DEVELOPING AND EVALUATING VISUAL ANALOGIES TO SUPPORT INSIGHT AND CREATIVE PROBLEM SOLVING

Dr. ERIC LUCHIAN

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Developing and Evaluating Visual Analogies to Support Insight and Creative Problem Solving

Eric Luchian, *BFA, MFA*

School of Computing and Communications
Lancaster University

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Declaration

This written thesis, including the portfolio of created visual analogies in static and multimedia formats (i.e., www.luchian.info), results entirely from my own work except where jointly authored (see Appendix 14-18) in publications as follows:

1. Luchian, E., & Sas, C. (2019). Erroneous Features in Freehand Sketching: Opportunities to Generate Visual Analogies. *Proceedings of the 23rd World Multi-Conference on Systemics, Cybernetics and Informatics: WMSCI 2019. 1*, pp. 86-92. Orlando, USA: IIIS.

2. Luchian, E., & Sas, C. (2011). Image Schemata in Animated Metaphors for Insight Problem Solving. *C&C '11 Proceedings of the 8th ACM conference on Creativity and Cognition* (pp. 369-370). Atlanta, USA: ACM.

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4. Sas, C., Luchian, E., & Ball, L. (2010). Investigating Visual Analogies for Visual Insight Problems. *Proceedings of the 1st DESIRE Network Conference on Creativity and Innovation in Design* (pp. 90-100). Aarhus, Denmark: ACM.

I hereby declare that work from this thesis has not been offered previously for any other degree or diploma to this or any other university, and to the best of my knowledge and belief, contains no material written or published by another person, except where due reference has been made in the text.

Signature:

Date: 31st March 2019

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Abstract

The primary aim of this thesis is to gain a richer understanding of visual analogies for insight problem solving, and, in particular, how they can be better developed to ensure their effectiveness as hints. While much work has explored the role of visual analogies in problem solving and their facilitative role, only a few studies have analysed how they could be designed. This thesis employs a mixed method consisting of a practice-led approach for studying how visual analogies can be designed and developed and an experimental research approach for testing their effectiveness as hints for solving visual insight problems.

The thesis' aim, therefore, is achieved through the following objectives:

1. To explore analogy in research literature in order to identify and integrate theories and methods for the development of visual analogies,
2. To design and develop a set of successful visual analogies to support analogical transfer in visual insight problems, and
3. To evaluate these sets of visual analogies and their effectiveness for visual insight problem solving.

Key findings indicate the value of embodied schema, of point of view for presenting the visual analogies, their pictorial depth, and how the insights are integrated within cue-based visual analogies.

The main contributions of this thesis include:

a) A richer understanding of the qualities of effective visual analogies for insight problem solving: leveraging image schemata drawing from embodied cognition, animations rather than static images, secondary depth cues such as light and shadows, gradient, and atmospheric perspective, and if more than one insight is needed for solving the problem, then all such insights should be supported by visual analogies.
b) A portfolio of two-dimensional and three-dimensional, static and dynamic visual analogies for two perceptual insight problems, i.e. the *8-coin* and the *cheap necklace* problems. The portfolio will experimentally measure the importance of surface, structural aspect, functions and relations of the

components that form the visual analogies for insight problem solving. These key elements of visual analogies are introduced and discussed in greater detail in the literature review chapters.

c) Guidelines for designing effective visual analogies for perceptual insight problems.

The research identifies the following theoretical and practical implications:

- Designers may benefit from the outcomes of this study and from the mixed research approaches that aid the investigation into the visual representational aspects of their practice.
- Researchers may benefit from the integration of practice-led and experimental research methods.
- Students may benefit from the implementation of visual analogies in the curriculum.

The study suggests that multimedia, human-computer interaction, and software engineer designers need to be aware of the nature of the visual representations used in their work and how, and why, these visual materials can help people solve problems, learn, facilitate interactivity, comprehend information, and explain new concepts.

1 Introduction

Most research on analogies has focused on verbal or text-based analogies, and less on the exploration of visual ones. Researchers and psychologists have taken for granted that there is a path leading to the development of human reasoning. Early childhood reasoning is primarily based on similarity, while rule-based reasoning, that helps people gain skills to form abstract concepts and use symbolic representation, is ingrained in adulthood. Similarity is associated with figurative qualities, and thus is largely visual. In his writings about the nature of mental visual imagery, Fodor (2008) stated that children think in pictures, while adults, in words. According to Kaufmann (1988), linguistic reasoning is used in problems that are familiar; however, for new problems, the use of imagery is more helpful because it involves fewer constraints from rules. Gentner and Medina (1998) proposed an integration of these two systems of reasoning, demonstrating that both are important in problem solving: one based on rules and the other on similarity. This is because they have shown that similarity-based reasoning is a powerful tool in insight problem solving. Indeed, visual analogies may be of particular interest as it is not only surface similarity that can be carried over to a new concept, but structural similarity, and in many cases, superficial similarity as well (Goldschmidt G. , 1995).

We argue that visual analogies have an advantage over verbal and text-based ones as they can be found and extracted directly from environmental sources as opposed to the other types that need to be inferred. An example of identifying clues to find a solution for an everyday problem is described below.

I rented a small flat in an old building close to the university, and after just a week of living there, I discovered that the showerhead was coming away from the wall. Upon taking a closer look at it, I noticed that the top mating bolt had become loose; it was rusty and worn-out and could no longer support the weight of the showerhead. As a result, the showerhead had slid to the slippery side of the shower walls, and was hanging only by the bottom bolt. It was a very old showerhead model, and I could not find the necessary pieces to repair it properly. For about a week, I was holding the showerhead in place with one hand while taking showers. One day, I went outside and saw an electric pole, all rotten and broken at the bottom, hanging in the air and being supported only by the electrical cables… and then, I had an "*aha"* moment. I went back to the flat, unscrewed the functioning bolt from the bottom of the showerhead tube, and fixed it at the top. Then, I threaded the rusted bolt and punched it in the loose hole at the bottom—that was the best that I could do at that point. It made no sense to have the faulty bolt supporting the weight of the entire showerhead.

As someone with a considerable amount of professional experience in visual art as a practitioner, my curiosity about visual metaphors and analogies intensified with each new piece of art created, and it is this curiosity that also motivated the work presented in this thesis.

1.1 Overview

The chapter starts with the motivation for and aims of the study, the rationale, research questions, and the summary of methods used in the research, and continues with the scope and summaries of the work. It concludes with contributions and the organisation of this thesis.

1.2 Motivation and Aims

> "The scientific man does not aim at an immediate result. He does not expect that his advanced ideas will be readily taken up. His work is like that of the planter – for the future. His duty is to lay the foundation for those who are to come, and point the way. He lives and labors and hopes." Nikola Tesla (1934)

1.2.1 Motivation

Analogies are powerful cognitive tools, supporting perception, decision-making, problem solving, and creativity. The analogy is one of the most common methods of explaining unknown concepts and new ideas. It allows the retrieval of previously un-retrieved relevant information or schemas (Yaniv & Meyer, 1987; Langley & Jones, 1988; Dreistadt, 1969; Olton & Johnson, 1976; Gick & Holyoak, 1980) whose activation can sensitise the problem solver to chance encounters with related stimuli (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995).

The use of analogy in reasoning and problem solving has been much investigated, mostly in educational psychology, and science education, instructional design, and computational modelling (Paivio, Rogers, & Smythe, 1968), while the focus on visual hints for problem solving has been less explored or their exploration has been restricted mostly to their facilitative role (Höffler & Leutner, 2007). Pressley (1977) states in his studies that pictures are better than words, as they engage multiple representations and associations with external knowledge, encouraging a more elaborate encoding than words (Paivio A. , 1971; Paivio, Rogers, & Smythe, 1968). The superiority of memory for pictures over words (Pressley, 1977; Reznick, 1977) starts in childhood and is maintained into adulthood (Kogan, Connor, Gross, & Fava, 1980), hence providing additional rationale for the value of exploring visual analogies as clues for solving insight problems.

This thesis extends prior work on visual analogies for insight problems by focusing not only on whether such analogies work, but also on what types of visual analogies are facilitative and why.

1.2.2 Aims of the Research

The main aim of this thesis is to gain a richer understanding of visual analogies for insight problem solving, and in particular, how they can be better developed to ensure their effectiveness as hints.

1.3 Research Question and Objectives

The main question asked by this thesis is: How can we design effective visual analogies that are able to facilitate solutions for visual insight problems? In order to address the research question, this thesis is divided into three research objectives:

1. To explore analogy in the research literature to identify and integral theories, and methods for the development of visual analogies,
2. To design and develop a set of successful visual analogies to support analogical transfer in visual insight problems, and
3. To evaluate these sets of visual analogies and their effectiveness for visual insight problem solving.

The focus of this thesis is on the development of a portfolio of visual analogies that are able to ensure analogical transfer. Creating, reflecting on, and evaluating these visual analogies in two perceptual insight problems have led to a better understanding of how they are formed and how they can inspire designers in their search for creative products.

1.4 Research Methodology and Methods Used

The thesis is based on the integration of practice-led research, and experimental methods, which are described in the Methodology chapter (see Chapter 4: Research Methodology and Methods Used). The choice of the methodology is based on the research question and design of the study.

1.4.1 The Use of 'I' and 'We' in the Thesis

Before moving on to the next section of the chapter that sketches the scope of the thesis, I will explain why I decided to use the pronoun "I" in some parts of the research instead of the customary academic "We". In attempting to document the creative process while generating visual analogies, either while looking for concepts, doodling, sketching, animating or refining them without any collaborators, participants, or authorities, I have found that using the narrative mode of writing (Bruner, 1986) is more appropriate and natural as it pertains to my personal experience. In contrast to the logical-scientific mode that takes the form of arguments (Britton, 1993), my notes (Schön, 1983), in the form of diaries and answers to questions in the generation stage of visual analogy development, are intended to capture the verisimilitude of my actions and document my thoughts during the creative act in terms of how I think at that moment. There is still debate, often quite controversial, on which mode of writing to use and where to use it. For example, French philosopher Simone Weil in her book *Gravity and Grace* (1997, p. 72) stated "we is a sign of the collectivity, whose ersatz force conceals the true vulnerability of the individual". Based on this view, writing the notes in "close-to-the-self" vocabulary may reduce the load to the memory and help the researcher to focus on solving the problem instead of formulating constraints around it.

1.5 Main Contributions

The thesis aims to make several key contributions, consisting of:

a) A richer understanding of the qualities of effective visual analogies for insight problem solving: leveraging image schemata drawing from embodied cognition, animations rather than static images, secondary pictorial depth cues such as light and shadows, gradient, and atmospheric perspective, and visual insights needed for solving the problem that are supported by the visual analogies.

b) A portfolio of two-dimensional and three-dimensional, static and dynamic visual analogies for two perceptual insight problems, i.e. the *8-coin* and the *cheap necklace* problems. The portfolio will experimentally measure the importance of surface, structural aspect, functions and relations of the components that form visual analogies for insight problem solving.

c) Guidelines for designing effective visual analogies for perceptual insight problems.

1.6 Thesis Structure

The thesis consists of twelve chapters. Chapter One introduces the topic of the research and theoretically sets the scene for the entire thesis. Chapters Two and Three include the literature review and background to the topic. Chapter Four describes the methodology and methods used in this thesis. Chapters Five through Eight document the visual analogy development practice along with diaries on created visual analogies and report on their effectiveness after being tested in a series of laboratory experiments with the focus on the solving process for the *8-coin* problem. Chapter Nine describes the visual analogy development process and the created analogies for another insight problem, the *cheap necklace* problem, and reports the results of the impact of these hints on participants' performance by testing them in the laboratory. Chapter Ten reports the results of the study based on the researcher's documentation of the creative process in the generation stage. Chapters Eleven and Twelve include a general discussion on this thesis and concluding notes. In the following subsections, the content of each of the twelve chapters is described in greater detail.

1.6.1 Chapter One - Introduction

This chapter introduces the topic, motivations for the choice of topic and the aims of the research. The chapter also outlines the research question and objectives, overview of the research methodology and scope of the thesis as well as summarising the contributions and structure of the thesis.

1.6.2 Chapter Two - Literature Review: Part I - Analogy and Problem Solving in the Context of Creativity

This chapter includes a comprehensive literature survey of fields related to this research, including the role of analogy and problem solving in the context of creativity. The chapter attempts to investigate the similarities and differences in the use of analogy and problem solving processes between a variety of fields and domains as mechanisms of and tools for creativity. Ultimately, the chapter seeks to examine an integration of these similarities and commonalities of analogy and problem solving applications.

1.6.3 Chapter Three – Literature Review: Part II - Visual Analogies: Static and Dynamic

This chapter involves a comprehensive literature survey of fields related to the use of visual analogies and their impact on human creative activities, creative processes, creative products, problem solving, and learning. The chapter narrows its focus on visual analogy as a tool for creativity and how visual analogy is developed.

1.6.4 Chapter Four – Research Methodology and Methods Used

This chapter introduces the methodology and methods used in this thesis. To generate and create the visual analogies for problem solving for this thesis, the practice-led method along with documentation of the process was used, and to test and evaluate them, the experimental method was used.

1.6.5 Chapters Five through Eight – The *8-Coin* Problem Experiments

These chapters outline the rationale, research questions, and methods for each of the four designed experiments. Sets of visual analogies for each study were developed and their effectiveness in the process of solving the *8-coin* problem was tested. The results were analysed, reported, and discussed, and each chapter ends with concluding remarks.

1.6.6 Chapter Nine – Solving the Cheap Necklace Problem with Animated Visual Analogies

This chapter introduces the design experiment, outlines the rationale, research questions, and method for the study involving another notorious insight problem—the *cheap necklace* problem. visual analogies are developed and tested in the laboratory setting for their effectiveness in the process of solving the *cheap necklace* problem, and the results are reported and discussed.

1.6.7 Chapter Ten – Sketching as a Generative Tool for Visual Analogy

This describes the study of how visual analogies is developed by using an experiential research method based on the author's structured reports on his practice to generate visual analogies. The chapter also introduces the design process, materials and tools used in the study, reports on the results, a discussion of the findings, and makes concluding notes in its final sections.

1.6.8 Chapter Eleven – General Discussion

The discussion chapter explores the extent to which the aims and objectives were achieved, and the research questions are addressed. The chapter also analyses the findings in relation to other works on visual analogy development processes and potential applications. Furthermore, it proposes guidelines for developing effective visual analogies for insight and creative problem solving.

1.6.9 Chapter Twelve – Conclusion

We reflect on the contributions of this thesis in the light of the research hypotheses outlined in Chapters Four through Nine, as well, on the proposed guidelines for developing effective visual analogies for insight and creative problem solving outlined in Chapter Ten.

2 Analogy and Problem Solving in the Context of Creativity

> “We must be clear that when it comes to atoms, language can be used only as in poetry. The poet, too, is not nearly so concerned with describing facts as with creating images and establishing mental connections.” Niels Bohr (Baggott, 2011, p. 47)

2.1 The Interdisciplinary Approach

The link between analogy, problem solving, and creativity has always been a central concept in cognitive science. Scholars from many different fields such as psychology (Bonnardel, 1999; Ball, Ormerod, & Morley, 2004; Catrambone, Craig, & Nersessian, 2006; Christensen, 2005; Casakin & Goldschmidt, 1999; Dreistadt, 1969), philosophy (Moravcsik, 2000), the arts (Arnheim, 1997; Finke, 1990; Patherbridge, 2010), linguistics (Chiu & Shu, 2007; Ashworth, 2003; Blevins & Blevins, 2009), artificial intelligence (Holyoak & Thagard, 1989; Hall, 1989), social sciences (Dunbar, 2004), neuroscience (Eysenck H. J., 1993; Ramachandran, 1988), and computing (Ohlsson S. , 1992; Newell, Shaw J, & Simon, 1958; Gero, 2000) provide complementary perspectives for investigating analogy and problem solving. In this context, analogies are considered tools for thought (Tversky, Morrison, & Betancourt, 2002; Lakoff & Johnson, 1980; Larkin & Simon, 1987; Goel, 1995), explanation (Novick L. R., 1988; Tversky B. , 2011; Van Gog, Paas, Marcus, Ayres, & Sweller, 2009; Gross & Do, 1995; Gentner, 1989) and communication (Kristensen & Gabrielsen, 2013; Kristensen, 2004; Patherbridge, 2010; Potter & Faulconer, 1975; Eisenberg, 1984) and can enable a thinker to interpret the source concept and make decisions.

In order to see the relationship between these three constructs, it is necessary to define them and ascertain the distinctions between them and their relatedness.

2.1.1 Conceptualization of Creativity

Creativity is a complex topic of study, and it is difficult to define. It involves processes and traits, including imagination, open-mindedness and tolerance of uncertainty, mastery of relevant skills, perseverance, ambition, flexibility, curiosity, willingness to experiment, and the ability to draw analogies (Bonnardel, 1999; Blanchette & Dunbar, 2001; Tversky B. , 2011). For example, a high intelligence score does not guarantee that an individual will be capable of producing a creative outcome, but this condition is necessary (Eysenck H. J., 1993) for a creative person, and so, must be tightly connected with creativity. Eysenck also proposes the use of two different terms for creativity: one that defines personality and one that defines the product by its "originality". As a result, creativity is understood and interpreted by many people in many different ways (Isaksen, Puccio, & Treffinger, 1993). One could regard creativity as being similar to a computer brain phenomenon, based on the idea that things are made from matter and are mechanically deterministic, continuous, objective and local. Organismic theorists state that in addition to the mechanism, the purposiveness and discontinuity in the development of an organism should be added to the mechanistic view. Idealists, on the other hand, believe that consciousness has primacy and not matter, so creativity is, essentially, subjective. The fourth view is that of the quantum theory of creativity (Goswami A. , 1999); this represents the newest of the four concepts and takes into account the needs of all previous views in terms of defining creativity.

There are many issues that hamper the definition of creativity, for example: differences between lexical and contextual meaning; differences between individual and societal creativity; or general and domain-specific contexts among other issues. Consequently, one overriding definition is inadequate, but rather, it is most appropriate to recognise creativity as an act that leads to a new idea, new thought or a new product. Accordingly to Goswami (1999, pp. 492-493), there are two kinds of creativity: fundamental creativity, which is "the creation of a new product of value in a new context of meaning" and situational creativity, which "involves a product of value based on the perception of new meaning in an old context or a combination of contexts".

