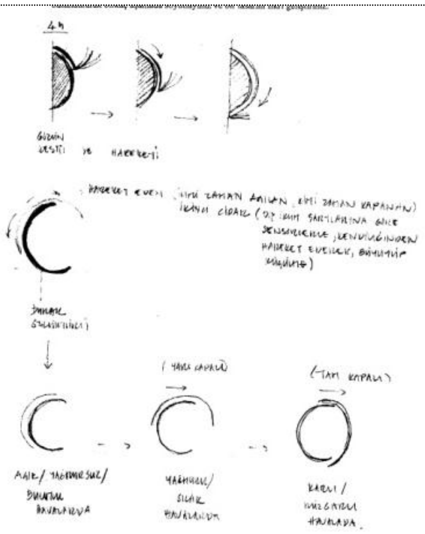
|  | |
|---|---|
|   |  |
| IYTE1-015 | IYTE1-054 |

Table 5.4. Examples for deep-structural transfer

| | |
|---|---|
|  | |
|  |  |
| IYTE2-051 | EXPERT 10 |

Distant domains analogies need more *deductive (global-to-local) approach* than *inductive* (local-to-global) approach (Ripoll et.al, 2003). In this study, novices who selected the long-distant source domains were generally not able to fully benefit from the full potentials of analogical transfer. Vosniadou (1989) and Dejong (1989) claimed that within-domain analogies are mainly based on surface similarities, and therefore are easier to establish whereas between-domain analogies are based on structural commonalties. Experts were generally able to make successful within-domain analogies. The critical point here is not so much about accessing the relevant domain, but rather, what you do with what is being selected as a source domain.

The creative output of novices was not constrained or blocked by *conformity* (Marsh et.al, 1997) during selection; however, they were fixated to the superficial features of their source selections. In the case of expert designers (Table 5.5), the creative output was constrained during the selection process (Marsh et.al, 1997), however, was expanded again during the solution process given their *schema driven abstractions* (Ball, 1997; Clement, 2009).

Table 5.5. Examples for expert designers’ deep-structural transfer from near domain

| | |
|---|---|
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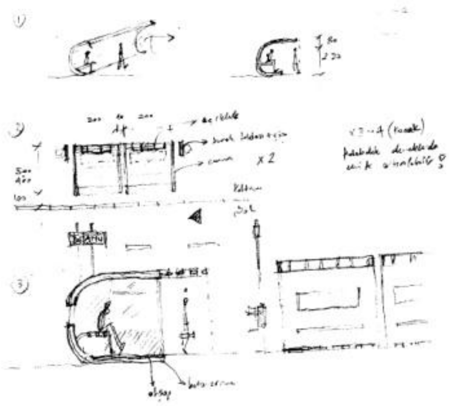
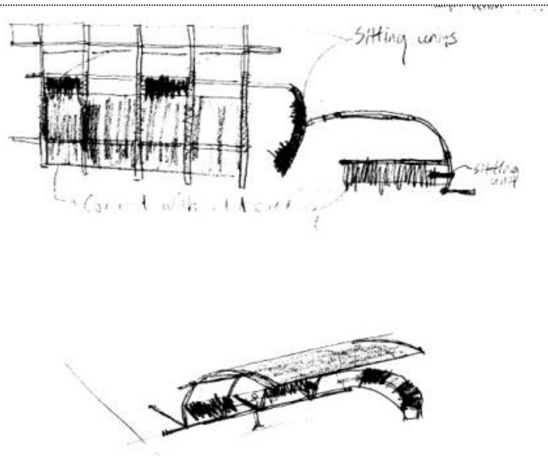
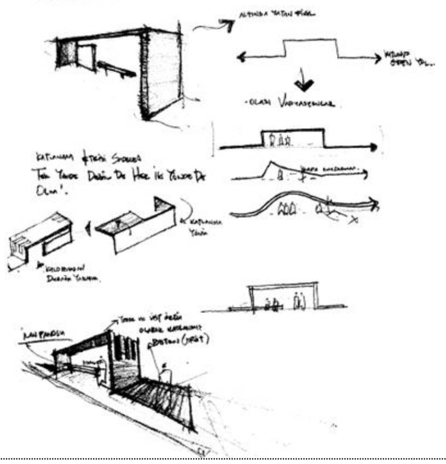
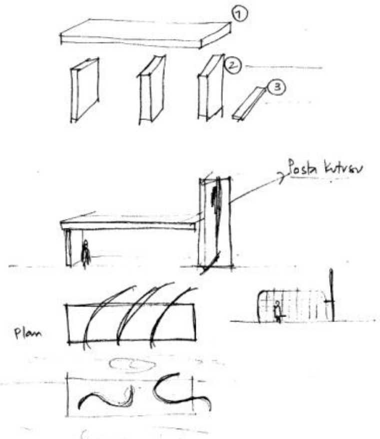
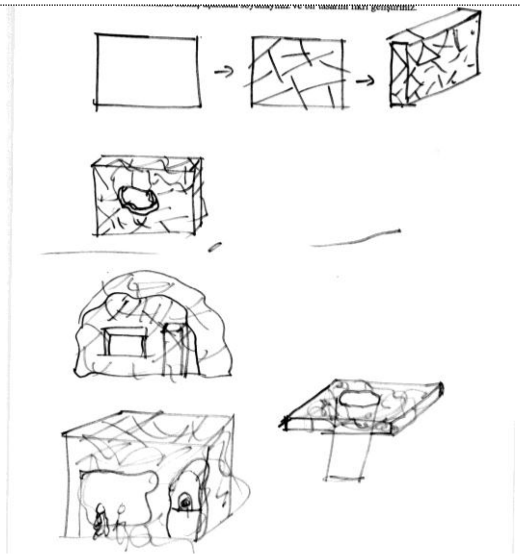
|  |  |
|  |  |
|  |  |