A popular definition adopted by creativity researchers describes creativity as "the ability to produce work that is novel (i.e., original, unexpected), high in quality, and appropriate (i.e., useful, meets task constraints)" (Sternberg, Kaufman, & Pretz, 2002, p. 1). Since the beginning of human history, people have "created" things; in many cases this involved the production of something new by a person with "divine power". It was only in the 19th century that the term "creative" was widely attributed to art disciplines. Masters of the arts, music, and poetry were more frequently mentioned and referred to in literature as creative people, and it appears that the first examination of creativity may be linked to the 1869 publication of Galton's *Hereditary Genius: An Inquiry into Its Law and Consequences*. By the beginning of the 20th century, the philosopher Henri-Louis Bergson had developed an organismic model of life's creative processes, stating that the "reality" of life is "productive of effects in which it expands and transcends its own being" (2002, p. 192). Since then, as research into creativity has begun to expand rapidly, the number of definitions which have been used for creativity has increased, as well. In his investigations on this subject, Taylor (1959) found that there are over a hundred definitions of creativity, and that all of them point at three aspects: genius, giftedness and creativity (Taylor & Getzels, 2007). Different labels are attributed, including uniqueness, novelty, discovery, effectiveness, and product usefulness, but in one form or another, originality is deemed to be essential. Creative things have to be both original and effective (Runco, 2007). For example, children may express creativity in original works of art or through a product that is not as fit, apt or effective as in the case of a product that is selected and accepted for "inclusion into the relevant domain" (Csíkszentmihályi, 1996, p. 28) or field. The problem in terms of the effectiveness and usefulness of the artwork of children may be explained by the effect of aesthetic qualities of balance, order, and expression (Arnheim, 1997) rather than functionality. The concept of aesthetic effectiveness and usefulness of a product is obvious in the creative arts. Words and the defined meanings of creativity simply indicate ways to understand it rather than limiting our interpretations. In light of this diversity of definitions and terms, Csikszentmihalyi (1996), in his "The Systems Model", attempts to answer this question in terms of the impact of creativity on culture or science, which changes some aspects of it. Rather than focusing on what creativity *is*, he turns to *when* creativity happens: "Creativity is any act, idea, or product that changes an existing domain, or that transforms an existing domain into a new one" (1996, p. 28).

Based on current studies, it is best to regard creativity as a multifaceted occurrence, rather than as a unitary construct of a single definition. Despite all the attempts to define and interpret the term, it does appear, however, that there are common agreements on a few of the basic concepts of what creativity means, whether for "little c" (everyday) creativity or "Capital C" creativity (Csíkszentmihályi, 1996). Many psychologists, artists, educators, and creativity researchers have come to the consensus that creativity is a complex, interactive network of paramount importance (Gruber, 1989; Csíkszentmihályi, 1996; Sternberg R. J., 1999) comprised of relationships between people, processes, and products (Kristensen, 2004; Florida, 2003) in social and cultural contexts. Interest in the study of creativity has increased considerably over the last four decades, with different models or approaches drawing attention to some crucial aspects of the creative process.

2.1.2 **Visual Analogies and Problem Solving in the Context of Creativity**

Creativity, visual analogy and problem solving have a strong, dependable relationship (Finke, 1990; Finke, Ward, & Smith, 1992; Gentner, 1986; Bonnardel, 1999; Sternberg R. J., 1999). A creative product or a creative activity, for the most part, is actualised by the desire to solve a detected problem in an earlier product or event. To proceed with the solving process, one needs tools to achieve the set goals, and visual analogy represents one of the most effective means of finding solutions (Benyus, 1997; Bonnardel, 1999; Eryildiz & Mezini, 2012). For example, in her book, Stafford (1999) describes the problem the architect Douglas Cardinal (Boddy & Cardinal, 1989) faced when drawing up a plan for a museum; in addition, she describes the visual analogies that the architect used to find solutions for the design of the building. The future architecture of the National Museum of the American Indian (2017) required a combination of modern and indigenous styles in order to give visitors the sense and spirit of Native America. As the project progressed, we read that Cardinal's

> "work tables are ringed by photographs of cryptic petroglyphs from the Southwest, carved sandstone canyons, the indigenous abstraction of Anasazi cliff dwellings, and rugged Alpine escarpments". "These natural masterpieces serve as potent reminders of how to conjoin ancient landscape with modern city, looming rock outcrop with concrete monument,"
>
> continues Stafford (1999, p. 52).

Most theories of creativity have evolved around problem solving (Simon H. A., 1996) and strategies for framing the ill-defined (Mumford, Reiter-Palmon, & Redmond, 1994; Schunn, McGregor, & Saner, 2005) or wicked (a mix of well- and ill-defined) (Buchanan, 1992; Coyne, 2005; Farrell & Hooker, 2013) problems into smaller sub-problems for analysis.

A known approach to solving these types of problems, including insight ones (Chronicle, MacGregor, & Ormerod, 2004; Chu, Dewald, & Chronicle, 2007; Dominowski & Dallob, 1995; Luchian & Sas, 2011), is through analogy (Bonnardel, 2000; Sas, Luchian, & Ball, 2010) and this entails a search for similar past problems and their solutions (Carbonell, 1982). Casakin and Goldschmidt (2000) offered empirical evidence indicating that in the design process, primarily, novices benefit from using visual analogy and that it is the most valuable type of reasoning for understanding concepts and exploring their potential when paired with previously acquired knowledge. A large part of these problems pertains to factors other than product qualities or functional efficiencies. Many art practitioners concentrate on finding new types of expression or on product aesthetics where the problem is often indistinct.

According to classifications found within the definition of creativity, the activities of creative people and the purposes of creative products should be measured to a greater extent, such as in terms of emotions and aesthetics. For example, in “found art” masterpieces, the display of simple objects in an exhibition space calls for aesthetic appreciation and engagement with viewers. However, in engineering and science, the intentions are usually quite clear – to explain an event, to develop a more efficient product, or to solve a problem.

Problem solving is the cognitive process that aims to move from a given state to a goal state (Mayer R. E., 1999; Christensen & Schunn, 2005; Gick & Holyoak, 1980). Many investigators believe that creativity is a distinct form of problem solving (Newell, Shaw J, & Simon, 1958) and that these terms refer to the same mental phenomena (Guilford, 1964). Creativity, design, analogy and problem solving are inseparably connected with each other (Gero, 2000). In a design process, when people are trying to transform existing situations into preferred outcomes, problem solving is explained as the activity of finding design solutions for a purpose (Simon H. A., 1974). Thus, the process of designing is perceived as a process of rational problem solving. In complex situations (i.e. building construction) where both the existing situation and the target goal lack clarity, people may break the problem down into a manageable hierarchy of simpler sub-problems.

Problem solving is a process that uses operators or moves to achieve a goal, consequently, allowing creative products to be discovered. The relationship between problem solving, analogy, creativity, and creative thinking is critical in the process of discovery and invention (Weisberg & Alba, 1982). Robert Weisberg explained that creative thinking begins with what is already known based on an analogy with the current problem.

Another addition to supporting creativity is introduced by Bonnardel (2000, p. 505) who argues that analogy-making "is one of the mechanisms that contribute to the emergence of new ideas".

A set of theories of creativity related to our studies, and to visual analogy development and problem solving, their relevant categories and their interactions, in particular, is discussed in more detail in the following section.

2.2 Theories of Creativity

Creativity is investigated in terms of the nature of existent theories due to its complexity and dynamism. Several theories tend to describe the nature of creativity through mechanisms and processes, and others seek an explanation of human behaviour. Many other researchers emphasise particular aspects of creativity in their studies in terms of the expression of creative talent, personality, creative thinking, or investigating the environment.

These theories have frequently been categorised in several reviews by providing a general framework for studying creativity. One of the earliest classifications of theories on creativity was developed by Gowan (1972) who suggests that they should be divided into five major groups: "1) cognitive, rational, and semantic; 2) personality and environmental factors; 3) mental health and psychological adjustment; 4) psychoanalytic and neopsychoanalytic and 5) psychedelic". In this thesis, we focus on the cognitive, rational, and semantic group of classifications for creativity, especially the cognitive and componential models, as they are pertinent to the mixed nature of our research.

Our study is concerned with the nature of practice-led mixed with experimental research, as well, human cognitive abilities such as perception, memory, and analogical reasoning, thus involving investigations across artistic and scientific fields of inquiry.

2.2.1 The Creative Cognition Approach

Creative cognition deals with the processes that take place in the head of a creator; it is much more than creative thinking. Many different processes, such as mental model construction, analogy, problem solving, conceptual expansion and design-by-analogy (popular in arts and design) and others, represent a series of operators believed to be involved in the cycle of human cognitive simulation. As Ward, Smith, & Vaid (1997) state: "Creativity may even better be thought of as the entire system by which processes operate on structures to produce outcomes that are novel but nevertheless rooted in existing knowledge."

The core of creative cognition consists of three subsystems: problem solving that is able to draw inferences for planning to attain particular goals, a memory system that searches for ways to identify information relevant to the problem, and an inductive system (e.g., analogy) that generates and restructures new ideas to be stored in memory with the scope of increasing effectiveness in problem solving. These three systems are dependent in conjunction with one other. They consistently interact, aiming to identify in the memory available analogies that might be applied to the target problem. While some researchers (Holyoak & Thagard, 1989; Johnson-Laird, Legrenzi, & Legrenzi, 1972), when reflecting on the imperfections in the correspondences and mapping of realistic visual analogies in the source with ones in the target, suggest that the analogy be abandoned from the subsystem, Gentner (1989, p. 199) insists that "our mental experience is full of moments in which a current situation reminds us of some prior experience stored in memory" leading to a shift in the "way we think about one or both situations".

In the creative task of generating novel and useful products (Csíkszentmihályi, 1996, p. 27), most creativity theorists include both generative and analytical processes which are more often referred to as divergent and convergent. It is worthwhile exploring some creative cognition models, as their main core is imagery and connections with research in psychology and other cognitive areas.

2.2.1.1 **Geneplore Model**

As its name suggests, the *Geneplore Model* (Finke, Ward, & Smith, 1992) consists of two processing phases: a generative phase followed by an explorative one. In the generative stage, one constructs mental representations named by authors' *preinventive structures*, which contain a variety of properties encouraging creative discovery. The generated *preinventive structures* features are used in the exploratory stage through analysis and interpretation of their meaning and validity in different ways which attempt to externalise an original product. The newly generated structures are regenerated and modified throughout the explorative stage until a satisfactory resolution is reached. If the explorations are unsuccessful, then the initial *preinventive structure* is abandoned and a new one is generated or an old version that may be more promising is modified and then explored again. The creative process in the geneplore model is cyclic. There are cases when the creative discovery can occur in a short time, without repeating the generation and exploration stages multiple times. However, cycling between these phases facilitates the expansion of conceptual possibilities in the search for the creative product and the introduction of product constraints. Depending on the nature of the task, the product constraints can be imposed at any time during either of these phases.

Although, the proposed geneplore model (Finke, Ward, & Smith, 1992), which provides an explicit account of the cognitive processes and structures by combining original experiments with work in cognitive psychology, is praised by Robert J. Sternberg, John Richardson, Jonathan Schooler and other researchers, Stuart Sutherland (1993) criticises particular aspects of the *Geneplore* generative phase as being too similar to the previous *concept specialization model* (Cohen & Murphy, 1984) and *structure-mapping theory* (Gentner, 1983). In this model, Sutherland continues, it is not clearly explained whether the exploratory stage happens at a conscious or unconscious level. In spite of the mixed opinions on the geneplore model, we find the theory useful, especially in the generative phase of the analogy development process, as it imitates the processes of work of some studio artists.

Another aspect that is related to our research is that the model includes in its cycle a product constraints component (e.g., pottery, furniture), thus resembling the evaluation stage of the visual analogy development process. These processes typically involve the generation cycle for an idea or subject for future artwork. The artist usually doodles, sketches the first idea on paper, bearing in mind the need to expand it, explores that idea and then evaluates it by enforcing the problem constraints. If the solution appears unsatisfactory, s/he goes back to generating a new idea or modifying an old one thus entering the cycle again.

2.2.1.2 **Embodied Cognition Theory**

Embodied cognition theory (Johnson M. , 1987) proposes that meaning and cognition are deeply rooted in physical, embodied existence, contrasting with the information-processing view of the mind. According embodied cognition theory, cognition emerges from the dynamic interaction of patterns of responding to perceptions and preparing for sensorial-motor actions, rather than through mere manipulation of internal representations of the outside world by an internal processor. A central construct in this theory is *image schemas* (Lakoff & Johnson, 1999), which are dynamic, multimodal and non-propositional patterns of direct experiences acquired through the recurrent interaction of the human body with the world through movement in space and object manipulation. Particularly important is that image schema can be found not just in speech, but also in gestures accompanying speech (Roth & Lawless, 2002). Such pre-conceptual, spatially structured representations are usually unconsciously employed (Rennie & Fergus, 2006) and directly relevant in perceiving and comprehending visual images. Lakoff and Johnson (1980), and later, Johnson (1987), discussed a subset of these schemas and diagrammed a few of them. These schemas include categories such as space (i.e., up-down, front-back, contact, verticality, proximity); containment (i.e., container, in-out, surface); locomotion (i.e., path-goal); force group (i.e., attraction, resistance, compulsion, blockage); balance (i.e., axis, point, equilibrium); unity-multiplicity (i.e., merging, splitting, part-whole) etc. The particular schemas are different to mental images; they resemble abstract analogue representations derived from a real experience that forms the first concepts which emerge in the human mind as opposed to the imagined ones which often include more detailed imagery recalled from visual memory. Mandler and Cánovas (2014) claim that because of their formation in conjunction with the physical world and psychological development during early childhood, image schemas are emergent and they are not innate knowledge structures. The *container* of an image schema consists of three basic structural elements: interior, boundary and exterior (Lakoff, 1993) and is often formed from the experiences accumulated by multiple perceptual channels. Each schema represents only the properties that are shared with the concept of its *container*.

Although these image schemas can be seen as essential components in constructing metaphorical and abstract thought, they occur in clusters and can become internally complex. Later, Mandler and Cánovas (2014) took up the theory and defined its terms much more clearly by describing the types of schemas and procedures involved in the cognitive structure of meaning construction. The concept is in line with Koestler's (1964) *Theory of Bisociation* and Fauconnier & Turner's (1998) *Theory of Conceptual Blending*, which asserts that novel concepts are born from a selection of blended known information. The three different substructures proposed by Mandler and Cánovas to form the cognitive structure of meaning are:

- Spatial primitives – the first primitive concepts allowing us to sense what we perceive: PATH, CONTAINER, THING, SCALE, MOTION, etc.

- Image schemas – abstract structures of events forming relationships by using spatial primitives: PATH to THING, CONTAINER in MOTION, etc.
- Schematic integration – conceptual structures that include non-spatial elements (i.e., feelings, emotions) in the model: PATH to THING to PLEASURE, CONTAINER in MOTION to NOISE, etc.

Although there is plausible research attempting to organise the structure of image schema families and their interconnections beyond a detailed description of procedures, the embodied cognition theory is not without criticism. Some scholars (Hedblom, Kutz, & Neuhaus, 2015) find that the theory still lacks explanations of how to add or remove the overlapped parts capturing the same basic schema from an integrated family; there is also a question about how change is normally captured over time in these schemas.

Being motivated by the use of primitive schematic 2D and 3D representations found in static images and time-based media, we believe that the embodied cognition theory (Lakoff & Johnson, 1980), as redefined by Mandler and Cánovas (2014), integrated with the concept of structure-mapping theory (Gentner, 1983) can be of great benefit in our study. To elaborate, most of these image schemas are formed from relationships of spatial primitives such as long or wide rectangles, squares, circles, triangles and such like; hence, they include a variety of shapes organised in space evoking happiness, sadness, calmness, and other feelings, which are embodied in our bodies and minds. For example, Kristensen (2004) talks about the spaces where creativity takes place as "scaffoldings", suggesting that these structures instil sensory impressions on the human body and support the process of imagination, concept transformation and acceptance of new ideas. Without a doubt, the author, in his research, referred to physical spaces for creativity, while we intend to capture these kinds of spaces in our constructed visual analogies. The kind of creative spaces captured in visual analogies might help people to retrieve the feelings they have had when performing certain activities (e.g., dancing, design making).

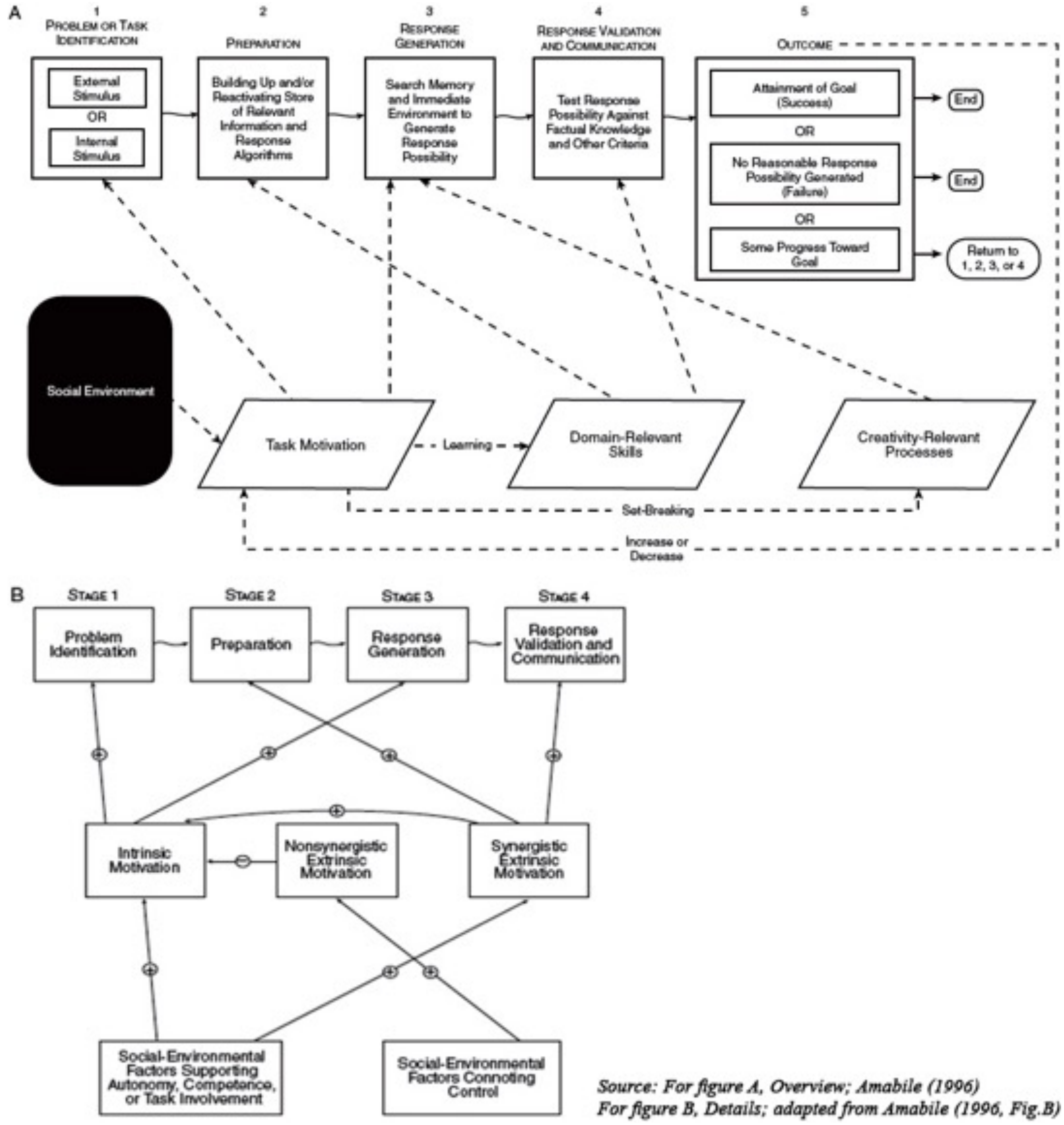
2.2.2 Componential Theories of Creativity

In contrast to creative cognition approaches that are based on stage-by-stage advancement, componential models do not require such linear dependency on stages to progress. These theories indicate the adoption of multiple "components" in creativity, when attempting to assess it more holistically and in-context including the process, product, creator or all of these factors. They allow for interaction between their components, which might include motivation (Amabile, 1983), knowledge, intelligence, cognitive style (Mayer & Massa, 2003; Massa & Mayer, 2006), personality and personality behaviour (Csíkszentmihályi, 1996), environmental (Dodds, Smith, & Ward, 2002; Eryildiz & Mezini, 2012; Christensen & Schunn, 2009) and situational context (Kirsh, 2009; Chun & Jiang, 1998), and cultural and societal influences (Csíkszentmihályi, 1988) in addition to the creative process (Wallas, 1926; Finke, Ward, & Smith, 1992) as the main component in the cognitive models. Finally, creativity involves more than the sum of an individual's perception in terms of each component or element. Without some components like knowledge and skills, it is not possible for creativity to occur; some components (e.g., motivation) could contribute to both its fruition or act in a negative way, all depending on the interactive relationships with other components (e.g., environment). At the same time, certain components (e.g., intelligence and affect), at high levels, could greatly enhance creativity. Despite the similarities and differences among componential theories of creativity, there is a consensus that this confluence of components is pertinent to knowledge, skills, personality, motivation, environment, and many other little things.

2.2.2.1 **Amabile's Approach**

Most current componential models of creativity take into account the latest developments and investigations in behavioural and social sciences. Inclusion of personality traits such as openness, flexibility, spontaneity, persistence, motivation and hard work, as well as the environment, culture and social factors are often the subjects of such studies, to investigate the links between creativity and personality, creativity and creative products. Componential theory of creativity proposed by Teresa Amabile is rooted in the following definition of creativity: "the production of ideas or outcomes that are both novel and appropriate to some goal" (2013, p. 134). A central argument in the theory is that creativity cannot occur without stimuli; thus, motivation should be considered a major instigator in terms of initiating an idea, solving a problem or undertaking a task. Her model includes three major components: 1) domain-relevant skills – high expertise in the domain or field; 2) creativity-relevant processes – cognitive and creative thinking processes; and 3) task motivation – a) the intrinsic motivation to engage in a creative task as "within-individual components" and b) the social environment – the surrounding conditions as the "outside component".

While philosophers, art historians and social scientists have explored inspiration and motivation in highly creative people for centuries, psychology was the first field to consider its linkage with creativity (Collins & Amabile, 1999). There was mutual consent that creative behaviour was associated with a spiritual purpose (Patherbridge, 2010), passion (Arnheim, 1974; Finke, Ward, & Smith, 1992), hard work (Csíkszentmihályi, 1996), and persistence (Newell, Shaw J, & Simon, 1958). These traits are described in meticulously detailed studies; however, what produced this level of motivation remains unclear.



Source: For figure A, Overview; Amabile (1996)
For figure B, Details; adapted from Amabile (1996, Fig.B)

Figure 2.1 Amabile's (1996) componential model of creativity

For example, when Picasso was asked how he found solutions to the problems which presented when he was creating a painting, he just replied: “I do not seek, I find”. To the same question, James Rosenquist (2009) responded similarly, stating: “In my work, I do not solve problems, I create new original ones.” These kinds of statements seem to hint at the ways artists are inspired to work, whether it is their personal techniques, scopes or beliefs, or individual traits that motivate them. Prior research had shown that factors from the environment could affect individuals’ performance on creativity tests and personalities (Barron & Harrington, 1981).

Along with the results of her own and colleagues’ studies, Amabile (1983) gathered overwhelming evidence to support the idea that motivation is a new and important component in the proposed theory. In this original version, she emphasises intrinsic motivation that implicitly motivates individuals due to certain internal factors like enjoyment in working on such a task or finding personal ways of searching for novel solutions. In her paper, she also introduces extrinsic motivators (external factors) such as the expectation of a reward from doing a task, knowing that the person or person’s work will be evaluated, being exposed to competition, and other similar factors.

Although her contribution is plausible, the original model was criticised due to its lack of detail about the relationships between intrinsic and extrinsic motivators, especially those factors in the environment that can be obstacles to or stimulants for intrinsic motivation and creativity. To refer to James Rosenquist (2009) again, as an example, in an interview, he once told a reporter that, initially, his motivation had been driven by money and that he knew there would be money in his work because he could draw and paint almost anything perfectly; however, it was only when he was making a living from his paintings that he started to look at other “bigger things”. Here, Rosenquist, as well as other pop artists (e.g., Andy Warhol, Roy Lichtenstein) in their notes (Warhol & Hackett, 2009; Berman & Gallery, 2003), seem to suggest that extrinsic motivation such as commissioned work is rarely creative, compared to the work produced as a result of intrinsic motivation, where the individual gains his/her independence and is ready to undertake a project that is interesting, appealing and satisfying.

After a series of reports by first-rate scholars in psychology, art and management that demonstrated that creativity could be influenced by an array of environmental factors, Amabile made serious revisions (1988; 1996) to her original model (1983) by including a comprehensive description of creative processes, specifying individual internal and external influences on creativity (see Figure 2.1).

The interest in Amabile's approach is twofold: firstly, the model can be used in the creative process in searching for the environment to generate visual analogies as an aid for problem solving and secondly, the analogy itself can be used as an external inspirational motivator in the task of creating visual material for our experimental studies. Also, the model's view of creative tasks that "there is more than one approach, problem, and to every problem, there is more than one possible solution" will be considered.

2.2.2.2 **Csíkszentmihályi's - A Systems View of Creativity**

After having studied creativity, creative products and creative individuals for a long period, Mihály Csíkszentmihályi concluded that, in the creative process, there is a strong link between the social system, culture and people, and that it is worthwhile to dig deeper to find answers to questions such as "Where is creativity?" not simply "What is creativity?". Furthermore, he goes on to say that "we cannot study creativity by isolating individuals and their works from the social and historical milieu", justifying the need for a new approach. He continues to argue that creativity is never the result of an individual's actions alone, but that it arises from the interaction of three forces that contribute to its construction. Compared to the previous models of creativity, *A Systems View of Creativity* model (see Figure 2.2) developed and proposed by Csíkszentmihályi (1988) offers interactive inclusion of the individual, with cultural and social factors that influence the creative process and assist in establishing a creative outcome. He describes it in the following terms:

> "This environment has two salient aspects: A cultural, or symbolic aspect which here is called the domain; and a social aspect called the field. Creativity is a process that can be observed only at the intersection where individuals, domains, and fields interact. … For creativity to occur, a set of rules and practices must be transmitted from the domain to the individual. The individual must then produce a novel variation in the content of the domain. The new variation must then be selected by a field of experts for inclusion in the domain. …. Creativity occurs when a person makes a change in a domain, a change that will be transmitted through time" (Csíkszentmihályi, 2014, p. 103).

Csíkszentmihályi (2014) explains what these components are and how they interact with each other in his model. The first system involves the individual drawing on domain information and making changes or extending it through components such as cognitive processes, motivation, and personality traits. The second system involves the process of people controlling, influencing, evaluating and selecting new ideas. The third system is the domain consisting of an established body of knowledge that accepts, disseminates and presents or rejects the creative products. Both the field and the domain influence the individual. The strength of this model is in its capacity to integrate findings from the wealth of studies about high-level creative personalities, creative processes and creative products from various domains, suggesting general patterns of creativity.

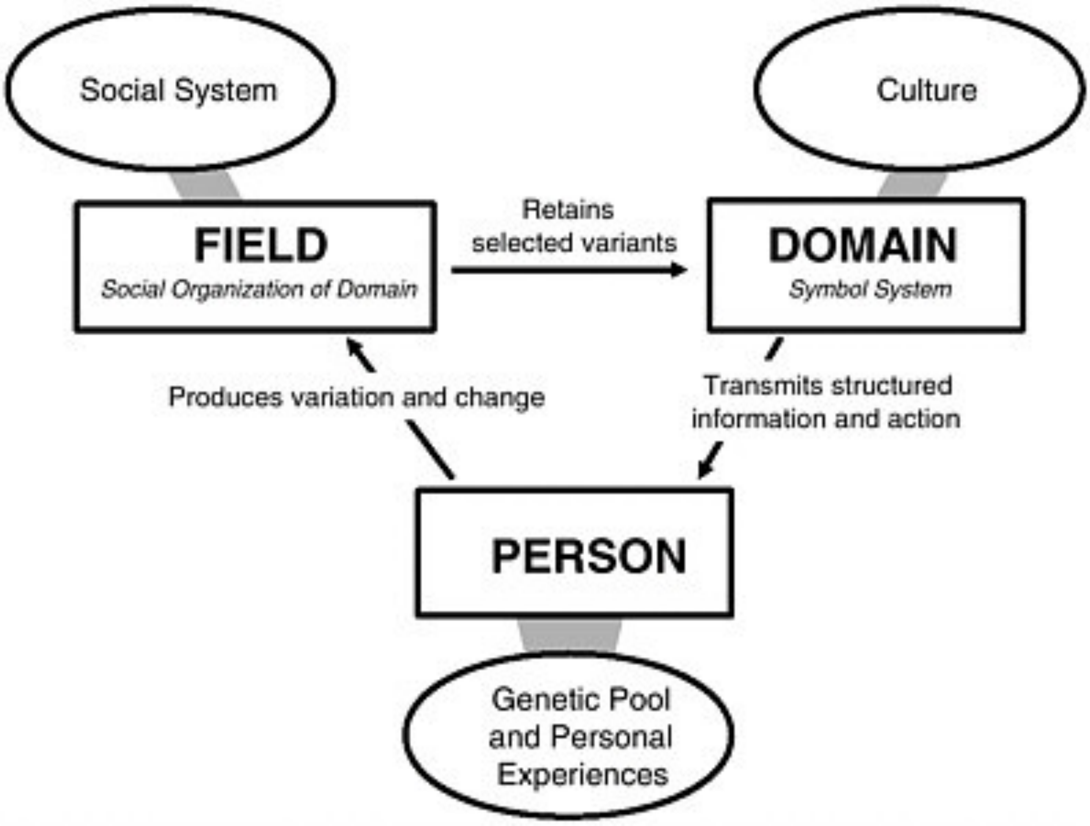


Figure 2.2 A Systems View of Creativity (Csíkszentmihályi, 2014)

However, an element of a pattern from one domain may or may not be similar to one from another domain. In the same way, a person may be creative in one domain and not in another. The body of knowledge gained in a domain may not be as useful in a creative act in another domain. Thus, this suggests that implementation of the model is restricted to a single specialised domain rather than multiple overlapping domains, often focusing on solving problems at the global, communal, or organisational level. Even though there is strong evidence supporting it, it is very difficult to test the approach. To measure creativity in this model, not only does the confluence of major components have to be considered, but so too do their relationships with the various levels and sublevels of components interacting with the three systems and model itself as a whole.

To conclude, this theoretical model supplies us with opportunities to better understand how new products are developed, what activities contribute to the product development and how, and more importantly, where the creativity is. The process of product development (e.g., visual analogy), and, in particular, the operationalisation of the concept of discovery at the reformulation and generation stages is an area of interest for our study. The theory states that in the early stages, the problem solver should not strive to achieve its structure too early, but should let the problem unfold in various forms through possible solutions. After selecting problematic elements, the problem is stated and attempts are made to solve it. This process seems to be employed by many practising artists, when the problem (concept) is loose and often generalised at first; after this, a set of sketches are produced for evaluation. After selecting the best concepts (possible solutions), problematic elements from the sketches are eliminated, then elements from different sketches are added, combined or merged to produce the best possible solutions for the problem. The model has its limitations as well, however; this is evident at the evaluation stage of the creative activity or product, when "the new variation must then be selected by a field of experts for inclusion in the domain." If a piece of art is not presented to the experts in the field, then how can that artwork be recognised and included in the domain?

2.2.2.3 **Woodman and Schoenfeldt - The Interactionist Model**

The model developed by Woodman and Schoenfeldt (1990) is composed of three key components: antecedent conditions, characteristics of the person, and characteristics of the situation. Here, the creative behaviour or act is a result of the multiple and complex interactions between an individual and a situation. The antecedent conditions component is often linked to pre-existing circumstances such as past historical enforcement, biographical information of creators and innovators. These antecedent conditions influence the person's state of mind. Both the individual's cognitive (e.g., knowledge, skills, style, preference) and noncognitive (e.g., emotional, perceptual, intuitive) traits are brought into play in attempting to find a solution to the given situation (e.g., social evaluation, reward) in a specific context (e.g., physical environment, cultural organisation). The behaviour of the individual is also influenced by the events of the past that are stored in long term memory, as well as the acquired information from a current situation. Woodman and Schoenfeldt (1990) describe the creative process "as dependent on an interaction between the main components."

In this interactive model, as in previous componential models of creativity, the individual's motivation comes from a unique interaction between the needs of society as a whole and the abilities and opportunities of its members (Csíkszentmihályi, 1988; Csíkszentmihályi, 1996). The revised version of the model (Woodman, Sawyer, & Griffin, 1993) includes a description of the model's application to groups and organisations that allows creativity to be studied not only in terms of groups of people from different domains, but also such factors as group vision and direction, group membership, positive leadership support and the effects of collaborative leadership on creativity in organisations. This is the first model that defines the concept of organisational creativity, blending previous research into a system that extends from the individual to the organisation, where creativity is viewed as an outcome of complex interaction between person and situation. The key to creativity lies in applying a fresh perspective, based on multiple factors including hidden ones that are formed by our cognitive apparatus, and which were not taken into account in previous studies. The link of a complex interaction between person and situation will serve to guide us in our research. We argue that integrating research methods with creative processes in visual analogy development, and the individual development of researchers, artists practitioners and developers, might help us to shed light on how visual analogy can be constructed and used by many of us. While it is praised for its contribution to the theoretical framework, the model still lacks validation in terms of which determinants (Klijn & Tomic, 2010) influence creativity most and in terms of the context in which creativity takes place (Kristensen, 2004).

2.2.2.4 **Sternberg and Lubart – The Investment Approach**

There are six different resources that may play a role in creative production: aspects of intelligence, knowledge, cognitive style, personality, motivation, and environmental context; these resources are identified in the model. Sternberg and Lubart's (1991) model, more or less rooted in economic theories, is based largely on Amabile's work

(1983; 1988) as well as other mainstream proposals (Csíkszentmihályi, 1988; Woodman & Schoenfeldt, 1990; Gruber, 1989; Guilford, 1964) which propose the convergence of the six resources listed above. The creative individual is the one who holds the resources and selects (invests) them to "buy low" (seeking new ideas with potential), with the aim to "sell high" after developing, producing, and publicly presenting the production for appreciation. As with other approaches, a combination of the three intellectual abilities, synthetic, analytic and practical, is important and required in creativity. With respect to the convergence of resources, the authors propose to break down each component into levels. For example, the motivation component may be *strong, medium* or *weak*. Thus, a *strong* level of motivation could partially compensate for a *weak* level of personality or individual's cognitive style. The interactivity between the componential levels leads to creative behaviour. For creativity to occur, all components should be present and interact with each other regardless of the strength of their componential level. For some components, such as knowledge and intelligence, there may be required thresholds for the strength of a level in order to contribute to creativity (e.g., knowledge – a minimum adequate level in order to allow for creativity). Although there are significant similarities in terms of the identified cognitive processes of intelligence, knowledge, personality traits, thinking styles, motivation and environment with other componential models (Amabile, 1983; Csíkszentmihályi, 1988; Woodman & Schoenfeldt, 1990), some researchers (Shaw & Runco, 1994; Amabile, 1996) expressed concerns about the absence of the emotional behaviour of a personality in this model. Thus, recently, Lubart et al. (2003) made revisions which led to the inclusion of emotional factors. Researchers (Sternberg & Lubart, 1991) argue that performance of a creative act depends on the individual's invested resources in an undertaken task.

2.2.2.5 **Runco and Chand – Two-Tiered Theory**

Based on several theories of creativity and cognitive topics including intellectual abilities, memory, judgement, classification and categorisation, Runco and Chand (1995) proposed a two-tiered theory of creativity. The first tier is composed of the influences on the process such as motivation (intrinsic and extrinsic), intellectual abilities (synthetic, analytic and practical), and knowledge (declarative, factual, conceptual, and procedural). The second tier sums up the components of the process: problem finding, ideation, and evaluation. The principal components from each tier can be subdivided into families of skills. For example, the problem-finding component may include a family of skills in problem identification, problem understanding and problem definition, while the ideation component represents a family of skills including ideational fluency, ideational originality, and ideational flexibility. The skills relating to experience and expertise from the knowledge component can inform the individual in terms of information on how to be creative by giving insights into how a problem can be reformulated or how a fixation can be overcome. In this approach, the process components are the primary ones, while knowledge and motivation are considered to be secondary as contributing but not controlling components. The confluence of componential families of skills should be flexible and fluent throughout the creative process. The knowledge influences the individual with the procedural "tactics for creative thinking" (Runco & Chand, 1995) in terms of how to find or get original and creative ideas, solve a problem and get something done. The flexibility of combining problem solving strategies with divergent thinking tactics, intellectual abilities and motivational factors makes this model an easy fit for use by a wide range of cognitive styles; it has also been an inspiration in our study.