Vosniadou (1989) claimed that the distance between target and source is not so much a defining characteristic of the quality of the analogical process. The defining characteristic, according to her, is *the salience of similarity* (Vosniadou 1989). Thus, structural similarity can be established between objects that belong to different conceptual domains as well as between objects that belong to similar domains related with expertise level, and goal. Since the design process is defined as an innovative and creative activity, exploring a large number of alternative solutions before focusing on the final design improves the universe of potential design solutions. But in this study (see Table 5.6) the student participants generally attempted to develop the final design solution before searching other alternatives as in the study of Casakin (2004). They were insufficient in encoding higher levels of knowledge. In general their first attempt for finding a solution would become the final solution, without much reconsiderations. However expert designers could be able to see casual relations of complex parameters in a holistic, integrated, and simultaneous view.

Table 5.6. Examples for novice designers' literal transfer from long-distant domain

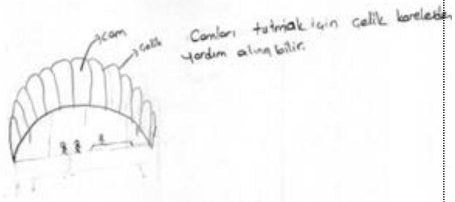
| | |
|---|---|
|  |  |
|  |  |
| IYTE1-009 | DEU4-003 |

Distant domain sources allow experts to explore new conceptual domains. In contrast, for novices, distance of source domain does not affect the creative process (Bonnardel et.al., 2004). Their designs show that novices generally cannot envision the potential utility of sources, because of the fixation effect. Students appear to focus on specific features with particular, narrower viewpoint, which make them to focus on *the more domain specific information*, while professional designers appear to focus to adopt a more general approach than students with a holistic view, which allow them to take into account *the domain general information.*

## 5.2.2. Expertise and Reasoning with Abstraction Categories

Higher levels of abstractions may enhance the analogical transfer while lower levels of abstractions may constrain it (Ripoll, 1998, 2001). A lower level abstraction creates a limited interconnection between source and target domain in analogy (Gick & Holyoak, 1983). Novice participants of this study were only able to make low levels of abstraction. They could only benefit from the superficial object attributes of the source domains.

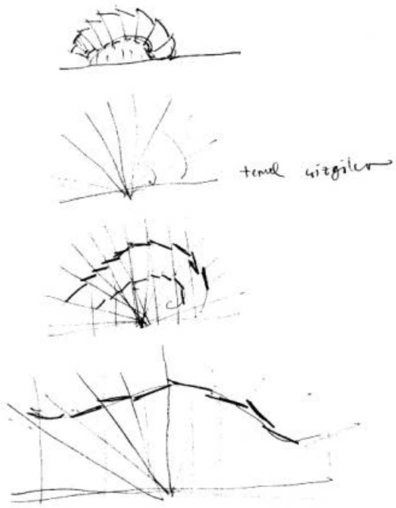
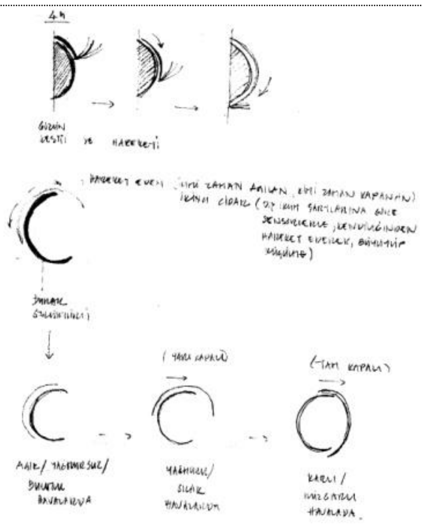
Table 5.7. Examples lower levels of abstractions of novices

| | |
|---|---|
|  |  |
|  |  |
| DEU1-038 | DEU1-062 |

Higher levels of abstraction (i.e., deep structural relational features in the form of schema based representation) play an essential role throughout the analogical reasoning process (Ripoll, 1998, Ripoll et al., 2003). Comparing the performance of student and expert participants in this study, it is observed that the solution-relevant higher level abstractions and representation of structural features are developed with education (Novick, 1988). Second and fourth year students generally focused on local syntactic relationships of source objects but used case-based reasoning. Syntactic approach to analogical reasoning fails in considering goals (pragmatic concerns) and other contextual constraints in guiding analogical inference (Holland et al., 1986).

Expert designers on the contrary considered the casual relations with a pragmatic approach (Table 5.8). Experts were able to make abstractions at multiple levels discovering the casual relations and the main aspects of source examples (Medin & Ortony, 1989).

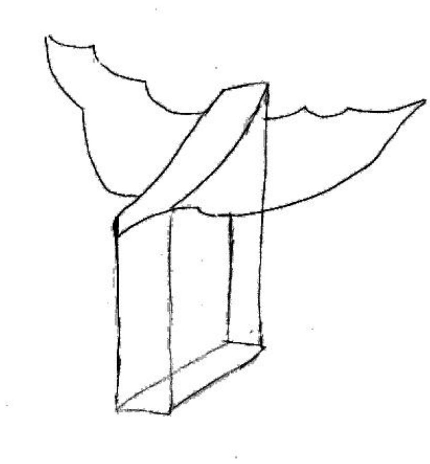
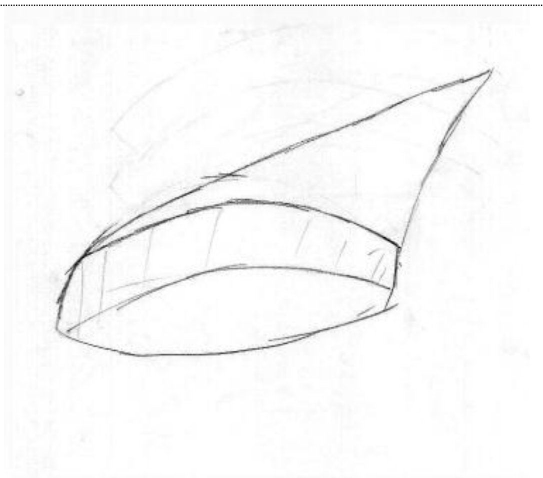
Table 5.8. Examples higher levels of abstractions of experts