2.3 Problem Solving

Creativity is a mental phenomenon that results from the performance of multiple cognitive processes (Ward, Smith, & Vaid, 1997). The area of problem solving was one of the processes that cognitive scientists referred to in the early stages of creativity as a standalone area for investigation. The use of particularly verbal and visual materials as tools for measuring the origination of creative ideas was applied in their experimental studies (Finke, 1990).

There are two kinds of problems: well-defined and ill-defined. In psychology investigations, these problems might be referred to as insight and creative.

Well-defined problems are those that have a definite initial state and goals, and for which the task environment and the set of actions/operations are known. The well-defined problems contain information on the state of the problem in a given current situation, what the situation should be when the problem is solved, what operators or actions need to be applied to reach the goal, and what is not allowed (restrictions) when working on the problem. There are some instances where the path to solving such problems is slightly different, yet in the end, the solver arrives at the same *correct* solution. These differences in the path may depend on the complexity of the problem or number of operations to be performed. For example, even though one has all the necessary information about the problem, an individual might not know how to use the operators, the order of the operators, or how and where to act to make the necessary changes leading to the solution.

In ill-defined problems, known also as creative problems, the initial goal is either given, discovered (e.g., a painter is no longer satisfied with the composition in his/her work) or affective in nature (e.g., a feeling that something is wrong with the painting), the actions (operators) to solve it might be missing or unknown along with the availability of problem restrictions, and the goal state is loose and does not evoke a single *correct* solution. MacGregor, Ormerod and Chronicle (in press) sighted several examples of mixed problems, labelled in their presentation as abstractly defined problems, where all components of a well-defined problem are present, except that its goal state is loose and abstractly defined. These types of problems can often be found in the fields of architecture and design engineering.

Researchers such as Simon (1974) suggest that similar heuristics are used in both types of problems, and that investigations into problem solving of one kind or another may not be particularly beneficial.

2.3.1 Theories and Approaches to Problem Solving

The main approaches in problem solving were developed over a period of several years; some are discipline specific, but only those that are relevant to our study will be discussed here. These are: Gestalt psychology, the associative theory (Mednick, 1962), information processing theory (Newell, Shaw J, & Simon, 1958), and the theory of hints (Kirsh, 2009).

2.3.1.1 Gestalt Psychology Approach

The Gestalt approach to problem solving stresses the idea of organised structures of mental representations. The school is well known for studying human perceptual processes. For Gestalt psychologists, the *wholes* have priority over the elements that form them, which means that the relationships between the elements in the visual field are based on what is seen rather than what they represent. Problem solving is thought to be a matter of perception. Thus, the primary requirement in order to overcome “functional fixedness” is in finding the right representation of the problem. According to this view, problem solving occurs when the perception of the situation is unexpectedly reorganised. The central concept of this approach is restructuring that leads to insight into the problem and consequently to its solution. Providing the *right* hint or path to reorganise the perception makes the solution available immediately, often in the manner of a sudden insight attended by the *aha experience*.

2.3.1.2 **Associative Theory**

According to Mednick (1962), creative ideas occur when a variety of distinct elements come together by giving birth to a new idea or a solution to a problem. Mednick's associative theory is based on Spearman's earlier model of intelligence (1923) that included three principles of cognition: 1) the principle of experience, 2) the principle of relations and 3) the principle of correlates. Based on this theory, the associative elements may be evoked as a result of the contiguous environmental appearance of stimuli that elicit associative elements, similarity of the associative elements of the stimuli eliciting these associative elements and through the meditation process on common elements. Mednick defines the process of creative thinking as "the forming of associative elements into new combinations which either meet specified requirements or are in some way useful. The more mutually remote the elements of the new combination are, the more creative is the process or solution" (1962, p. 221). He considered that the individuals producing a larger number of associations to a problem have a much greater chance of developing a creative solution to that problem. Mednick went even further to assume that one's ability to make the so-called "remote associations" can be measured; thus, he developed the Remote Associative Test. This test contains analogies with three exposed elements, and the fourth is left blank (e.g., Dream : Break : : Light: ______). The test was supported by several studies in the earlier stage (Bowden & Jung-Beeman, 2003; Mednick & Mednick, 1967), but later research showed mixed results or no support for it, hence suggesting its revision (Gick & Holyoak, 1980).

2.3.1.3 **Information Processing Theory**

Another major approach in problem solving is the information processing theory developed by Newell, Shaw, and Simon (1958). Their model is extracted from the research on developing programmes designed to carry out human tasks in the ways that humans do (e.g., chess), through computer simulations of human behaviour with the sorts of "good" and "bad" moves that people make. According to information processing theory (Newell, Shaw J, & Simon, 1958), a problem is presented as a problem space, the goal state and the states of transformation of information as procedures. They can be isolated as facts and specified as propositions, in the same way that Newell et al. (1958) apply the idea in a computer simulation of problem solving to a means-ends strategy, where the system establishes sub-goals for each step in the process. The information processing theory highlights the top-down executive role of knowledge and experience in problem solving (Weisberg & Alba, 1982; Newell, Shaw J, & Simon, 1958; Simon H. A., 1978). One looks first at the situation to analyse it, then, based on his/her knowledge and experiences about that situation, develops methods and strategies to find solutions. By combining the knowledge (top-down processes) with information from the problem (bottom-up), the ordinary thinking processes are put into play in the search for problem spaces to find a solution that meets the goals. In contrast to Gestalt psychology, the approach claims that problem solving is a matter of searching for the right path from one location to another location in the "problem space". Thus, the central concept of the information processing theory is based on procedures in searching for feasible paths that lead from the initial state of the problem to its goal state.

This model is still a valuable asset in the domain of computing and mostly applies to the multidisciplinary fields of cognitive sciences; however, it might not be compelling when attempting to solve problems with large problem spaces.

2.3.1.4 **Theory of Hints**

Early experiments have shown that problem solving is an interactive process in which people perceive, analyse, transform, evaluate and create constraints, affordances (Gibson J. J., 1977), structures in the environment and construct hints such as graphs and diagrams (Tversky B. , 2011; Gick & Holyoak, 1983; Christensen & Schunn, 2009), forms and artefacts (Bonnardel, 2000; Patherbridge, 2010; Kristensen, 2004; Arnheim, 1997) to solve problems they face. David Kirsh (2009) states that although classical theories are at the foundation of problem solving literature and have contributed tremendously to this field, still, certain details and questions are unclear. He suggests that a better understanding of what a *hint* is and does might contribute to building an integrated model in situated cognition. More investigations about the role of such *hints* will make those theories more viable. Hints are a part of the history of problem solving and come in many forms: verbal and non-verbal, behavioural, and environmental.

Problem solving processes are more a matter of how effectively people use the available aids and hints provided by the tightly linked environment in which they live and act, rather than relying only on their existing knowledge and internal cognition. In his work, David Kirsh (2009) recommends *scaffolds* and *resources* as instruments/mechanisms for people to complete theirs tasks, viewed as *hints* which give clues about observed objects such as shape, form, colour and spatial information. They also provide information about the subjects and their activities in an exploration of search space, information about responses to internal and external stimuli, about constraints on generating candidates of acceptable solutions, and information about selection criteria for how to abstract and encode their features in the problem solving process. He proposes the inclusion of hints as an addition to the previous theoretical concepts of the problem solving process. Further investigations in this area will add value to the current models. The integration of the agent-environment interaction in the problem solving process proposed by David Kirsh provides the key for an alternative theory on how people solve problems in concrete instances and settings. Very often, artists are inspired in their search for new creative ideas from real life situations such as themes or actions that occur in the environment, the characteristics of people and things, their properties and functions, as well as using knowledge, skills, and tools to bring their projects to fruition. There are several other examples of successful solutions to everyday problems when people have used hints from interacting with the environment, one of them is mentioned in the introduction of this thesis and thus, this theory's principles are well worth considering.

This theory might help us to shed some light on the question of how people search for and select relevant hints from the environment to solve problems so we can use their findings in the construction of visual analogies.

2.3.2 **Processes in Problem Solving**

Generally, all the proposed models vary from four to seven or more process phases beginning with finding, recognising, defining or refining the problem, progressing to seeking some possible solutions, evaluating the alternatives and setting out to explore them to find the best solution, validating the solutions and sometimes reflecting on the process in order to determine how to apply the results.

In *The Art of Thought* (1926), Graham Wallas outlines four major steps in the creative process: preparation, incubation, illumination, and verification. The first stage, preparation, is centred on learning about the problem or object and understanding the task that needs to be done. At this stage, the information relevant to the problem/task is gathered and the cause is defined. The second stage is the incubation processing information stage, and is recognised as an unconscious process that explains how progress can be made even when a person is not thinking about the problem. At this stage, Wallas suggests that the individual should stop focusing on the problem and allow the subconscious mind to take over and incubate the information. Incubation occurs when our minds are relaxed and not engaged with demanding tasks. Incubation usually takes place when people are sleeping, watching television, walking on the beach, etc. Illumination is the third stage, and is known as *insight* that leads to the *a-ha experience*. Insight usually occurs in problems with a single solution in contrast to divergent thinking where multiple ideas are generated. The last stage in Wallas's model is verification, where the solver verifies the result; very often, this stage includes recursion that allows the solver to revisit the stages and reflect on them.

Other approaches vary in terms of type and number of processes; however, they derive from Wallas's classic four-stage model. For example, Barron (1988) reinforced this classic four-stage process using the analogy of giving birth: conception, gestation, parturition, and bringing up the baby. In a more recent model proposed by Koberg & Bagnall (1991), the processing stages were increased to seven: accepting the challenge, analysing, defining, ideating, selecting, implementing, and evaluating. Cropley & Cropley (2010) argue that the seven-stage model is the most appropriate for studying creativity, as it clarifies and defines the creative product and its functionality. They suggest that the preparation stage should be divided into (1) preparation and (2) activation stages; the first refers to the required component of being familiar with a field (Csíkszentmihályi, 1996) and the second stage represents when the problem awareness develops. Next follow the (3) generation, and (4) illumination stages. In the generation stage, a number of candidate solutions to the problem are generated, then the individual progresses to the illumination stage when a promising solution is selected from the candidates. The following verification stage is when the selected solution is scrutinised to determine if it does what it is supposed to do. Researchers (Cropley & Cropley, 2010) suggest breaking it up or adding the following stages to it: (5) verification (similar to the bringing up the baby in Barron's model and selection in Koberg & Bagnall's terms),

(6) communication, when the result is made available to the public, and (7) validation, when the external environment comes into play, and the product or idea is labelled as being or not being creative.

In investigations into problem solving, especially in psychology, researchers focus on its nature in specific domains, teaching skills, intellectual ability, contextual. Thus, the relationships between varied creative stages are complex and need to be distinguished by problem type. Unsworth, in her study (2001), identified four such relationships where:

> "(a) a person solves a problem defined by other people at the other people's behest (what she called *responsive* creativity),
>
> (b) a person solves a self-discovered problem to satisfy other people's demands (*expected* creativity),
>
> (c) a person is self-motivated, but the problem is defined externally (*contributory* creativity), and finally,
>
> (d) a person solves self-defined problems for his or her own personal satisfaction (*proactive* creativity)."

The processes of visual analogy construction are investigated in this thesis, and a fusion of stages will be used, for the most part, employed by design practitioners and not following a linear path as described in the aforementioned models. For example, in the case of this study, the process of visual analogy construction for the *8-coin* and the *cheap necklace* problems begin from the generation stage as the knowledge and problem awareness have been obtained earlier from the literature in the field and serve as raw material for the preparation/activation stage(s). These stages may interact with each other (Cropley & Cropley, 2010) or loop (Shaw, 1989), for instance, when a designer advances to the verification stage examining a potential solution that gives an ambiguous result and has to return to fix it or generate another candidate.

In this thesis, the visual analogy construction part of the study will be considered to be *contributory* creativity (Unsworth, 2001) as a type of problem solving process when a person is self-motivated (researcher), but the problem is defined externally (gap in the field).

The second type of relationship between the solver and the problem when "a person solves a problem defined by other people at the other people's behest" which is branded by Unsworth as *responsive* creativity will be observed in participants engaged in our experimental application with the scope of testing the effectiveness of visual analogies in the development process. Strategies used in the problem solving process for both components of our study are the visual analogy development process and the testing of the effectiveness of created visual material; these will be discussed in the next subchapter.

2.3.3 Strategies in Problem Solving

Research carried out on the differences between effective and ineffective problem solvers (Kepner & Tregoe, 2013; Woods, 2006) show that in problem solving, some factors and human traits are more important than others. The most influential ones for each step in the process have been identified. For example, the person's attitude and belief that the problem can be solved plays a major role throughout the whole process. The type of questions asked, the accuracy of the problem description, the use of mental images, drawing charts, sketching and using notes without jumping to conclusions are very important actions in the problem identification and problem understanding stages of the process. Actions like using effective mental imagery, drawing charts and sketching, using analogy in the problem solving process along with procedural tasks such as breaking the problem into sub-problems, finding and building concepts from the information to hand, perseverance to overcome the fixation, using heuristics and keeping track of the progress are trivial in the generation and illumination stages (Fogler, LeBlanc, & Rizzo, 2013). Selecting a candidate solution, checking and rechecking the accuracy of all facts and relationships for the solution to the problem are imperative in the verification stage of the process. These identified characteristics in effective problem solvers are not employed linearly in the process, nor is there a common strategy applied by every person or to all types of problems (e.g., insight or creative, simple or complex). As opposed to theories which serve as models in the problem solving field, strategies mostly depend on the characteristics of individuals, their preferences, and the individual's premeditated actions, which are often derived from practical experience. A strategy might be similar to a theory, but it is more adaptable by nature and easier to change during the problem solving process. A strategy can be changed only by the solver's mind during the task.

As Fogler and LeBlanc (2013) point out, one of the factors that distinguishes effective solvers and non-solvers is the right state of mind even before engaging in solving a problem: "I know how to solve it or I don't know it". When encountering a problem, people become active in the problem solving process, attempting to understand the facts and relationships, analysing and looking for hints that may lead to a solution to the problem.

Taking risks is another strategy, which is often applied after the solver has reached a mental block in the problem solving process, such as: "Let me try some crazy ideas; what do I have to lose?". Some characteristics of risk takers are that they are flexible in their thoughts, adventurous, explorative, happy to try different things outside their area of expertise, able to question the established patterns in the field, and well able to handle criticism.

Paradigm shift and representational change theory (Ohlsson S. , 1992; Knoblich, Ohlsson, & Raney, 2001) are other strategies used intensively in problem solving. Paradigm shift is a model based on a set of rules defining boundaries for the problem by specifying what is successful in them, then replacing the old set of rules with a new one allowing the problem at hand to be seen differently. However, if the new set of rules is not adequate for the current problem and there is no other opportunity to initiate new rules, this strategy might hinder creativity more than facilitating it. "This is the way we have always done it" – is often applied and this attitude hinders creativity.

Representational change theory (Knoblich, Ohlsson, & Raney, 2001) strategy is similar to the paradigm shift, except that here the fixation can be overridden by representing the problem in a different way. More details and a notable application of this strategy are described in the following section on The Cheap Necklace Problem section (Section 2.3.4).

Using heuristics strategies suggests following some rules of thumb to cut down the problem space. For example, an individual could choose to solve the *Towers of Hanoi* problem by applying the hill-climbing technique, while another person might solve it by applying the means-end analysis heuristic (Weisberg, 1988). Hill climbing is specific to using one's sense of direction during the problem solving task. Checking all possible moves, and going in the direction that gets one closer to the goal state reassures the solver that s/he is moving in the right direction.

The means-end analysis technique might start with the following scenario: "I want to move the large disk to the goal peg, but I cannot as there are other smaller disks stacked on top of it. So, based on this conclusion, I am thinking how to clear that peg so that I can move the large disk onto it". The continuous search for possibilities to find a system of next moves to clear the space for larger disks (they should be placed at the bottom) is characteristic of this type of heuristic.

Another known approach is to solve problems by analogy. This strategy requires the solver to search for related problems from the past and transform their solutions into potential solutions to the current problem (Polya, 1945; Carbonell, 1982; Blanchette & Dunbar, 2001; Clement J. J., 2008). In his research, Clement (1981) described how scientifically trained subjects used analogies in the given problem solving tasks. He found that spontaneous analogy plays a significant role in solutions for a number of trained participants.

According to the transcript analyses, the author formulated four fundamental processes in making inferences by analogy:

1. The analogous concept B is generated, or "comes to mind" based on the given initial concept A of an incompletely understood situation.
2. The analogy relation between A and B must be "confirmed".
3. Concept B must be well understood, or at least predictive, and
4. The subject transfers conclusions or methods from B back to A.

Analogies are generated spontaneously, they have to be attentive, and the processes can occur in any order. The last three stages of the process sound more analytical; however, the first stage seems be entirely intuitive. How analogies are generated is somehow elusively described in Clement's (1981) report; it seems there is little information on how to proceed in terms of finding a starting point for generating analogous situations. However, the literature in the design field suggests several techniques used by design practitioners. Observed initial starting points for producing an analogy are reported in many studies for which designers handle the transfer of information from familiar situations to formulate new ideas. For example, the biomimicry routine (Benyus, 1997) is used by many engineers (Ball, Ormerod, & Morley, 2004; Christensen & Schunn, 2009) and architects (Rao, 2014) to generate ideas for future buildings; additionally, it is successfully used by interior designers (Sorrento, 2012) to create sustainable interiors for living. The synectics technique (Gordon, 1961) is another technique which gives an initial starting point for generating an analogy. This technique is mostly based on the premise of creating a new idea from combining two old ones. Here, it is well worth mentioning the other two techniques required to get started in the generation process: the WordTree (Linsey, Wood, & Markman, 2008) method, a superordinate and semantic search for analogous situations or cases, and the design strategy used by Function and Flow Basis (Wood, Stone, McAdams, & Hirtz, 2002) users.

Admittedly, this is difficult for many people to do, as the tasks involve breaking away from old assumptions about the original problem and how it was seen before.

Nonetheless, focusing on one's own past experiences or gathering more information on how another might come about, may give people insight into how and where to look for ideas to generate an analogy.

2.3.4 **Insight Problems**

Insight problem solving is considered to be a creative thinking act, thus suggesting that images are strongly associated with creative thought (Finke, Ward, & Smith, 1992; Hadamard, 1954; Koestler, 1964; Paivio A. , 1971; Christensen, 2005; Gruber, 1989) and communication (Kristensen & Gabrielsen, 2013). Many researchers (Guilford, 1979; Smith & Amner, 1997) believe that in incubation, the seemingly idle interval is accountable for the progress of transformation in the information of a problem. The incubation period provides the solver with the opportunity to form associations for the cognitive transformations that lead to the insight. Insight has links to creativity and discovery (Finke, 1990) and is recognised as an aid to the solution of insight problems. Investigations on insight, the creative processes of moving from the phase of not knowing how to solve the problem to the moment of sudden discovery of the solution, have not been able to explain the processes that lead to such success.