| | |
|---|---|
|  |  |
|   |  |
| EXPERT 05 | EXPERT 10 |

## 5.2.3. Expertise and Use of Representational Systems

Visual representations might either hinder analogical reasoning (Anderson et al., 1984; Chen, 1995) or enhance analogical reasoning (Gick and Holyoak, 1983; Beveridge, 1987; Cardoso, 2011) or they could have no impact (Casakin, 1999). In this study, it is probable that visual representations used created a limitation for novices. Previous research revealed that visual representations of source domain facilitate the analogical transfer in problem solving (Beveridge & Parkins, 1987). First year students could not envision the potential utility of inter-domain sources (Bonnardel & Marmèche, 2004; Casakin & Goldschmidt, 1999). As the problem solving studies of Gick and Holyoak (1983), Beveridge and Parkins (1987), Chi, Feltovich, & Glaser (1981), and Novick (1988), and design studies of Casakin (2003) showed problem domain representation alter according to expertise levels. In this study, novices generally made pictorial representations and experts designers solved problem breaking down of complex problems with different type of structural feature representations (Table 5.9).

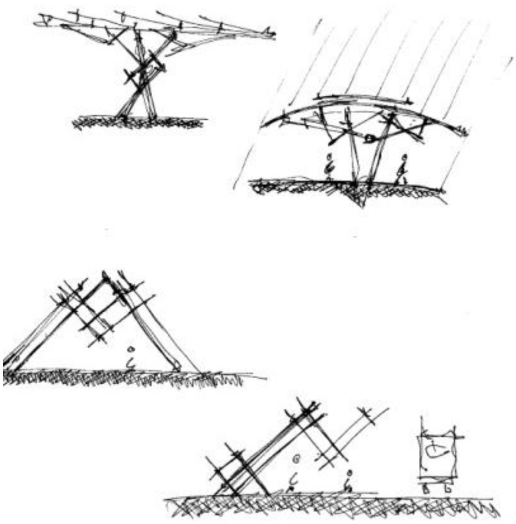
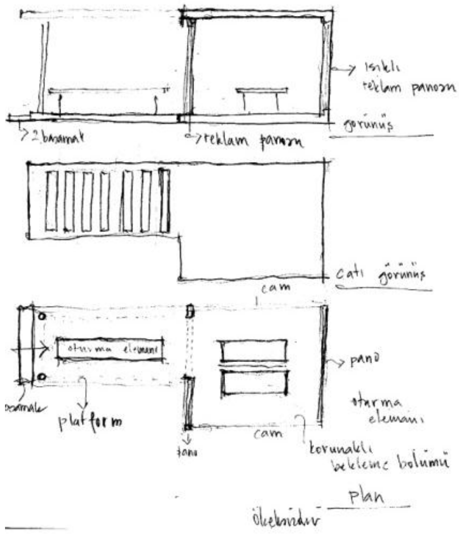
Table 5.9. Examples of mere appearance transfers

| | |
|---|---|
|  |  |
|  |  |
| IYTE1-017 | DEU1-093 |

What is the basic property of expertise which leads experts to successfully foresee the potential utility of distant source domains? Experts in this study were able to make representations of different levels of abstraction focusing on casual relations of the parts and the whole (Table 5.10). An important goal of information visualization is to expose different types of relationships within abstractions.

Participants of this study used different types of representations changing according to level of expertise. Novices used pictorial representations while experts used abstract representations. The skill of abstract representations naturally develops with education and expertise. Briefly, expertise in creative design accompanied with the elaborate use of visual thinking and abstraction have a critical role in analogical reasoning in design.

Table 5.10. Examples of analogical transfers

| | |
|---|---|
|  |  |
|  | <br> |
| EXPERT 03 | EXPERT 02 |

## 5.2.4. Expertise, Design Fixation and Originality

Medin and Ortony (1989), Novick (1988), Jansson and Smith (1991) and Bonnardel (2000) argued that salient properties of source domains might cause design fixation effect in the lack of sufficient domain knowledge which develops with expertise. In this study the effect of "design fixation" was observed in different types. Novice designers' designs were generally directly linked (Leclercq & Heylighen, 2002) and closely associated (Malaga, 2002) with the source domain whereas experts' were indirectly linked (Leclercq & Heylighen, 2002) and remotely associated (Malaga, 2002). Experts' designs indicated signs of deep structural similarities with the source analogues. Design fixation occurred at different stages: first, at level of "negative transfer" (Chrysikou & Weisberg, 2005) by focusing on the specific features of source domains (Jansson & Smith, 1989, 1991); second, by "focusing source domain information content" (Holyoak and Koh, 1987; Keane, 1987) in the solution generation process. Experts were able to take into account multiple aspects of sources, and benefit from them in the solution generation phase (Bonnardel & Marmèche, 2004; 2005) contrary to novices. Briefly, the analogical process for experts and for novices differ from each other.

Analogical reasoning mechanism depends not only on the characteristics of the subject (knowledge level, education, expertise, etc.), but also on the characteristics of the experimental setting (Bassok &Medin, 1997). Remote or long-distant domain sources correspond with surface dissimilarity, whereas local domain sources correspond with surface similarity. As Holyoak (1985) suggested, whether reasoner focuses on surface similarities between source and target domain or not, they generally will be affected from salient features and block alternative associations to activate correspondences in the selection process. Findings suggest that visual displays, various systems of representations such as photographic images or abstractions, in the course of source domain selection have a great influence on the analogical transfer (Catrambone, 2002; Casakin, 2010). Casakin (2004) found that novice and expert designers were able to retrieve deep principles from the available visual sources, selected between-domain sources as well as within-domain sources, and created successful analogies given the appropriate type of visual representations. In this study, source examples were represented with photo-realistic images and observed different type of design fixation effect according to expertise. It is obvious that the representation of information is a critical element in the way it shapes the goal of the reasoner. Beveridge and Parkins (1987) clearly showed that the goal-driven (pragmatic) abstraction which constrains the goal of the reasoner is an important part of the problem solving process for making associations between source and problem domain and transfer of knowledge to the target domain. Similarly Chrysikou (2005) found that specific instructions to combine multiple levels of thought could help designers in avoiding the fixation effect.

### 5.2.5. Expertise and Generation of Analogical Design Stages

Distant analogies are seen as creative *"mental leaps"* since originality in novel solutions is bound to using new strategies (Holyoak & Thagard, 1995; Ward, 1994). In this study, in the idea generation stage, first year students behaved as if they were searching for*"mental leap*s". Mental leaps would, however, require an immense cognitive effort in transferring knowledge across a variety of settings to create new ideas in the generative process (Dahl & Moreau, 2002; Jansson & Smith, 1991). The novices in this study lacked such skills and followed a single step transfer procedure without any intermediary abstractions. In Novick's term (1988), they followed an incorrect procedure.

The analysis of sketches indicate that in the solution generation stage novice designers saw target domains as solutions stage novice designers saw target domains as solutions in a *single step processing mode* (Hummel & Holyoak, 1997), although they generally aimed at originality and behaved as a creative thinker in the retrieval stage. Single processing mode is a very limiting analogical strategy.

Expert designers behaved less as a radical creative thinker; retrieving the local sources contrary to novices, but more as a modest creative problem solver; mapping, transferring, adapting and evaluating target domain. Knowledge transfer from near domains are more likely to be only a metamorphosis of sources with preserving more *attribute features* and these deviations are seen as effective *"mental hops"* (Ward, 1998). Experts were more qualified in transferring knowledge 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 sub-steps in *"mental hops"*. Multiple continuous, related stages were useful for establishing a target domain which was coherently integrated with the source domain. Also, the ability of schema-driven reasoning (Novick, 1988; Linden et.al., 2004) and the ability to think through visual representations (Gross & Do, 1995) led them work in a systematic and continuous direction.

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 could reach neither creative "mental leaps" nor effective "mental hops".

In the light of the results given above, we could derive the following comparisons between novice and expert behaviors:

- Novices aimed at originality and novelty while experts aimed at practicality and productivity.
- Novice designers generally focused on only source domain (thinking around source domain), while expert designers generally focused on source and target domain simultaneously (movement between source to target and movement around target).

- Novice designers perceived the given source domain representation itself as the source of knowledge (i.e., representation was a limitation), while experts saw the given source domain representation as triggering deeper knowledge.
- Novices created a path including different unrelated stages and sub-stages in analogical design; on the contrary experts created a path including related stages and sub-stages in analogical reasoning.
- Novice designers generally established anomaly and mere appearance similarity; while expert designers generally established analogy and literal similarity between a selected source and target.
- Novices connected the problem domain and source domain with first order relations at the superficial level; while experts were reasoning in a more holistic way breaking down the problem into its smaller simpler sub-parts and understanding the relationships analytically.
- Novices focused on specific sub-functions as generic functions. Experts focused on generic function as a strategy and developed specific functions.
- Novice designers think in a more detached, analytical way, contrary to experts who identified a holistic system.

Table 5.11. Comparison of novice and expert designers according to some parameters

| NOVICE | **VS.** | EXPERT |
|---|---|---|
| Superficial Similarity | **Level of Similarity** | Deep-structure Similarity |
| Simple | **Analogical Design Stage** | Complex |
| Irregular | **Representation** | Specialized-Detailized |
| Mere Appearence-Literal | **Similarity Type** | Analogy |
| Playful | **Level of Target Domain** | Masterful |
| Domain Specific Abstraction | **Level of Knowledge** | Domain General Abstraction |
| Formal | **Analogical Reasoning Process** | Relational/Casual (Strategic) |
| Playfull | **Idea Genaration** | Rigit |
| Rigit | **Solution Generation** | Masterfull |
| Anaytically | **Reasoning Type** | Analogically |
| Analytic, detached | **Cognitive Behavior** | Experience-based. |
| Originality | **Consideration** | Practicality |

# CHAPTER 6

# CONCLUSION

Analogical reasoning, which is considered as a vital part of cognition (Hofstadter, 2001), fosters *creativity* and *discovery* in such domains as design and science. Ward (1998) categorizes analogies into *inventive* and *explanatory* analogies. This study investigates the notion that analogical thinking is a ubiquitous mechanism of creative problem solving in the frame of design. The study examined the extent to analogies which are presented as part of *associative reasoning system* (Sloman, 1996), support *inventive* and *creative* thinking in design. Associative reasoning system enhances those cognitive mechanisms that will help us perceive things within different alternative parameters. This research extends the current literature by taking analogical reasoning as a holistic process, consisting of and relating to *cognition, context*, *process*, and *purpose*. Most likely, cognitive system uses various highly different ways of analogizing. In the light of views from analogy literature and creativity literature, analogical reasoning should be explored and associated by current models such as divergent versus convergent thinking (Guilford, 1968; Gabora & Saab, 2011), mental leaps (Holyoak, 1985) versus mental hops (Ward, 1998), syntactic (Gentner, 1989) versus pragmatic view (Holyoak, 1985) of analogy, perceptual versus conceptual categorization (Clancey, 1999), close associative versus remote associative (Malaga, 2000), case-based versus schema-based reasoning (Ball, 1997; Clement, 2009), lower-level perception versus higher level perception (Chalmers et. al, 1991), strategic and theoretic transfer (Haskell, 2001), analogical reasoning versus rule-based thinking (Sloman, 1996).