However, there are different proposed views of insight: insight as nothing new, insight as formulating the problem, insight as overcoming a mental block, insight as completing a scheme, insight as reorganising visual information and insight as finding a problem analogue.

Additionally, insight is often explained by restructuring or reorganising the problem. Gestalt psychology describes the process from the perceptual point of view in the context of the idea that humans tend to make sense and to construct meaning from partial perceived information. The information processing theory explains insight as a linear search: "to solve a problem is to proceed step-wise through the alternatives, until an action sequence is found which leads from the problem to the solution" (Ohlsson S. , 1992).

The 8-Coin Problem

Ormerod et al.'s (2002) study investigated performance on insight in the *8-coin* problem providing participants with verbal hints. In their first experiment, researchers compared the relative influence of move-availability and figural-integrity factors on performance. They used a two between-subjects factors design on two levels (Table 1). Participants were randomly assigned to one of the four conditions and individually tested. Before the experiment, instructions were provided. Their instructions were replicated in our study with the following deviation: instead of verbal hints, the participants were provided with visual hints (e.g., printed images, graphics and abstract shapes or animations) which are described in detail in the materials and procedure subsections of our experiments on this problem. In the first two minutes in Ormerod et al.'s (2002) study, participants worked on the problem without hints; then they were told: "the solution requires that the coins should be arranged in two separate groups".

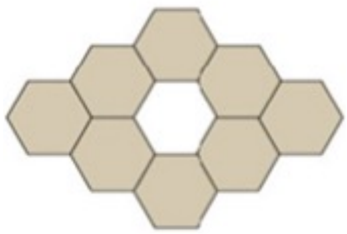
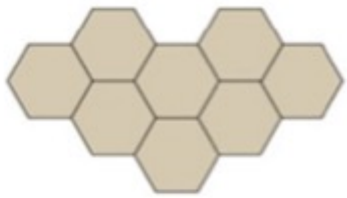
Conditions		Move Availability Stimulus	
		Non Move Available	Move Available
Figural Integrity Factor	Tight	 10	 6
	Loose	 12	 8
Cumulative number of problem solvers in each condition after verbal 3D hint. Number of participants per condition = 14.			

Table 1 The starting configuration used in Ormerod et al. (2002) study 1

Participants who did not find the correct solution after working on the problem for two minutes with the grouping hint were provided with a second verbal 3D hint: "the solution requires the use of 3 dimensions".Their results showed a significant effect on move availability whereby participants solved the problem more often in the no move availability. The figural integrity and its interaction with move availability were not significant in this experiment.

Despite the clearly explicit nature of verbal 3D hints in their Experiment 1, not all participants were able to discover a path to the problem solution, which according to researchers, is an indication that the used verbal hints were "for some participants, at any rate, ambiguous and unsatisfactory" (Ormerod, MacGregor, & Chronicle, 2002).

In their second experiment, they investigated the effects of providing an additional 3D visual hint as part of the initial configuration of the *8-coin* problem.

The design for this experimental study used two between-subjects factors consisting of four different starting configurations for the eight coins and representing visual hint and non-visual hint on two levels as in the previous experiment: no move availability and move availability. In the visual hint conditions, one coin was stacked vertically over another coin as a hint for participants. The procedure was the same as in Experiment 1, except that participants were allowed to work on the problem for a total of eight minutes. The initial period working on the problem was extended to six minutes, and if participants couldn't find the solution in this period, they were provided with the grouping hint and allowed to work for one minute. Participants who failed to find a solution after working with the grouping hint were given the verbal 3D hint and allowed an additional minute to find the solution. Ormerod et al. (2002) hypothesised that participants in the visual hint conditions provided with quality hints should solve the problem more often than participants in the no-visual hint conditions.

They found that there was no effect of visual hint in terms of participants' performance, although some participants were able to see the relevance of the visual hints and solved the problem before receiving any hints.

The Cheap Necklace Problem

Another example of an insight problem is the *cheap necklace* problem. With a focus on various aspects of insight, earlier studies by such researchers as Silveira (1972), then later Norlander et al. (1998), Fioratou (2005), and Chu et al. (2007) used this simple, yet difficult-to-solve problem in their research.

The *cheap necklace* problem is as follows: there are four chains, each one consisting of three closed links (see Figure 2.3); the goal of the problem is to connect all four chains into one closed necklace within budget; the cost of opening a link is 2 cents, and the cost of closing it again is 3 cents; the budget for this task is a total of 15 cents.

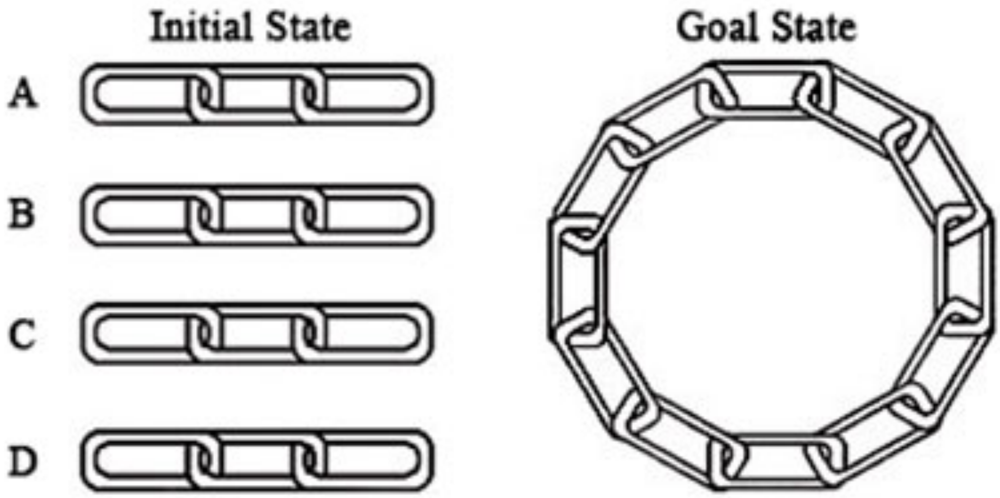


Figure 2.3 The cheap necklace problem

The solution requires a deviation from the regular and frequent attempts of participants to join the chains together by opening the first link of a chain and connecting it to the next chain by closing that link between them, then repeating the task until all four chains are connected into one chain of 12 links. Upon reaching this point, participants realise that in connecting the chains in such a manner, the budget of 15 cents has been reached; however, the ends of the chain are still unlinked, and an additional link still needs to be opened and closed to complete the necklace. These moves are consistent with the "hill-climbing" heuristic (Newell, Shaw J, & Simon, 1958) strategy which requires the best moves to be selected step-by-step to increase the chance of shortening the path towards the goal state of the problem. Evidently, the hill-climbing heuristic strategy fails to facilitate participants in making progress towards finding a solution to the *cheap necklace* problem, frequently leading to fixation (Knoblich, Ohlsson, & Raney, 2001; Ohlsson S. , 1992; Chronicle, Ormerod, & MacGregor, 2001; Fioratou, 2005; Chun & Jiang, 1998).

According to representational change theory (Ohlsson S. , 1992), the fixation can be overridden if the solver manages to revamp the representation of the initial state of the problem. In the case of *cheap necklace* problem, the situational fixedness consists of the assumption that each chain is an entity and should be maintained as such in completing the necklace. People make such assumptions because of their knowledge about the functionality and specific characteristics of the things, their identity, and practicality in the real world. They fail to see the application of these known specific features in other than ordinary situations. Thus, this functional fixedness preventing solvers from seeing how the single links of a fragmented chain may serve to interconnect the remaining three chains in a complete necklace. Ohlsson (1992) suggests overcoming the fixation through constraint relaxation, a way of removing the inhibitions in terms of what is regarded as an acceptable solution from the problem representation. Constraint relaxation (Knoblich, Ohlsson, & Raney, 2001) consists of a set of mechanisms that might help the solver to reorganise or change the ways they are looking at a problem. When the solver has reached an impasse, researchers suggest thinking about unfamiliar functions of the problem representation (Ohlsson S. , 1992), breaking up the representation into chunks (Ohlsson S. , 1990), or taking a break from the problem (Sio & Ormerod, 2009; Christensen, 2005).

Although many laboratory studies using the proposed mechanisms to overcome the fixation are plausible, researchers do not explain clearly how to make solvers change their minds on problem representation.

Chu et al. (2007) used the *cheap necklace* problem in one of their studies. They conducted three experiments investigating the effects of hints which originated from two theoretical positions: criterion for satisfactory progress theory (MacGregor, Ormerod, & Chronicle, 2001) and representational change theory (Knoblich, Ohlsson, & Raney, 2001).

In their first and second experiments, the researchers found that there was no significant difference between the groups in terms of the proportions of those who solved the problem. Although the criterion for satisfactory progress hint condition (hint was provided verbally) generated fewer trials to find the solution than the number for the control group, the result was not significantly different in the representational change theory hint and control groups either.

Their third experiment investigated a combination of representational change theory and criterion for satisfactory progress hints and how they would affect the solution rate. Obtaining a significant difference in terms of solution rate between the conditions, it was concluded that an integration of both theories might be more effective than the representational change theory or criterion for satisfactory progress alone.

In another study, in the eight of Fioratou's (2005) experiments on the *cheap necklace* problem various mechanisms of fixation induction were investigated by using the visual material as an aid. The investigator (2005) claims that 97% of participants fail to solve the *cheap necklace* problem as given (Figure 2.3), and that there is no easy fix for fixation; however, based on the success rate for finding solutions by using visual material, it seems that the problem solver needs to be aware of existing patterns that might be found in the environment.

In another study on the same problem, reserchers Norlander, Bergman, and Archer (1998), focused on the effect of different forms of incubation time. Providing participants with incubation time to facilitate different problem solving activities, Norlander et al. (1998) obtained a slightly higher rate for positive effect in this problem. Fioratou's (2005) and Chu et al.'s (2007) studies, along with Norlander et al.'s (1998) study, fall in line with the proposed mechanism of relaxing constraints in representational change theory. None of these studies used visual analogy as a facilitative tool. Interestingly, the only verbal analogy used in Chu et al. (2007), "destroy in order to create" as a hint, did not help participants to extract a usable conceptual representation of the solution.

A provided visual hint (Figure 2.4) in Fioratou's third experiment generated 57% ($p < 0.0001$) correct solutions compared to only 5% in the original condition, suggesting that the image representing "three separate links" contains the additional procedural information that one needs to gain from the action-oriented problem solving experience. Furthermore, in both Chu et al.'s (2007) and Fioratou's (2005) studies, experiments investigated the effect of transferring prior knowledge from one problem to the next, and the majority of participants failed to generalise procedural strategies to an analogous problem. Although researchers used hints in their studies, most of the visual ones do not qualify as analogies. For example, the one in Figure 2.4 shows the top chain as in the initial state for the problem (Figure 2.3), except that in the hint partition into three separate links is indicated, the first required step in the procedure to solve the problem. This type of imagery seems to be instructive material rather than analogy. The principles of analogy and relationship with the problem "A is to B as C is to D" is violated. Mathematically speaking, if $C = A : 3$, then $D = B : 3$, which means that the whole group of three chains from the bottom of the hint (B) should stay disconnected as opposed to the problem goal state of being connected into one complete necklace.

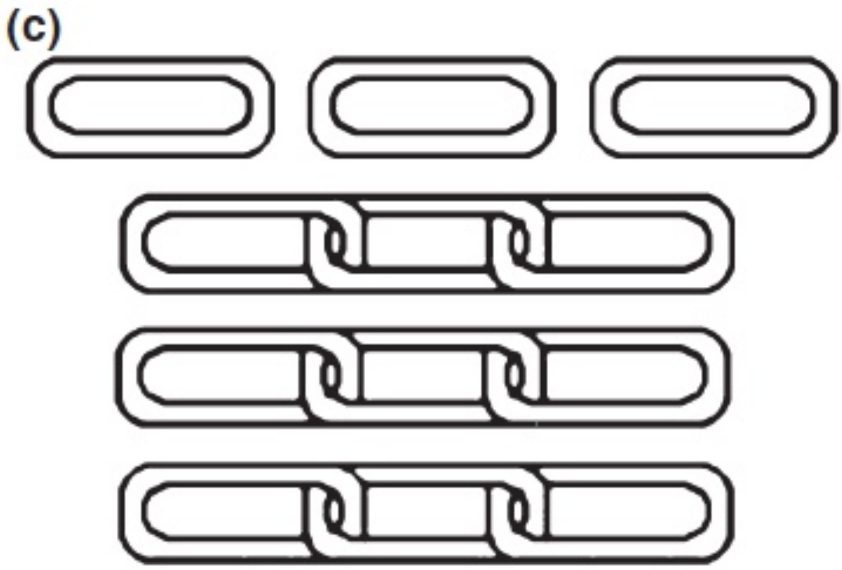


Figure 2.4 A hint used in cheap necklace problem by Fioratou (2005)

We argue that visual analogies for multi-move problems may need to capture more than one action, including their relationship, in order to draw analogical similarities and in order for their correspondences to be recognisable, and one of the most effective tools for capturing procedural multi-move actions is a time-based multimedia format. The insignificant results on the solution rate for the *cheap necklace* problem obtained in the previous studies suggest that the given verbal hints were either ignored by participants or were found to be difficult to decode and recode to provide the new restructured path for looking at the problem. The participants' failure to see relatedness between the hint and the problem might be a matter of vagueness and generalised conveyance of procedural executive tasks in the hint. We consider that visual analogies capturing the problem insights through an integration of visual analogy principles and elements with the problem procedures conveying the action-oriented tasks might be more effective in problem solving than verbal ones, especially for multi-move problems when insights follow a particular order and unfold in time (i.e., animation, video).

2.3.5 Creative Problems

Much of the research deriving from the *classic* cognitive psychological literature on problem solving (Newell, Shaw J, & Simon, 1958; Simon H. A., 1974; Simon H. A., 1978) report that there are similarities and differences between processes in insight (well-defined) and creative (ill-defined) problem solving regardless of which model is followed. Attempting to represent the problem, both problem solvers apply strategies by specifying an initial state for the problem, a goal state, operators, restrictions on these operators, and a procedure to solve the problem. To move from the initial state of the problem to its goal state, one must use operators (tools) and/or procedures (actions). For example, in insight problems, where there is generally one correct solution, the initial state, goal state, operators and restrictions on operators are specified by the problem description.

The legacy of psychology research on analogical reasoning has paved a solid path for investigators from other fields like art, computing or design. From a rigorous cognitive perspective, their suggested models in problem solving appear to be effective when applied to well-defined general problems, but are hardly ever universally accepted and applied in a design-specific context.

A comparison of research between insight and creative problem solving reveals key characteristics that differentiate designers' use of sources and their analogues. One of the major differences between these two types of problems is in the definition of the problem search space, wherein the well-defined clearly specifies what one is searching for, while in the ill-defined problem, one faces multiple adequate answers. The back-and-forth process followed by an established plan to reach the goals hardly works in creative problem solving as the search space is much larger and requires a consistent interpretation of the moves and actions to translate the process into a concrete context. While working on an ill-defined problem, it is harder to judge where one is at any point during the process in the search for a potential solution; therefore, one might look for relevant and useful analogues structures instead of focusing on planning strategies and paths to reach the set goals often used in the solving process for well-defined ones. In both cases, once a potential solution analogue is identified, one needs to link it to the real-world context to evaluate it and make decisions on what structures, elements, actions, or processes are seen as relevant for the problem which is faced. The given constraints in well-defined problems guide their solvers to generate strategies and methods for solving it, while in the ill-defined ones, where the constraints are loose, their solvers focus on generating abstract concepts. Particularly, in creative design, designers make use of several hints to generate new potential target scenarios or concepts rather than relying on the mapping of identified analogies in terms of the distinctive structural level of hints.

The processes in creative problem solving might be the same as in insight problem solving. However, design practitioners prefer to describe them somewhat differently. For example, in the preparation stage, a designer considers how “to create a new product” and not “to find out what is the problem here”. In essence, they follow the same stages to reach their final goals, except that in the creative problem solving process, the individual inspects the “potential new product” in a non-analytical fashion using intuition, experience and memory to define the relationships between the product features, while in the insight problem solving process, the individual is solely focused on finding and understanding the problem in the initial stage. In contrast, designers are more likely to present a set of flexible, ill-defined tasks that evoke a variety of responses and any number of potential candidates that could lead to a solution to the presented problem. In the initial phase, the imaginary representations of the product are built, then, by scanning the environment, impressions are gathered (e.g., through sketching, drawing) to externalise these mental images and use as references for later stages. This stage places more emphasis on the use of imagination and intuition rather than rational processes, which are not totally discounted but play a secondary role in creative problem solving. Usually, the resources and tools designers use in the search for their concepts are very different, as is each individual’s mindset and the setting and location in which the creative act takes place. In a chapter on problem solving and situated cognition, David Kirsh (2009, p. 268) writes: “If we could appreciate the abstract in the concrete, we would recognise analogies and be able to transfer learning from one domain to another more readily than we do. The reason we do not is because our understanding of problems is usually tied to the resources and tools at hand. We are hampered by the mindset appropriate to the setting in which our activity takes place”.

An increasing number of studies exploring analogical reasoning in problem solving focus on image-based analogues, and there is a good justification for this.

Designers seek inspiration from a wide range of sources, experiences, and in a variety of contexts. There is considerable evidence that practitioners from design fields look at images in the early stages of the design process (Goldschmidt G. , 1991; Kristensen, 1999; Mezini, 2012; Purcell & Gero, 1998; Rosenberg, 2008; Tversky B. , 1999; Gero, 2000) in a search for potential analogue solutions.

In the design practice, where the form is at the core of investigation, an image search is a common strategy employed during the generation stage in the design process (Goldschmidt G. , 1991; Do & Gross, 1996; Purcell & Gero, 1998; Schön, 1983; Suwa & Tversky, 1996). Because final designs often depend on successful concept generation stages, it is crucial to understand how ideas are generated and what practical techniques can facilitate the exploration of product solutions.

It has been argued that a designer, in contrast to an insight problem solver, is presented with a set of sub problems in the initial state of the problem. Designers do frequently use images or pictorial references in their search for potential solutions, and this is their way of closing the visual gap in the problem. The process occurs in a cycle and the problem conditions are defined and redefined according to their fitness for both problem constraints, problem-oriented and independent solutions. The pre-established requirements for the problem are reflected in the problem-oriented constraints and could be of a practical, economic, or environmental nature, while the independent ones derive from the designer's knowledge and understanding of the design problem. Independent constraints might be imposed by the artist's aesthetic taste, choice of the selected resources, techniques and inspiration.