In the study, the analogical design process was investigated in two main phases: *the idea generation phase* and *the solution generation phase.* In the idea generation phase, ideas are generated and manipulated; and in the solution generation phase, the ideas are evaluated and executed. In the idea generation phase, *divergent thinking*, which is lateral thinking, was useful when retrieving or selecting analogical sources for new ideas. *Convergent thinking,* on the other hand, is mostly used in *analogical solution* *generation phase*, when one is mapping and transferring knowledge and evaluating ideas.

Novices tried to establish similarities and made connections between generally distant source and target domains, showing signs of divergent thinking. Expert designers, on the other hand, generally focused on the near domain source examples, showing signs of convergent thinking. Second and fourth year students were in between these two types of cognitive behaviors. They were generally insufficient to perceive higher-level casual relations and fixed on the superficial characteristics of the source examples (Jansson & Smith, 1991). This group of participants generally made literal transfers and were neither divergent thinkers nor convergent. In analogical reasoning process, divergent and convergent thinking styles need to be combined. Briefly, experiment results show that first year students were able to produce creative ideas more than the expert designers. However they generally focused on the given representation of the selected source example and inferred and transferred knowledge at pictorial, or attributional, or superficial level.

The great value of convergent thinking is that it helps focus deeply on a certain idea, however, it also leads to see the larger picture. Design education requires both focus and divergence. Several studies investigating cognitive and design fixation indicate the possibility of not being able to move away from the known examples. Analogical reasoning might allow students focus on *domain specific knowledge* in relation to *domain general knowledge*. Understanding pragmatic view of analogical reasoning is a base for *creative process* to achieve *practical solutions* with *original ideas* from diverse interdisciplinary sources. There are several factors which is shown to influence the analogical reasoning process such as the knowledge base of designers (Casakin, 1999; Gick and Holyoak, 1983), type and context of problem (Anderson et al., 1984), type of representation (Beveridge, 1987; Novick, 1988; Chen, 1995), timing (Tseng et.al., 2008), and goals (Holyoak & Thagard, 1987; Tseng et. al., 2008). In this study, it is suggested that permanently integrating relevant instruction in design education will reduce the interference that causes fixation. Casual relation and strategy based knowledge transfer to a new context enhance novices' in analogical solution generation and support expert designers in creative idea generation. Concerning this last issue, Koestler (1964) and Hesse (1966) pointed out the fact that analogies used in creative acts are the result of a casual relations established in the mind.

Analogical reasoning processes are constrained by the cognitive processes and strategies mentioned above. Relational and casual thinking strategies are important not only for imagination, but also for inert knowledge phenomenon (Reeves & Weisberg, 1994). Novice designers need to acquire expertise for developing their *episodic memory* through abstract thinking.

First, abstractions actively shape and facilitate analogical reasoning while reasoning through *representational systems*. The issue of knowledge representation was studied in a number of domains such as chess (e.g. Chase and Simon, 1973), physics (Bransford et al 1989; Chi, Feltovich and Glasser 1981), medicine (Patel and Groen, 1991), microbiology (Dunbar, 1995, 2001), computer sciences (Davies et al., 1995), and design (Casakin & Goldschmidt, 1999). Findings showed that experts tend to encode and represent information and structure a goal-significant knowledge base considering an extensive context. Conventional representational systems provide a window for a specific way of seeing. Each representational system focuses on certain aspects of a source domain or certain stage of the design process. In this respect these systems are fundamental to the design education to work on different levels of knowledge. Representation systems also can be transferred and adapted from interdisciplinary domains to provide better tools for goal-driven thinking. As a result, it is suggested that analogy develops the use of representational systems, perception of source domain characteristics, and the context of analogy use.

Second, what is important is to be able to see the different features of a source example. Surface features reflect the perceptual features of a source domain and are usually constraining. Structural properties reflect the causal relationships and are transferable to a wide range of new contexts. Gentner (1989) and Keane (1988) argued that superficial characteristics serve to visual perception while structural features serve to deeper and more pragmatic knowledge base for analogical transfer. Successful analogies are based on structural knowledge transfer from interdisciplinary sources, which opens up the space of research for creative ideas. The source domain should be considered in a broader context through its casual relations. Since students lack a structured body of domain knowledge, they often fail to see the structural features of a source domain. The ability to understand structural relations of a source domain triggers spontaneous transfer in analogy.

Third, *the context of analogy use* shapes the analogy process. In artificial settings, participants of a study are given the source examples and are passive, which makes it harder for them to see their relevance for distant domains. In the laboratory setting, the source objects are represented by superficial characteristics (photographs, names, etc…). In real-life settings, the source domains can be perceived in their own context. Studies have shown that people in general are masterful analogical reasoner (Blanchette & Dunbar, 2000, 2001). This study followed the reception paradigm, therefore, is limited in the way it could describe the analogical reasoning among designers. Difficulties in the spontaneous access and use of analogy in the real-world setting were reported to be associated with the level of expertise. Novices need to benefit from explicit instructions in analogical reasoning to develop their skills of analogy use.

Finally, the educational system is an important factor that develops knowledge base, productive procedural thinking, but, the study results indicate that it could be constraining the creativity. It will be better to use analogical reasoning especially in the idea generation process as well as the solution generation process and also relating these two separate processes.

The study findings indicate that goal of the reasoner affect the analogical thinking and reasoning as one of the most important factors. In-vivo studies show that the pragmatic considerations such as audience are important in the analogical reasoning. When the purpose is the explanation of the unfamiliar domains via the easily perceivable familiar ones (explanatory analogy), people generally use distant domain analogies (Blanchette & Dunbar, 2001). In science, for example, whenever experts are communicating with other experts, they generally use near domain analogies, contrary to experts communicating with lay people who used between domain analogies to explain the unfamiliar domain with a more familiar domain.

The source domain retrieval is the result of both the type of the target domain (i.e., explanatory or inventive) and the context of their use (i.e., in vivo and in vitro). The interactions between these factors shape analogical process. Overall, the goal of the reasoner is the main factor that influences the selection or retrieval of sources in design, science, and politics.

In general, it is concluded that accessing a useful source analog and transferring the structural features of a source domain are both important for creative thinking. Syntactic approach to analogy emphasizes the rule-based thinking (Gentner, 1983) whereas pragmatic approach emphasizes strategic thinking (Holyoak, 1985) in a broader context. The source domains which are more distantly related to the problem would impact idea generation only when there was an open goal to solve the problem (Cagan et.al, 2008). Goal-driven thinking triggers the successful analogical knowledge transfer (Holyoak, 1985; Holyoak & Thagard, 1989) and increases the positive pragmatic effect of distant information from interdisciplinary sources.

With increase in expertise, structural knowledge transfer and convergent thinking ability increase as well. Structural knowledge combines system knowledge in the light of structural and casual relations. Education develops the ability of analogical reasoning (Dominowski, 1995; Finke et. al, 1992). However it conditions the designers in the selection of source domains. In the light of this study's findings, novice designers need support to foster productive thinking from expert designers whereas expert designers need more divergent thinking. It could be asserted creativity requires both creative idea generation and effective solution generation, which could fostered through systems abstractions. Novice designers need to be trained in relational thinking in knowledge transfer process. Sophisticated thinking in the idea generation process, systematic thinking in the solution generation process could be more developed by the methodological and systematic use of analogy in design processes.

## 6.1. Limitations of the Study

This study has certain limitations that need to be taken into account when considering the extensions and contributions. In this study, although analogical transfer is very extensive phenomenon, it has been studied from a rather narrow empirical perspective. The experimental study design naturally brings forth many limitations as far as the generalization of the results of the study is concerned.

***The sample condition***

The differences among participants could relate sample condition. One is the context of sample. One limitation of this research is based upon the two schools selected for analysis. We recruited the student participants from two separate schools to minimize the impact of particular pedagogical approaches on analogical transfer. Research results may be different for other schools. Other one is to sample size of the study. An important strength is that this is a larger-scale study. The sample size of novice designers used in this study may create a sufficient statistical power. However, in this empirical study contrary to the novice designers, the sample size of expert designers was narrower. The inferences of this study may be different, expert designers might have observed in a larger sample size and novice designers might have observed in more than two educational contexts. It is difficult to make generalizations about entire population with this collected data.

***Measurement condition***

The measurement limitations commonly associated with the use of the Delphi Method. First, researchers who labeled the responses to categorization were already familiar with the research subject in Delphi procedure. Second, the personal backgrounds and experiences of the panel members may be the critical factor for their perceptions in the panel. Also more than three respondents would be critical for the results of this research. In example selecting procedure the sampling may be another constraint that affected the consensus on source domain examples. In analogical categorization procedure, insufficient representations may be the factor that affected the the consensus on analogy levels of sketches.

In this study content analysis is not used for making statements for this study. Rather it is used to make comparisons and justifications with the main statements. Thus content analysis is not a sole basis of the claims of this study. Findings of this particular study are limited to the framework of the categories and the definitions used in that analysis. Different researchers might use varying definitions and category systems to measure the statements. There are some other limitations to the possibility of applying statistical tests to the data-set as well as methodological limitations in relation to structuring a coding scheme.

***Experiment condition***

The results from the study could have been different under different experimental conditions. One factor that could affect the findings of this study is the type of instructions given to the participants in the experimental tasks. We know that different type of **instructions** change significantly analogical reasoning (Casakin, 2010; Casakin & Goldschmidt, 1999; Chrysikou & Weisberg, 2005; Dahl & Moreau, 2002). If we had told our participants to be radically creative the results could have been different. The reason why instructions matter, as suggested by Holyoak and Thagard (1989), is because they set a particular goal which shape the analogical process. Dahl and Moreau (2002), for instance, asked subjects to use more than one source domain specifically and found that they produce more analogies; and the number of analogies invoked is positively associated with the originality of the design product.

The given information for the source domains and examples also could affect the selection of the source domains. For example, the format and number of visual displays provided to participants could have been manipulated also to determine how realistic versus more abstract representations impact analogical reasoning. The visual displays we provided were all real-life photographs rather than abstract representations. Christensen  and Schunn (2007) found that representations in the form of prototypes are more constraining than sketches. In this study abstract representations were not preferred to cause a particular direction in analogical transfer. Rather, in this study the aim was to see the cognitive behaviors, when real-life photographs given as a reminder of the source examples. However, we could have provided more than one visual display of different format to decrease fixation to visual displays on superficial level.