In her study, Bonnardel (2000, p. 506) describes this process: "The designers' mental representation evolves as the problem solving progresses. This specificity of design problems is based on an iterative dialectic between problem framing and problem solving".

Another argument is that in the case of creative problem solving processes, the use of analogy is employed to a greater extent intuitively and spontaneously as opposed to the more calculated and analytic approach used in insight problem solving. visual analogies as verbal analogies are mapped across an array of levels that include their structural, functional, affective, directional, spatial, and other distinctive features of the hints.

2.4 The Role of Analogy in Problem Solving

The importance of reasoning by analogy has been widely investigated and documented in science. Reasoning by analogy (a.k.a. analogical reasoning) is the type of thinking that involves arguments between two objects, systems of objects or concepts that highlight accepted similarities between the two to support the claim that some more similarities exist. Solving a problem through analogy occurs when one finds a known concept or situation and applies it to a problem that has similarities with that concept or situation. Processes include identifying properties of objects, identifying relationships between objects, relationships between the relationships of objects, keeping all of these in mind or storing them for further manipulations, and evaluations to formulate answers (Goswami U. , 1992; Sternberg R. J., 1999) are associated with analogical reasoning. The more complex an analogy, the more difficult it is to meet the prerequisites of solving it. Efficiency in solving an analogy (Duit, 1991; Christensen & Schunn, 2005; Ball, Ormerod, & Morley, 2004) depends on working memory (Paivio, Rogers, & Smythe, 1968) components, storage capacity, executive functioning, evaluation, and decision-making capabilities.

Research in cognitive psychology shows that analogising is a skill that develops over time. According to Piagetian's theorists, young children develop their analogical reasoning skills during the "formal-operational" (at 11-12 years of age) period of reasoning; however, a number of authors (Vosniadou, 1989; Gentner, 1989; Goswami U. , 1992) argue that the shift occurs much earlier than that and children's analogising improves as they acquire more knowledge.

Knowledge-based views do predict improvements in children's performance, and they might recognise relational similarity, but the shift is not global, and mostly depends on children's ability to understand conceptual relations between the source and target.

The process of analogising involves the transfer of structural and/or conceptual information from a source domain to a target problem.

Studies on analogical transfer have identified three main stages: (i) encoding the source and target analogues, (ii) retrieval of the source by the target, and (iii) mapping the source to the target (Gick & Holyoak, 1983; Weisberg, 1988). According to Chen (2002), there are three distinctive types of similarities between problems, structural, procedural and superficial, that share causal relationships in terms of some of their components, procedures to enforce the solution principles into explicit operations, and solution-irrelevant details. Differences between the problems' similarities play an important role at each stage. For example, easily recognised similarities between the structures and/or principles derived from the source during the encoding stage may lead problem solvers to successful mapping, consequently generating more accurate solutions. Gick and Holyoak (1983) conducted several investigations on the role of analogy in creative problem solving and found that subjects more often solved a problem when they were told that the previous problem was related. It appears that most participants have difficulty locating the analogues, but once an analogue is discovered they can apply it quite effectively to the problem they face.

2.4.1 Structure-Mapping Theory

Structure-mapping theory (Gentner, 1983), models of similarity, analogy, and metaphor in perceptual and conceptual tasks, particularly, describe how the meaning of analogies is derived from the meaning of their parts. Its strength in explaining analogy comprehension resides in its identification of two principles for mapping knowledge from the source to the target domain. The *systematicity* principle (Gentner, 1986) states that connected knowledge is preferred over independent facts; and the *structural consistency* principle suggests *one-to-one* mapping between each part of the target and each part of the source, as well as between each of the attributes of these two parts. The system of matching objects, their attributes and relations is what Gentner called aligned structure (Gentner & Medina, 1998). Relevant in this structure is the distinction between *alignable* differences and *nonalignable* differences. The former involve correspondence between non-identical objects while the latter refer to the lack of, or wrong correspondence, between non-identical objects (Gentner, 1986).

The theory also emphasises the distinction between surface and structural analogies. Whereas the former relates to the easily accessible aspects of object properties, the latter target the higher order relationships based on relevant but less accessible properties. Although surface analogies are easier to understand, they do not guarantee the transfer of structural relations between the source and target domain, while the opposite is true for the structural analogies.

Whereas a wealth of research has explored the role of analogies and metaphors in comprehension, learning and problem solving (Duit, 1991; Novick & Holyoak, 1991), the process of transferring meaning from a source to a target domain has been predominantly explored through conceptual metaphors. We argue that the current research bias is regrettable given that, as described by Lakoff (1993), metaphor is not a figure of a speech but a mode of thought (Forceville, 2002), and we advocate that visual metaphors need to be rigorously explored.

3 Visual Analogies: Static and Dynamic

The value of visual analogies in problem solving has been extensively researched, with most of the work focusing on their benefits (Goldschmidt & Smolkov, 2006; Smith & Blankenship, 1991; Dundar, 1995), but less investigated is how visual analogies are actually developed.

Efforts to address the bias towards conceptual metaphors have led to research in visual analogies including those for computer displays, diagrams (Jones, 1993) to capture complex systems (Tversky, Morrison, & Betancourt, 2002), or animated arrows to hint insight problem solving (Beveridge & Parkins, 1987). Such interest in visual analogies is linked to the arguable superiority effect of pictures over words for memory and cognition. The dual-code theory proposed by Paivio (1971) suggested that pictures, by evoking both imaginal and verbal codes, are likely to be redundantly encoded. Nelson's sensory–semantic model (1984) suggested that pictures are more memorable because they provide more distinctive representations, whereas Gestalt psychologists have long advocated the role of perceptual factors in metaphor transfer (Kogan, Connor, Gross, & Fava, 1980).

Weldon et al. (1989) showed that pictures can be categorised more quickly than words (Potter & Faulconer, 1975), and produce more elaborate codes (Craik & Lockhart, 1972). In addition, diagrams are particularly useful for attracting attention and sustaining motivation, structuring content and representing visuospatial information (Tversky, Morrison, & Betancourt, 2002).

3.1 Visual Analogy and Problem Solving

Several studies have suggested that the *insight* in problem solutions occurs unexpectedly following impasse, and that it is predominantly preconceptional (Ghiselin, 1954; Koestler, 1989; Wallas, 1926; Metcalfe & Wiebe, 1987; Schooler, Ohlsson, & Brooks, 1993; Hadamard, 1954). Both anecdotal reports of prominent thinkers (Poincare, 1952; Polanyi, 1967) and empirical research (Bowers, Regehr, Balthazard, & Parker, 1990; Metcalfe, 1986) provide evidence to support James's (1890) claim that most of the insight occurs in the absence of words, and that it is only afterwards translated into language. Although we have previously discussed the importance of verbal and visual stimuli in problem solving, most studies suggest that language overshadows insight (Schooler, Ohlsson, & Brooks, 1993) and that verbalisation during a creative act may cause creators to favour the manipulation of information from working memory over the information to be retrieved from long term memory. Reports from several studies on cognitive activity relying on nonreportable processes indicate vulnerability to verbalisation, i.e. learning (Reber, 1989); implicit memory (Schacter, 1987) in automated motor skills (Norman & Shallice, 1986) and creativity (Finke, 1990).

3.1.1 **Visual Analogy in Insight Problem Solving**

In insight problem solving, analogies have usually been used to convey a representation of the problem's solution (the source), to which the actual problem solution can be mapped (the target). The insight problems have been cued with both verbal and visual analogies. The most relevant studies are summarised below. Analogical reasoning facilitated by visual hints has been shown to be effective in insight problem solving particularly in the case of Dunker's radiation problem (Dunker & Lees, 1972). Findings have shown that this verbal problem can be successfully solved when visual diagrams are used as hints for the target while highlighting that they are not equally effective. For instance, consistent with previous findings, Gick and Holyoak (1983) and Pedone et al. (2001) showed that the static diagrams representing arrows converging on a focal point did not lead to a higher success than for the control group. In contrast, Beveridge and Parkins (1987) used transparent blue plastic strips, hinged together at one end, to simulate the motion and arrows to suggest the lines of force. While extending the same idea of apparent motion through animated arrows, Pedone, Hummel and Holyoak (2001) also employed longer sequences of diagrams to represent more problem states between the initial and the final state. Such visual analogies containing references to lines of force for capturing the insight for problem solving, (i.e., convergence principle for the radiation problem), were particularly effective in supporting their transfer to the target solution. We speculate that this is due to the fact that visual representations of lines of force allow immediate, non-mediated access to image schema (see Section 2.2.1.2). Catrambone et al. (2006) also argue that the limited effectiveness of the static diagrams is due to their failure to convey a spatial schema of force, whereas animated arrows are better suited to eliciting it. Catrambone et al. (2006) further explored the role of perceptual kinaesthetic information in analogical reasoning in the radiation problem. They showed that verbally enacting the general story as a source of analogical transfer while using wooden blocks to simulate it leads to significantly higher spontaneous transfer than both sketch and verbal conditions. This suggests that enactment made the kinaesthetic features more salient. Another insight problem where visual hints where successfully used is the *8-coin* problem (Ormerod, MacGregor, & Chronicle, 2002) described in more detail in Section 2.3.4 of the previous chapter. The task requires an array of coins to be arranged by moving only two of them so that in the solution, each coin touches exactly three others. The primary insight for solving the problem requires a shift to moving the coins in three rather than two dimensions (i.e., stacking), and since this leads to two groups of coins, an additional insight is grouping. The research discussed above represents a few studies that explore visual hints in insight problem solving, and they suggest that when perceptual information is captured by the artefacts, either kinetically or kinaesthetically, their success rate is higher than when verbal hints alone are offered.

3.1.2 **Visual Analogy in Creative Problem Solving**

Eminent examples of scientific discoveries made by analogy have been documented throughout human history. The best known example of using remote analogy (Weisberg, 1988) or spontaneous analogising (Ball, Ormerod, & Morley, 2004) is Archimedes's discovery (3rd century B.C.) of how to measure the volume of irregular forms. The king had asked Archimedes to determine if his crown was made of pure gold, as he had ordered, or if it contained other substitute materials. At the time, the weight per volume of pure gold was known; however, the numerous details of organic forms made it impossible to measure the crown's volume accurately. The solution was not found until one day when Archimedes stepped into a bath and noticed that the volume of water spilling onto the floor increased as he lowered his body into the bath. The analogy suggested immersing the crown in a container of water and then measuring its accurate volume in order to answer the king's question. Analogies are defined in terms of the similarities between the elements of the target, i.e. the mass/volume of gold in the crown, and the elements of the source, i.e. mass/volume of water displacement (Tijus & Brézillon, 2008). Based on these similarities between the source/base and the target information, cognitive psychologists have classified analogies as local, regional or remote (Weisberg, 1988). Other categorisation identifies analogies within a domain, between domains and long-distance ones (Dunbar, 1995; Vosniadou, 1989; Christensen

& Schunn, 2009). While analogies within a domain are particularly efficient in supporting creative thinking (Perkins, 1981) and problem solving (Mayer, 1999), analogies between domains support innovation and originality (Christensen & Schunn, 2009) when they capture similarities at both structural and conceptual levels. Analogies are used to explore, study, and explain phenomena in the natural world. Leonardo da Vinci studied birds in flight, various animals, and the movements of snakes, which led to various inventions (e.g., helicopter – birds, tank – tortoise, wormgear – worms) (Wamsley & Atalay, 2009). Some of these analogies can be classified as regional. Another example of using a local type of analogy is the development of the pointillist style in painting. Claude Monet's impressionistic paintings inspired Paul Signac to scientifically experiment with the perception of colours on his canvases (Clement & Houzé, 1999). The brushstrokes were reduced to small dots of pure colour with the intention that they should blend in the eyes of viewers rather than on the canvas. The used analogy comes from the same field of painting and is classified as a local or within domain analogy.

3.2 Static Versus Animated Visual Analogy

Whereas most of the work on visual representations has focused on static diagrams (Tversky B. , 2011; Do & Gross, 1996; Clement J. , 2004), logo design (Kristensen & Gabrielsen, 2013; Daly, Yilmaz, Christian, Seifert, & Gonzalez, 2012), or visual material for learning (Mayer R. E., 2003), the advent of multimedia technology and computer graphics has allowed the development of animated diagrams (Tversky, Morrison, & Betancourt, 2002; Mayer & Moreno, 2002), and an exploration of their impact on perceptual and cognitive tasks has started to emerge. There are several reasons to expect that both animations and static pictures support learning. On the one hand, as showed by Höffler and Leutner (2007), animations can support the understanding of the process of transformations between different problem states, reducing the cognitive load required to imagine it; and they are usually free of additional signalling hints which make static pictures more difficult to interpret. On the other hand, unlike static pictures, animations are more complex and provide transient information that can be taxing for the working memory (Tversky, Morrison, & Betancourt, 2002). In a well-cited paper, Tversky et al. (2002) critically reviewed a wealth of research on graphics and their role in learning by highlighting both the challenges and principles of their effectiveness. Researchers showed that despite their appeal and expected intuitiveness, graphs and animated graphs, in particular, have led to mixed results in terms of their use as aids for learning. For example, to test the effectiveness of graphics in teaching Newton's laws of motion to elementary school students, Rieber and Hannafin (1988), and Rieber (1989) used text, static diagrams and diagrams that animated the path in their experimental studies. They found no differences in student performance between groups receiving static and animated graphics. Byrne et al.'s (1999) experiment on the effectiveness of animated graphics shows that animations were equivalent to static graphics in teaching algorithms to college students.

According to Tversky et al. (2002), animation has an advantage over static images as it relates to conveying extra information and additional procedures. It appears that this media is ideal for conveying change over time (Schnotz & Grzondziel, 1999). However, the animation must be carefully constructed and used. According to the *congruence* principle (Tversky, Morrison, & Betancourt, 2002), "The structure and the content of the external representation should correspond to the desired structure of the internal representation" and the real change should be conveyed naturally through the change expressed in the metaphor. It is difficult to perceive and understand many complex animations, especially in terms of their concepts, even for emerging people in the field, so, following the *apprehension* principle (Tversky, Morrison, & Betancourt, 2002) when creating animated graphics would ensure effectiveness in terms of learning, teaching and problem solving. The animations must show the objects/characters at a slow speed, and be clearly drawn/modelled so the viewers will observe their movements and changes over time. According to the *apprehension* principle (Tversky, Morrison, & Betancourt, 2002), the structure and the content of the animation should be readily perceived and comprehended; thus, a prerequisite in their construction is to convey only the essential information for the concept and eliminate extraneous information. For example, the American commentator David Weinberger stated that slicing one's attention is like slicing a plum – "You lose some of the juice." Rubinstein et al. (2001) also reported strong evidence indicating this, by showing that the cost of multitasking could be very high. They indicate that task performance was approximately 50% slower on average (especially when the tasks were relatively complex) when two tasks were involved compared to single task performance (Eysenck M. W., 2006, p. 129).

The main problems with the reviewed body of work is that most studies showing increased learning performance have suffered from confounding animation with additional information not available in the static graphs (i.e., fine spatio-temporal actions on objects rather than just objects and relationships between them), or additional facility to understand and explore the animation (i.e., interactivity). Animation can be represented discretely or continuously, and the use of discrete steps seems to be preferred over continuous smooth motion because people tend to conceive the latter as a sequence of steps (Hegarty, 1992; Zacks, Tversky, & Iyer, 2001). Animations are also costly to develop and challenging to understand, since people usually attend to their perceptually salient information rather than more important but less accessible causal information (i.e., surface rather than structural properties (Gentner, 1983)). Tversky et al. (2002) suggested two cognitive principles for developing effective visualisations. The congruence principle requires that the structure and content of the visualisation correspond to those of the conveyed concept, while the *apprehension* principle (2011) requires that the structure and content of the visualisation are accurately perceived and understood. The first principle suggests that animations are intuitive ways to convey information about a process involving changes over time, while the second principle argues that animations should be more schematic and less realistic to enable their understanding. Tversky et al. (2011) concluded that the information that may be best conveyed through animation is change over time captured by the exact discrete sequence and timing of operations.

However, in a more recent meta-analysis, Höffler and Leutner (2007) have shown that dynamic visualisations were more effective than static visualisations, and that this effect was greater when the animation was representational, highly realistic, and when procedural-motor knowledge was to be acquired (e.g., image schemas). These findings are particularly important since they not only support the superiority of animations, but they also provide insight into the features associated with their effectiveness, and suggest the use of embodied schemas in their construction.

Also, these findings are supported by neuroscience research on the mirror neuron system that has offered insights into the neural bases of learning by observation and imitation. Van Gog et al. (2009) suggested that visualisations depicting human movement might trigger an automatic and therefore effortless process of embodied simulation as a result of the mirror neuron system . These are some of the neuroscience findings among a larger body of work providing empirical evidence for the theory of embodied cognition (Gallese & Lakoff, 2005). In this study, we will also explore the role of kinetic and kinaesthetic information in analogical reasoning. A relevant starting point is that embodied cognition theory focuses on the role of image schemas in perceiving and comprehending visual representations of action forces and gestures.

We assume that implementing the image schema in the early stages of visual analogy development for our experiments will not only give us a better understanding of how to construct them so that they are effective, but also of what extraneous information should be eliminated from them in order not to distract solvers from the problem.

3.3 Visual Analogy Representation

Static and dynamic pictorial images were used in previous experimental studies as a source of investigation into visual analogies in insight problem solving and creative problem solving, and their impact on human creative activities or created products. This section describes the properties of the pictorial surface of elements used in the visual analogy development process, as well as the psychological space in which the main elements of analogy will be placed and how analogy will be conveyed in the picture frame (paper, TV screen).

3.3.1 Pictorial Properties of Visual Analogy

Giving explicit instructions to use analogy and exposing subjects to visual displays, Casakin and Goldschmidt (1999) examined how this method could contribute to the enhancement of design in problem solving. The goal in their investigation was to gather evidence on the effect on the performance expert-novice designers involved in a creative design problem when stimulated by visual analogy. In their experiment, a group of experts and a group of novice designers participated. Twelve images related to the architectural domain and 12 images related to other fields were used as visual stimuli for solving three creative design problems. In the paper, there is only one example of the displays used in the experiment as a source for solving one of the three problems; only four pictorial and three 2D images were used for the visual display. Therefore, it is unclear and difficult to deduct from the report which visual displays worked best. Firstly, this is because the ratio of used pictorial 2D images, as a strong source for the solution, was not mentioned, and secondly, the result was scored on a scale as a creative solution and not as a well-defined insightful problem. Thirdly, the figure-ground relation of dimensionality was not described in their report for any of the used visual material in experiment. “The figure-ground relation represents the perception of dimensionality on a flat surface, and no more than two planes are considered. Both of them have to be boundless, and one lies in front of the other" (Arnheim, 1974). The simplicity of their shapes and symmetry predisposes one area to function as the figure and the other as the ground. Adding more information to the image, we tend to see, at a different level depending on our knowledge and experience, three-dimensionality. Why do we see depth? The law of simplicity is the key to this question. "A pattern will appear 3D when it can be seen as the projection of a 3D situation that is structurally simpler than the 2D one" according to Arnheim (1974). Artists use the relative size of an object, its occlusion, orientation, elevation, shadows, texture gradients, colours, linear and atmospheric perspective to show the illusion of depth on a 2D surface (e.g., canvas, paper, or TV screen). Robert Solso (1994, p. 162) classifies these elements of depth perception as pictorial cues.