The role of complicated multi-factorial approach of the study must be taken into consideration for this research. The difference between groups may be affected by the factor used in the experimental setting. One could also have changed the experimental set up and asked participants to produce source analogues to be used in the later stages of the design, therefore, follow a production paradigm in the study (Blanchette & Dunbar, 2000; Dunbar, 2001). Dunbar and Blanchette (2000) propose that when people are offering the source analogues rather than giving them they are more likely to perform deeper analogies. Consequently, in-vivo studies of designer could also lead to different results with regard to analogical reasoning in design. Studies of scientists working in a lab (Dunbar & Blanchette, 2001), of politicians and journalists (Blanchette & Dunbar, 2000, 2001), and of scientists from history (Gentner et al., 1997) indicate the prevalence and strategic use of deeper and within-domain analogies.

## 6.2. Implications of Main Findings

The insights gained from this research should be of interest to practicing designers wishing to generate creative solutions and educators wishing to promote cognitive skills of design students. Analogy can be an extremely useful *exploratory* tool in scientific research in design. This cognitive strategy can be used to generate insights and investigate properties of a model. Analogy can also be an extremely useful *explanatory* tool in communicating design to experts and novices. The findings of this study, regarding the features of deep structural analogies, may be useful to educators when devising or evaluating the likely efficacy of an analogy. When used in a structured, integrated way, analogies can provide experts and novices with fresh insights that can be further developed through representational tools.

As most researchers, I believed that associative reasoning have helped to *strengthen designers' creative potential* in their respective research areas and in scientific thinking. However, they warned that analogical reasoning methodology should never be used where their inner systems are unknown. If this happens, it will be difficult to obtain insights and analogical reasoning may actually weaken or fixate one's capabilities. This study can be is a particularly useful research, with possible implications for the use of analogical reasoning in a systematic way in design education.

## 6.3. Future Research

The conclusions as well as the limitations of this study also bring forth some fruitful and interesting possible avenues for future research. The most important avenue for future research obviously lies in continuing the elaboration of the parameters of the analogical transfer.

Understanding the analogy mechanism in a holistic view stimulate future research. Perception of the interdependence and independence of components to different domains or origins will yield original ideas. To notice the originality level, first of all designers should be aware of and discover the origins of their ideas. By unmasking and discovering the origins of ideas, designers will be able to develop their analogy mechanism.

This research discussed analogy mechanism through some basic parameters. It is suggested that each parameter should be researched through finer-grained sub-parameters in the interaction of analogy mechanism use (i.e. finer grained knowledge of representational systems and analogy mechanism interaction in design and design education, finer grained knowledge of abstraction categories and analogy mechanism interaction in design and design education, etc…).

In addition to widening the scope this research, it could also be seen as interesting to study the emerging design fields. It would be exciting to gain an understanding of the analogical transfer process in relation to different types of design fields to develop relational predicates.

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# APPENDIX A

# MODELS USED IN RESEARCH

## 1. Models used in Experimental Tasks

1.1. First Task: Rating the Source Domain Examples

1.2. Second Task:

Task A: Source Domain Group and Example Selection

Task B: Explanation of the reasons

1.3. Third Task: Analogical Design Process

## 2. Models used in Delphi Procedure

2.1. Models to Categorize Visual Data

| | |
|---|---|
| IZMIR THE INSTITUTE OF TECHNOLOGY<br>DEPARTMENT OF ARCHITECTURE<br><br>**FIRST TASK: Rating the Source Domain Examples**<br>**DATE** | |
| **Age :** | **Gender: : Mr/Mrs** |
| **Graduation year:** | Do you have any design education before BSc? **Yes/No** |

Assume that you will design a bus stop. Some source domains will be given to you. The important point here is to understand the ideas and concepts behind the selected source domain. Rate the following source domains according to appropriateness.

| Source Domain Number | 1=Poor | 2=Fair | 3=Average | 4=Good | 5=Excellent |
|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 |
| 2 | 1 | 2 | 3 | 4 | 5 |
| 3 | 1 | 2 | 3 | 4 | 5 |
| 4 | 1 | 2 | 3 | 4 | 5 |
| 5 | 1 | 2 | 3 | 4 | 5 |
| 6 | 1 | 2 | 3 | 4 | 5 |
| 7 | 1 | 2 | 3 | 4 | 5 |
| 8 | 1 | 2 | 3 | 4 | 5 |
| 9 | 1 | 2 | 3 | 4 | 5 |
| 10 | 1 | 2 | 3 | 4 | 5 |
| 11 | 1 | 2 | 3 | 4 | 5 |
| 12 | 1 | 2 | 3 | 4 | 5 |
| 13 | 1 | 2 | 3 | 4 | 5 |
| 14 | 1 | 2 | 3 | 4 | 5 |
| 15 | 1 | 2 | 3 | 4 | 5 |
| 16 | 1 | 2 | 3 | 4 | 5 |
| 17 | 1 | 2 | 3 | 4 | 5 |
| 18 | 1 | 2 | 3 | 4 | 5 |
| 19 | 1 | 2 | 3 | 4 | 5 |
| 20 | 1 | 2 | 3 | 4 | 5 |
| 21 | 1 | 2 | 3 | 4 | 5 |
| 22 | 1 | 2 | 3 | 4 | 5 |
| 23 | 1 | 2 | 3 | 4 | 5 |
| 24 | 1 | 2 | 3 | 4 | 5 |
| 25 | 1 | 2 | 3 | 4 | 5 |
| 26 | 1 | 2 | 3 | 4 | 5 |
| 27 | 1 | 2 | 3 | 4 | 5 |
| 28 | 1 | 2 | 3 | 4 | 5 |
| 29 | 1 | 2 | 3 | 4 | 5 |
| 30 | 1 | 2 | 3 | 4 | 5 |
| 31 | 1 | 2 | 3 | 4 | 5 |
| 32 | 1 | 2 | 3 | 4 | 5 |
| 33 | 1 | 2 | 3 | 4 | 5 |
| 34 | 1 | 2 | 3 | 4 | 5 |
| 35 | 1 | 2 | 3 | 4 | 5 |
| 36 | 1 | 2 | 3 | 4 | 5 |
| 37 | 1 | 2 | 3 | 4 | 5 |
| 38 | 1 | 2 | 3 | 4 | 5 |
| 39 | 1 | 2 | 3 | 4 | 5 |
| 40 | 1 | 2 | 3 | 4 | 5 |

| | |
|---|---|
| IZMIR THE INSTITUTE OF TECHNOLOGY<br>DEPARTMENT OF ARCHITECTURE<br><br>**SECOND TASK-A: Source Domain Group and Example Selection**<br>**DATE** | |
| **Age :** | **Gender: : Mr/Mrs** |
| **Graduation year:** | Do you have any design education before BSc? **Yes/No** |

1. Please chose one of the most approprite source domain group below to design bus stop. Then select a source domain in the group. Put a thick inside the box.

**Grup 1**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |

**Grup 2**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |

**Grup 3**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |

**Grup 4**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** |

**Grup 1 - BUS STOPS**

1

2

3

4


5

6

7

8


9

10

## Grup 2 - ARCHITECTURE


1


2


3


4


5


6

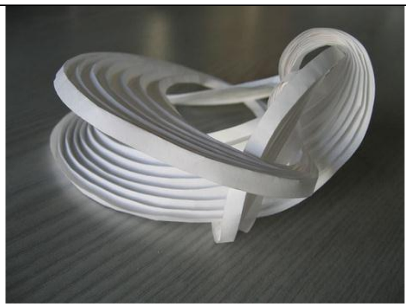
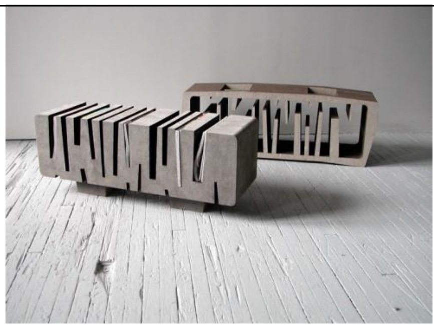

7


8

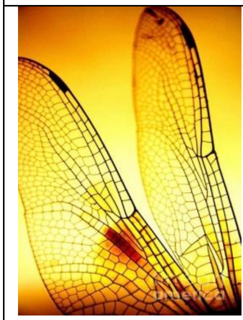

9


10

**Grup 3 - ARTIFACTS**

| | |
|---|---|
|  1 |  2 |
|  3 |  4 |
|  5 |  6 |
|  7 |  8 |
|  9 |  10 |

**Grup 4 - NATURE**

| | |
|---|---|
|  1 |  2 |
|  3 |  4 |
|  5 |  6 |
|  7 |  8 |
|  9 |  10 |

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**SECOND TASK- B: Explaination of the reasons**
**DATE**

Please explain the reasons and aims behind your selection(s).

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**THIRD TASK: Analogical Design Process**

**DATE**

Please develop an analogical design idea considering your source domain selection in one or few step.

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**Model for Categorization of Visual Data**

**DATE**

## DESCRIPTION:

| | Attributes shared | Relations shared |
|---|---|---|
| **Mere Appearance** | | |
| **Literal Similarity** | | |
| **Analogy** | | |
| **Anomaly** | | |

1. **Anomaly:** No Interpretation
2. **Mere-Appearance Similarity:** Formal Interpretation
3. **Literal Similarity:** System and Formal Interpretation
4. **Analogy:** System Interpretation (purpose)

Please categorize sketches of novice and experts designers according to analogy levels below.

| DESIGN NO | Literal Similarity | Analogy | Mere Appearance | Anomaly |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |
| 6 | | | | |
| 7 | | | | |
| 8 | | | | |
| 9 | | | | |
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| 25 | | | | |
| 26 | | | | |
| 27 | | | | |
| 28 | | | | |
| 29 | | | | |
| 30 | | | | |
| 31 | | | | |
| 32 | | | | |
| 33 | | | | |
| 34 | | | | |
| 35 | | | | |
| 36 | | | | |
| 37 | | | | |
| 38 | | | | |
| 39 | | | | |
| 40 | | | | |

# VITA

## PERSONAL INFORMATION

| | |
|---|---|
| Date of Birth | **1977** |
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## EDUCATION

2005 – 2012 **Ph.D. Program in Architecture**
Izmir Institute of Technology, Faculty of Architecture, Department of Architecture, Izmir, Turkey.
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2001 – 2005 **Master of Science Program in Industrial Product Design**
Izmir Institute of Technology, Faculty of Architecture, Department of Industrial Product Design, Izmir, Turkey.
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2000 – 2001 **Non-Degree Advanced English Education Course**
Izmir Institute of Technology, Graduate School of Engineering and Science, The English Preparatory School, Izmir, Turkey.

1995 – 2000 **Bachelor of Architecture**
Dokuz Eylül University, Department of Architecture, İzmir, Turkey.

## WORK EXPERIENCE

1999-2000 **Rasyonel Architecture Office**
Izmir, Turkey.

2002 – 2010 **Research and Teaching Assistant**
Izmir Institute of Technology, Faculty of Architecture, Izmir, Turkey.

## RESEARCH AREAS

**Phd** Cognitive Science, Creativity, Associative Reasoning System, Cognitive Strategies in Analogical Reasoning, Creativity, Novice and Expert Differences

**MSc** Foot and Footwear Interaction, Human Engineering, Anatomic and Biomechanical Analysis of Human Foot, Footwear Design Biomechanics, Foot and Footwear Interaction as a Dynamic System