3.3.2 **Scale and Multiple Psychologies of Space**

A relevant model for organising the visual elements in analogy is the concept of spatial scale proposed by Montello (1993), whereby he classified the properties of objects in space into multiple spatial psychologies. Visual working memory and visual perception regularly interact with each other at several levels. The memory contents influence the visual perception each time they interact. According to recent evidence, the contents of visual working memory may affect the perception of presented stimuli in a scene (Pan, Zuo, & Yi, 2013). They can guide visual perceptual selection (Olivers, Meijer, & Theeuwes, 2006; Pan, Xu, & Soto, 2009; Soto, Heinke, Humphreys, & Blanco, 2005) and alter perceptual experience (Saad & Silvanto, 2013; Scocchia, Cicchini, & Triesch, 2013). In this development process, I am concerned with the question of how size, depth and space can be represented in visual analogies to match the target correspondences. Space is a fundamental part of human cognitive functioning in daily life, a communication tool, and it also plays a significant role in image-making domains. The critical role of spatial perception is not simply determined by the space perceived by the visual retina; factors like the angle, distance, elevation, occluded objects, contextual cues and even sound can alter visual perception of the size of and space occupied by objects.

As visual analogies are developed for the purpose of aiding problem solving, the terms of psychological properties of space proposed by Montello (1993) will be used throughout the whole process of visual analogy development for this study including my diary notes. Montello (1993) called for a distinction between the properties of space when they are studied as problems in information systems or geography (e.g., cartographic coding and decoding) and the properties of space when studying human perception, behaviour and thought. He argues that the relationships between objects in space are treated as scale-independent in terms of the properties of space for information systems or geography, whereas the property of space in studying human perception, behaviour, and thought is not scale-independent. Although the author offers considerable evidence for the importance of a qualitative psychological scale classification, he suggests further directions for investigation to obtain more evidence on its validity and utility. Also, such a distinction could help researchers answer questions about what and how humans can learn about space from a direct experience, so he proposes the classification of psychological space in multiple scale classes. Montello's scale of space classification is based on the projective size of objects in space relative to the human body with a focus on the functional properties of each class.

Figural space can be perceived from one place and does not need appreciable body movement. It is a space of small objects (object space) and pictures (pictorial space) that can be touched and/or manipulated to grasp their spatial properties.

Vista space can be visually captured without significant movement from one place as well. However, this is the space of single rooms, visible streets, town squares and horizons where space is projectively about the body size or larger.

Environmental space is the space of cities, large buildings and stadiums which are much greater than body size and the properties of which must be apprehended from direct experience requiring considerable locomotion over a period of time.

Geographical space cannot be apprehended from direct experience through body locomotion; it refers to an area of countries, the solar system and the like, which require the integration of spatial information into instances of figural pictorial spaces as symbolic representations such as maps, models, or graphs.

3.4 Making Analogies

Several models, theories, and types of analogies have been extensively used in domains such as logic, science, linguistics, mathematics, education, AI, and arts; however, our focus concerns, in particular, the visual analogies for problem solving. Analogical reasoning involves the source knowledge holding the analogous phenomenon and the target domain containing the problem to be solved (Vosniadou, 1989). The source and the target are linked through their similarities. Similar relationships are based on shared object attributes, relational structures or relations relating relations (Goldstone, Gentner, & Medin, 1989). Gentner's (1983) structure-mapping theory provides a framework of analysis and understanding of analogies and how people interpret and classify them. Mapping knowledge from a familiar domain (the base) into another, less familiar domain (the target) is at the core of this theory.

Several methods for visualising ideas to support analogical thinking have been developed and we briefly review two more commonly used techniques: WordTree design-by-analogy and mind map technique.

The WordTree design-by-analogy (Linsey, Wood, & Markman, 2008) method promotes a systematic re-representation of the design problem, which invites designers to think about product functions and customer needs, and these "problem descriptors" are linguistically re-represented in a WordTree diagram. The potential analogies are identified both from within the domain and from distant domain(s). Statements on identified analogies are written, analysed, and implemented in an idea generation session. The model guides designers to search for multiple analogies, in a similar way to the technique used for the counterpart TRIZ model (Altshuller, 1998). Another method associated with the visual representation of ideas is Siquera's (2007) Mind Map technique. Here, the visualisation is captured through a diagram of words, tasks and pictures arranged intuitively according to the importance of their concepts and the ideas are spatially organised in groups.

3.4.1 **Generating Visual Analogies**

One strand of research in generating analogies has focused on the various stimuli in the creative process that can help overcome fixation (Chun & Jiang, 1998; Smith & Dodds, 1999). The term fixation is frequently used to describe the types of impediments that cause mental blocks or lack of progress in creative thinking, such as perceptual blocks. Fixations usually occur when people are confronted with inappropriate information, make less accurate assumptions, are biased by previous knowledge or fail to retrieve the appropriate knowledge from long term memory. Known remedies for fixation are incubation (Smith & Dodds, 1999; Sio & Ormerod, 2009) and the use of visual stimuli (Goldschmidt & Smolkov, 2006). The way visual analogies for insight problem solving are generated, developed, and evaluated for their effectiveness is explored in this thesis. Many studies show that the use of visual stimuli promotes conceptual learning and problem solving (Goswami U. , 1998). The visual and spatial hints aid comprehension (Gentner & Rattermann, 1991) of abstract relationships (Kosslyn, 2006; Dominowski & Dallob, 1995; Vosniadou, 1989; Christensen & Schunn, 2009) and can also increase transfer (Gick & Holyoak, 1983). However, unsuccessful visual stimuli may produce confusions and misunderstandings that can lead to their uselessness or even harmful misconceptions (Clement J. J., 2008). Investigations on how to create effective visual stimuli may offer a cognitive backup to help people to reap maximum benefit from visual analogies (Richland, Zur, & Holyoak, 2007). Using the think-aloud evidence from videotaped subjects during problem solving, Clement (2008) identified at least three different methods that expert scientists use to generate analogies: via a principle, via associations, and via transformations. Some of the cases in his studies were qualified as newly invented with inconclusive results suggesting a need for further investigation. Although Clement's findings are plausible, we argue that his investigations were limited in that only mental interpretations in analogy-making were used.

According to psychologists' views on the developmental curve (Crain, 2010), reasoning based on similarity in early childhood follows rule-based reasoning in adulthood; therefore, similarity relates to the figurative quality and is largely visual (Gentner & Rattermann, 1991). Studies of design fixation have shown that people who saw examples of inappropriate "hints" have a hard time moving beyond those hints in tasks for creative idea generation (Landau & Lehr, 2004). The visual information supporting mapping is not always easy to perceive, and requires testing to explore its effectiveness in problem solving.

Although research in constructing visual analogy is limited, some studies suggest that contextual cueing (Chun & Jiang, 1998, p. 28) plays an important role in visual tasks and "is driven by incidentally learned associations between spatial configurations and target locations". Natural scenes are sought by an observer as very rich and complex and may constrain visual processing, but an image can prioritise object recognition for selection and facilitate meaningful regularities between objects and context. In fact, Chun & Jiang refer to the same characteristics of stored schemas (De Koning B. B., Tabbers, Rikers, & Pass, 2007) in long term memory. In their research report, Himmel & Nadolski (2002) presented guidelines for effective cueing suggesting that hints should reflect the relationships between and within tasks, be task-ordered to saliently describe relevant task characteristics and redirect attention from extraneous to germane processes; hints should also support practice, and facilitate cognitive transfer. Such understanding of which types of hint characteristics are more effective for supporting problem solving could benefit from more empirical work which explores the process of generating them. This thesis explores the construction of effective cueing in problem solving through a practice-led research method to identify the principles used by a visual professional in analogy-making. Inspired by the findings that indicate that analogies are often employed by artists, architects and designers, particularly in the initial stages of planning, generating and visualising ideas (Do & Gross, 1996; Kandinsky, 1979; Patherbridge, 2010; Tversky B. , 1999), we crafted an appropriate methodology for our study (Chapter 4 - Research Methodology and Methods Used). Additional psychological (Ball, Ormerod, & Morley, 2004; Larkin & Simon, 1987; Vosniadou, 1989), neurophysiological (Wharton, et al., 1998) and developmental (Goswami U. , 1998) data on analogy-making (Kowaltowski, Bianchi, & de Paiva, 2010), through the practice and reflection of practitioners, further support this methodology.

Just as the first-person accounts of artists and researchers on their creative processes may open up new ways of understanding what is being selected as a hint for a given problem, as well as how and why, the work in this thesis also argues that analogy construction can be examined by a practice-led approach, properly documenting and reflecting on this process.

Another study (Garner, 2001) suggests that freehand sketching in the design process may be a powerful catalyst in the generation process as the “inherent-imperfect” lines and shapes of sketches create vagueness in visual representations, thus continuously stimulating reinterpretation. Suwa and Tversky (1997) pointed out the need to develop computer-based design tools involving sketching capability, which would “enrich perception” of designers, while Purcell and Gero (1998, p. 390) consider drawing as an “essential part of the process of thinking about a design problem and developing a design solution”. Both studies suggest further investigations into sketching processes as they may reveal new mechanisms and tools supporting the cognitive, transformational, and creative processes.

3.4.1 **Sketching as a Thinking-Act Tool**

Sketching techniques facilitate reflection and provide a rich medium for discovery and communication of design ideas (Tohidi, Buxton, Baecker, & Sellen, 2006), in particular, in the early stages of ideation and exploration stages (Rogers, Green, & McGown, 2000). The techniques vary from plan to plan, section to section, project to project, and from person to person, and for centuries, have been used as a tool for observing, musing, studying, thinking and discovering (Suwa & Tversky, 1996; Goldschmidt G. , 1991) rather than to impress people with aesthetic qualities as in the case of many finished drawings. Leonardo da Vinci and modern painter Carlo Carra used lines, shadows, arrows, dots, maps, and handwriting, all crowded onto the same page, in their sketchbooks (Patherbridge, 2010). Ideational sketching, both as a process and artefact, is a thinking space, where thinking is presented in the immediacy of the thinking-act (Rosenberg, 2008; Do & Gross, 1996). Some of the sketches resemble gestures, and some are more elaborate drawings; however, as the artist goes on to work on a larger project, the process continues, and other ideas arise unexpectedly, get in the way, and either change the direction or improve it (Patherbridge, 2010). Drawing is a form of externalisation of thought (Tversky B. , 1999). There is a collection of media (dry and wet), materials (pen/ink, charcoal, graphite pencil, pastel, chalk, marker) and techniques (scribbling, hatching, stippling) to be considered in the drawing process; however, this study will draw attention to sketching as a means of thinking and externalising ideas and its role in the ideation and generative processes of analogy-making for problem solving.

3.4.2 **Selecting an Environmental Stimulus**

The analysis of natural life forms and principles of such constructs may be employed in the design processes as they often inspire designers and architects (Patherbridge, 2010; Tversky B. , 1999; Siqueira, 2007; Finke, 1990; Gross & Do, 1995; Gero, 2000). A variety of sources of inspiration can be found everywhere. But how do we select the appropriate information for a particular problem to be solved? How do we extract information from the infinite stimuli provided by the natural world to support design solutions? How do we select and integrate the appropriate information into a reliable analogy for a specific design problem? Which tools, processes, and principles should be used in this process? Where do we look for them? In a museum? A park? Or, a children's playground? To answer these questions, we might take a closer look at the way nature works, adapts, and evolves. We might look at how designers, architects, and engineers seek to imitate forms, functions, properties, and principles of living structures in their practice. For renaissance artists, nature was considered the best teacher

(Patherbridge, 2010). The perfect proportion, harmony, balance, form, and function were the basis of elements and principles of aesthetic design.

However, identification of analogies that will prove effective in creative thinking can be as difficult as reflection in the creative processes of architects while working with constraints such as sustainability, materials, efficiency, environmental fit, maintenance, and cost (Eryildiz & Mezini, 2012; Kibert & Grosskopf, 2007). One might be inclined to seek inspiration from local architecture, another may look through historical documentation of architecture, and another might choose to look for structures, functions and principles from the natural world; it is the latter approach that was considered in the work presented here.

3.4.3 Methods to Generate Analogies

In a study by Harpaz-Itay et al. (2006), the transfer performed by participants trained to solve verbal analogies was compared with the transfer performed by participants trained to construct them. The success rate was measured by the overall effectiveness of participants in solving a verbal analogy in the first group and constructing an analogy in the second group. Both groups received training in three kinds of analogical tasks: verbal, figural and numerical. Their results showed that the group which had received training in visual analogy construction performed better in the numerical and figural tasks than those who had been trained in solving the analogy. Authors suggest that the advantage seen among constructors can be attributed to a higher-level activation of problem recognition, strategy planning and task performance supervision metacognitive components. Even though both groups received training in Sternberg's (1985) seven metacomponents of analogy, the *encoding* strategy was used mostly by constructors due to the demands of their task. Contrary to Bernardo's (2001, p. 146) explanation claiming that the improvement in the *constructors* group was due to the "reverse-mapping process" only, Harpaz-Itay and colleagues (2006) reinforced the idea that there is a difference in dependency for the task in the context of and situation between the two roles. For example, a problem solver is more likely to focus on solving the structural mapping (Gentner, 1983), the number of relationships (Halford, Wilson, & Phillips, 1998), and familiarity of these relationships (Goswami U. , 1992; Chen, 2002) in solving analogy, while an analogy constructor is more likely to focus on self-explanation and analogical comparison (Nokes-Malach, VanLehn, Belenky, Lichtenstein, & Cox, 2013) which are more dependent on prior knowledge and cognitive style (Mayer & Massa, 2003). Nokes-Malach et al. (2013) suggest that self-explanation and analogical comparison facilitate conceptual learning; thus, these components, along with *encoding*, could be more important for analogy-making than for solving them. The focus of the present research is on analogy development. Therefore, in this subchapter, we describe methods of generating concepts for analogies primarily using the abovementioned components in addition to the required mechanism of mapping the problem representation (target) into a similar schema (base) learned from previous experiences. Clement (2008, p. 33) considers the generation stage of an analogous case to be "the most creative part by some even an unconscious part of using an analogy, and therefore it may be the one which is least well understood". Here, he goes on to clarify what he means by generating analogy: "accessing or constructing an analogy and raising the question of whether there is a valid analogy relation between it and the target problem". Clement (2008), in his experimental studies, observed that spontaneously generated analogies are mostly effective when used by well-trained scientists. He identified three methods of generating analogies: via a principle (abstract – often mathematical or verbal), via a transformation (changes – A & B) and via an association (a situation familiar to the unresolved problem). The first and least used was the generation of analogy via a principle. This method represents a form of explaining things in learning as well, and is used more frequently through examples of how a principle is applied to other things. Representations or relations based on a principle might sound like the analogy: "the cat's tail is like the steering wheel for a car" – suggesting the principle of navigation control. The method can be applied successfully to both types of analogies: near and far. The second method of generating analogies is via transformation, when objects, situations or contexts are modified within limits to obtain new objects, situations or contexts that still resemble the old ones that enhance new interpretations. Analogies generated via this method are often used within a field or domain (near analogy) for innovation or to improve things.

In the case of insight problems, most of the laboratory studies involving visual analogy as hints have suggested that subjects need to be instructed to use an analogy in finding the answer to a problem, as visual analogy is rarely used spontaneously (Christensen & Schunn, 2009; Dundar, 1995).

Dual simulation (Clement J. J., 2008, p. 205) strategy is another process that involves imagistic simulation. The researcher provides evidence from think-aloud case studies that expert problem solvers use to generate imagistic simulations by applying intuitive schemas shaped by prior knowledge. The mental process of imagistic simulation involves the perceptual/motor system for acting on or simulating transformations, the movement of objects, or scenarios for an event.

The "Genelope" model (see Section 2.2.1.1), proposed by Finke et al. (1992, pp. 45-46), is based on a continuous cyclic movement between generative and exploratory phases involving "preinventive structures" – loose sketches of ideas including associations, transformations, synthesis and analogical transfer.

Other known methods and techniques have been used and tested in design and architecture studios and include biomimicry (Benyus, 1997), brainstorming, doodling and sketching (Suwa & Tversky, 1996), drawing (Do & Gross, 1996), visualising goals, or working with dreams and images (Goldschmidt & Smolkov, 2006). Biomimetic analogy (Benyus, 1997) was successfully used in the design processes of architects like Santiago Calatrava (inspired by the ideal proportions and rhythm of natural forms) and Mick Pearce (who studies and applies the principles of nature (Mezini, 2012) to his self-regulated style of architecture). Biomimicry is considered a form of complex analogy that demands an understanding of evolutionary systems found in nature (Kowaltowski, Bianchi, & de Paiva, 2010).

It is worth mentioning that integration of these methods would offer stimulation and be more useful, particularly, in the idea generation stage of the design process (Gero, 2000).

3.5 Evaluating Visual Analogy Relations

Research shows that experts, as well as novices, can generate and use multiple variations of analogies (Ball, Ormerod, & Morley, 2004; Beveridge & Parkins, 1987; Blanchette & Dunbar, 2001; Christensen & Schunn, 2005; Clement J. , 1981) during insight and creative problem solving. However, while not all generated analogies are potent, how do these experts choose the right ones for their problems? How can one tell whether a proposed concept is authentic? How can the analogy be evaluated and validated with regard to the analogous relationships between source and target? In another biometic example, the Zimbabwean architect Mick Pearce (Beatley, 2012), before designing the largest retail and office complex in Harare, studied termite mounds with a view to figuring out how to minimise the cost of air-conditioning in such a massive building. The architect was confident that the inferences from the analogy would help him find a solution allowing him to build a sustainable, self-sufficient architectural complex. The validity of analogy here was deductible from the inspired context (Clement J. J., 2008). This micro crowded living habitat idea gave the architect confidence through analogy appropriateness. To find a solution for the building's sustainability, Pearce learned from termites and looked mostly at how the principles from these living organisms can be transferred into engineering. The use of the termite mound analogy solution saved the owner of the building more than $3.5 million in energy costs in its first five years (Beatley, 2012); however, this is not an indication that the architect knew exactly that that would be the case when he chose this particular analogy as inspiration for his design.

Indisputably, most of the analogies used in creative problem solving are intuitive, often deeply entangled with the personality and identity of their creator. Some of these analogies may lead to highly-optimised solutions, but we can never demonstrate why and how exactly they were chosen, or if the resulting solutions are the best. The triple role of analogy (providing insights into a problem solution, explanation tools, and informing the design process) in most of creative activities and situations makes it difficult for us to deduct or generalise a validation path.

Another view on the analogy evaluation process is described in a study by Forbus et al. (1997) and was presented at the Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society. This model is rather an extension of Gentner's structure-mapping theory (1983) that is based on comparing structural correspondences through the mapping of distinct symbolic relationships identified in the source and target. Depending on the nature of overlapping correspondences, the evaluation of mapping provides an estimate of match quality.

The authors claim that their model of analogical inference is the first to match the models of mapping and retrieval (Holyoak & Koh, 1987; Hummel & Holyoak, 2005) at a level of generality. Based on their experimental studies and case-based reasoning examples (Falkenhainer, Forbus, & Gentner, 1986; 1989; Gentner, 1986), they provide evidence of how structural evaluation of analogical inferences can be used to estimate a promising inference by its form and the mapping that generated the analogy (Keane, 1994). In their experiments, they used an MAC/FAC retrieval model (Forbus, Gentner, & Law, 1995) to retrieve the likely needs cases with the highest score support for optimal advice for the problems that intermediate thermodynamics students faced. Students used a brief description of the problem as an input in the CyclePad application and then, based on that description, the expert mode modified the design and suggested how to fix the problem in “watch me” mode.

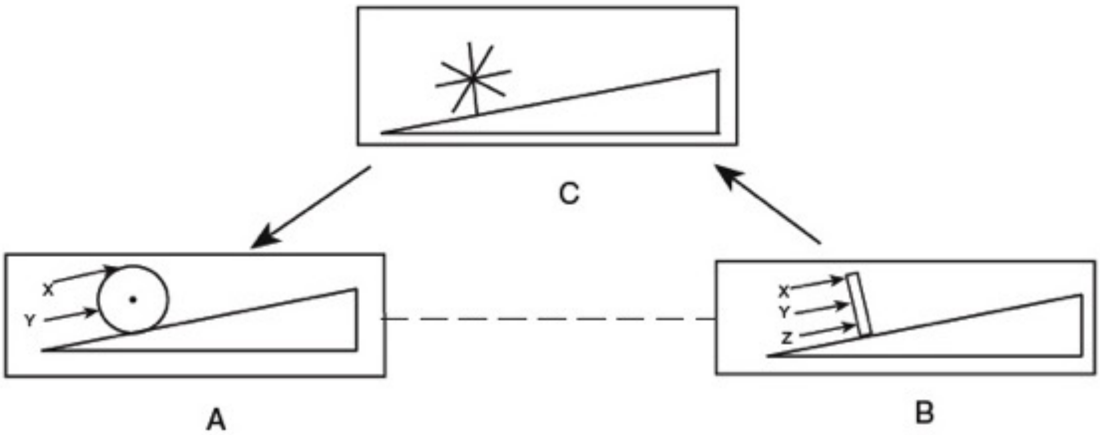
They found that CyclePad provided the optimal advice for students in problem solving tasks when they chose analogical inferences generated by the CyclePad application which had the highest scores.

The authors aimed to measure the structural evaluation of candidate inferences in two stages: support and extrapolation. Support would answer the question of how much structural support an analogical inference derives from the mapping that generated it, and extrapolation, consequently, relates to how far an analogical inference goes beyond the support lent by the mapping (Forbus K. D., Gentner, Everett, & Wu, 1997).

Although this model is plausible and contributes to the literature, it turns out that it is domain-specific and that one can rely only on the database of similar problem solving cases from CyclePad or other similar applications. It is also unlikely that the model alone can predict genuine solutions to real-world problems, which are more complex than simple algorithm calculations. Not every possible combination of natural objects mappings and correspondences is equally probable, and even if it were possible for them to be computed in the future, the interpretations of those constructs sometimes differ drastically between the human brain and computer algorithmic output.

An analogical bridging model for analogy evaluation proposed by Clement (2008) includes evidence that experts are capable of imagining and inventing new forms, representations, and new concepts beyond simple algorithms that derive from structural mapping.

The evidence that he provided is based on the case studies of invented representations that have been constructed by participants to find solutions to the given problems. One of the tasks given to participants (Clement J. J., 2008, p. 48) was to solve the *Wheel Problem* (see A in Figure 3.1): “You are given the task of rolling a heavy wheel up a hill. Does it take more, less, or the same amount of force to roll the wheel when you push at x, rather than at y?” The participants were told to solve the problem “in any way that you can” without any suggestions about any specific problem solving methods or strategies to employ. In this study, seven experts in technical fields participated (advanced doctoral students or professors), three of whom used analogy to find the solution to the problem. Of the three who used analogy, two used the bridging method. After generating the lever analogy (see B in Figure 3.1) as a potential solution to the wheel problem and having doubts about the result, a participant generated an in-between analogy (see C in Figure 3.1) in the form of a spooked rimless wheel.



<u>Figure 3.1 Bridging analogy for "Wheel Problem" from Clement's (2008) book</u>

This bridging analogy captures an array of levers at different angles that gave the participant confidence in the validity of the original analogy, and in effect, in the problem solution.

It seems that in order to evaluate an analogous case, one has to generate one or multiple (reported in the same study) intermediary analogies that share features with both the problem and the original analogy, regardless of whether they may be dependent on mapping or discrete symbols or not. Although the author uses close-domain analogy in his studies, the bridging model can be applied to any domain when evaluating an analogy's relationship between a problem and an analogous case. It is claimed that many of the bridging analogy examples in this study are innovative and creative, and that the analogy is not retrieved from memory or past experiences; however, in his wheel problem case study, Clement used a small pool of participants, with a small range in participants' educational levels, thus making it difficult to deduct common credible patterns. The model also lacks a satisfying explanation for the usefulness of such transitive analogies. All of these models are creative and useful developments in analogy construction. Our work lies at the cross section of the methods discussed above, as we integrate the theoretical framework with the formal practice-based techniques. Overall, what remains unexplored in the previous research is the use of a developed set of visual analogies specifically for particular problem solving tasks to sort out how we can construct better and more effective analogies for learning and problem solving.

3.6 Applying Elements and Principles of Art and Design in Analogy-Making

Visual analogies support both problem solving and learning when they take the form of graphically displayed information about task characteristics and task execution. The elements and principles of art and design provide support for insight and creative problem solvers to create the meaning of their own from what created graphic material presents. A better visual display of analogy (Goldschmidt G. , 1995) leads to better performance by problem solvers. visual analogy application describes the process of capturing the relevant task information through the elements and principles of the graphic display (Samara, 2007; Saad & Silvanto, 2013) in a variety of media formats. An effective display of visual analogy should reflect the relationship between the source and target task characteristics (Gentner, 1989; Forceville, 2002; Barsalou & Wiemer-Hastings, 2005; Catrambone, Craig, & Nersessian, 2006; Christensen & Schunn, 2009), present them effectively and just-in-time (Schnotz & Grzondziel, 1999; Michas & Berry, 2000; Tversky, Morrison, & Betancourt, 2002; Wagner & Schnotz, 2017) to facilitate cognitive transfer (Duit, 1991; Casakin & Goldschmidt, 1999; Richland, Zur, & Holyoak, 2007) and optimise available working memory (Baddeley & Mehrabian, 1976; Paas, Renkl, & Sweller, 2003; Pan, Xu, & Soto, 2009).

Barsalou (1999) described a theory of perceptual symbols that may help in better visualising and producing dynamic simulations. The perceptual experience of the natural world, stored in our long term memory image schemas, is capable of representing abstract concepts at a skeletal level of aspects such as shapes of objects, structure of elements arrangements, spatial relationships between objects, and actions that transform these objects and their relations into new configurations over time. This human perceptual experience, captured through graphic symbols, can be integrated with visual analogy construction. Barsalou's model is based on two attentional assumptions which are contained in a perceptual symbol and which are captured in imagery. The first assumption is the selective attention that isolates the information in a perception and the second is storing this information in long term memory. For example, during a perceptual experience, one can focus on the shape of an object ignoring other objects' features or its relationship with the environment. Thus, it is very likely that a schematic representation of the object will be stored in long term memory. During our everyday experiences, large numbers of such schematic representations are stored in long term memory. These schematic representations can serve as essential symbolic functions for understanding, learning and decision-making.

Activated by external stimuli of an event or situation, the brain automatically selects the appropriate schematic representations from long term memory to form mental simulations that help us make sense of a particular event or situation, understand it, interpret it and make decisions relating to it. As noted by researchers such as Fauconnier & Turner (2002) and Langacker (1999), the perceptual symbol and cognitive linguistics share many common assumptions that are grounded in the experiential systems of the brain and body.

Perceptual symbols are similar to image schemas described in Lakoff and Johnson's embodied cognition theory (1999). Section 2.2.1.2 describes the embodied cognition theory and discusses the approaches and points of view of other researchers along with examples of the practical applications of image schema. Findings (Klatzky, Pellegrino, McCloskey, & Doherty, 1989; Decety & Ingvar, 1990; Hummel & Nadolski, 2002) suggest the inclusion of imagery of forces (kinetic), body motions and gestures (kinaesthetic) in the concept of symbolic schematic representation. Thus, we strongly believe that capturing in the visual analogy a recreation of an experience that at least resembles some aspects of a current perceptual or motor experience (i.e., visual hint – recreation of a past experience, problem solving – current experience) may be useful in insight and creative problem solving tasks. Furthermore, it is possible to conclude the accounts of this exploratory work to outline my proposed guidelines for how to develop effective visual analogies for insight and creative problems. Contrary to the views of cognitive linguists, some researchers (Ohlsson S. , 1999; Landau & Lehr, 2004) claim that Barsalou's theory (1999) offers nothing new, but is just a reformulation of tools and mechanisms derived from modern findings.

Because of rapid technological advancement, the digital display of imagery and representations has become a common media format. Computers can handle all kinds of media formats, from simple to sophisticated displays such as motion graphics, film, interactive video, and animation.

The significance of visual analogy delivered in a dynamic format is threefold: i) it serves as a hint for guiding attention; ii) once the attention has been directed to the main actions captured by the analogy, the assumption is that an association of the displayed visual analogy components with the target problem would be made, and iii) it initiates a response from the problem solver or creator. The recent literature findings suggest that the effectiveness of visual analogies in insight and creative problem solving tasks is subject to a strategic implementation of adequate visual elements and principles of art and design in their construction, along with other principles or analogies used in different domains. The mixed results of the effectiveness of dynamic media in learning and problem solving are described in Section 3.2. Castro-Alonso et al. (2018) claim that one of the reasons that such evidence is not conclusive in dynamic media research is that researchers manipulate too many effects of confounding variables in both static and dynamic visualisations (Lowe & Schnotz, 2014) in their experimental studies. Many of the published articles include several variables that do not match the information required for a static problem presented in a dynamic format or representations that are not delivered in the same mode (e.g., paper vs computer screen or monochrome vs colour) (Mayer R. E., 2003; Castro-Alonso, Ayres, & Paas, 2016). Tversky et al. (2002) suggested for an appropriate control of variables involved in static versus dynamic comparisons. Upon examining the issues in animation, they proposed two principles for making such dynamic visualisations effective: the *apprehension* and *congruence* principles. This means that the designer of visual material should also be knowledgeable about or aware of what information the visualisation has to convey before even considering these principles. According to researchers, they should carefully consider the *apprehension* principle and *congruence* principle while creating visualisations for conveying concepts, for learning, or in our case for visual analogy construction. Both these principles are described in detail in Chapter 3, Section 3.2 along with examples on how they are employed in creative practice.

These aspects of analogy construction and visualisation in relation to how people perceive them are important in any field that uses: information recording, support for off-loading memory, conveying concepts in visual material, learning enhancement, and promoting inference and creative thought.

4 Research Methodology and Methods Used

This chapter outlines the main methods used in this thesis, and the rationale for their selection. The main research question focuses on understanding how visual analogies that are able to facilitate the incubation effect in problem solving can be constructed.

4.1 Overview of the Methods Used

For this thesis, a mixed-method research approach has been used, triangulating practice-led with experimental research methods (Fielding, 2012). The reason for this choice is that the construction of visual analogies requires practice through, for example, drawing or animation, while testing their value to support insight problem solving is commonly achieved through experimental studies. In addition, by reflecting both on the process of generating analogies and on the experimental data, new insights have been gained into how the visual analogies can be further improved (Charmaz, 2006; Morgan, 2007).

The practice-led approach leverages the author's expertise as a fine artist to develop the visual analogies. For this project, this approach also included the collection of data on the practice of designing and developing visual analogies, as it unfolded over the duration of the PhD project. Most often, practitioners from the field of art and design aim to produce artefacts; however, creative processes are rarely documented in written words. This means that although the final artefacts may be publicly available, usually the creative process remains hidden. Documenting the practitioner's creative processes and reflecting on the artefacts produced can support an understanding of how such outcomes are generated.

The experimental approach has been chosen because of its ability to control for different variables, while allowing for accurate measurements. This, in turn, has allowed the identification of cause and effect relationships: which features or properties of visual analogies work best and which ones are less effective in supporting insight problem solving. The overall experimental approach consisted of five experimental studies which built upon each other and through which the visual analogies were developed, and continually revised in order to ensure an increased success rate in the ability of participants to solve two common visual insight problems. We now describe each of these two research methods in more depth, starting with the broader context of practice-based research for which we will focus specifically on practice-led research.

4.2 Practice-related Research

Research through professional practice is often called practice-based research or practitioner research. Over the last three decades, concepts underpinning practice-related research have become widespread in a variety of disciplines, yet, there are differences in its uses (Candy & Edmonds, 2018). Different terms, such as practice-based (Frayling, 1993; Candlin, 2000; Nelson R. , 2013), design-based (Schön, 1983; Barab & Squire, 2004), arts-based (Barone & Eisner, 1997; McNiff, 1998), arts-informed (Cole, Neilson, Knowles, & Luciani, 2004), practice-led (Mäkelä, 2007; Smith & Dean, 2009), studio-based (Stewart, 2001), artistic (Hannula, Suoranta, & Vadén, 2014), or applied (OECD, 2015; Krueger & Casey, 2014), have been used to refer to this type of research. While such concepts often tend to be used interchangeably, they have also given rise to an increasing debate about the role of the practitioner, the practitioner's creative processes and produced artefacts in research. For instance, Rust, Mottram and Till (2007) defined practitioner's research as:

> "research in which the professional and/or creative practices of art, design or architecture play an instrumental part in an inquiry".

This suggests that creative practice can be explicitly leveraged within research inquiry; however, they do not clarify the role of the artefact in this process. In fields such as engineering, design, or education, research involving practitioner's professional practice is often called applied research. The definition from the *Guidelines for collecting and reporting data on research and experimental development* from the OECD's Frascati Manual (2015) defines applied research as the "original investigation undertaken in order to acquire new knowledge …, directed towards a specific practical aim or objective". This definition also emphasises the value of practice, either as method or instrument, for exploring and answering research questions. Such definitions initiate a compelling discussion on the relationship between practice and research (Smith & Dean, 2009), professions and academia (Nelson R. , 2013). Practical material is noted as being used either as an instrument, device, or as an outcome of the research which, together with practitioner's creative processes, can be seen as the driving force behind the research. We now look at different types of practice-related research.

4.2.1 **Different Types of Practice-related Research**

Practitioners in art and design often imply that research is a fundamental part of their professional practice (Rust, Mottram, & Till, 2007; Hannula, Suoranta, & Vadén, 2014), which, in turn, supports the motivation for using practice within research. Describing different ways of thinking about research, Frayling (1993) identified three types of research: *for practice*, *through practice*, or *into practice*. In research *for practice*, the aim of the research is to serve practice; in research *through practice*, practice serves the purpose of the research; and research *into practice* aims to observe the working processes of others. We now describe each one in more detail.

Research *into practice* does not necessarily involve a researcher's practical competence, which is crucial for the other two types of research (Frayling, 1993; Mäkelä, 2007). Therefore, this type of research *into practice* can be conducted by a fellow non-practitioner researcher by observing, documenting and analysing practitioners' activities. While such research uses practitioners, along with their activities and artefacts for research purposes, the investigator plays the role of an outside observer (for example, as an art historian or curator), and does not apply his/her competence and practical expertise in the process of "the making and the products of making" (Mäkelä, 2007). In contrast with research *into practice*, both research *for practice* and *through practice* relate to a researcher's competence both as artist/practitioner and researcher (Frayling, (1993). Frequently, research *for practice* tends to be labelled as: artistic, design-based, arts-informed, arts-based, creative practice, studio-based or, more generally, practice-based research, while research *through practice* is labelled as practice-led, design-led, applied research or research-led practice (Candy & Edmonds, 2018; Smith & Dean, 2009). While research *for practice* emphasises the creative practice in itself along with the produced artworks and their aesthetic and artistic qualities, research *through practice* advocates a form of practical procedure that may lead artists/researchers to scientific understandings through the process of reflecting on their own creative processes and produced artefacts (Schön, 1983).

Several practice-based doctoral theses report that their created artworks are of high artistic value and that the body of produced artworks is their main academic contribution (Smith & Dean, 2009). For example, in the visual arts, most theses contain two main components: 1) a body of artworks of artistic or aesthetic value presented in the form of an exhibition, and 2) a critical explanation or interpretation of the study problem relevant directly to the artist practice and exhibited artwork. A contrasting perspective (Newbury, 1996; Scrivener & Chapman, 2004) claims that the creative processes, new techniques of producing artefacts, along with the produced artefacts, are the main contribution, where practice and the artefacts are used in the research as instruments. To differentiate them, Mäkelä (2007) highlighted the need to articulate the research methodology (Jones & Benachour, 2018). Based on its qualities, research *for practice*, which tackles the problem of artworks and their creation, is a form of practice-based research, while research *through practice* emphasises practice and its produced artefacts (Jones & Benachour, 2018). In an effort to bring clarity to the differences between these related concepts, Linda Candy (2006) categorised practice-related research into practice-based and practice-led:

1. If a creative artefact is the basis of the contribution to knowledge, the research is practice-based, and
2. If the research leads primarily to new understandings about practice, it is practice-led.

4.3 Practice-led Research

Previous work has shown that in practice-led research (Candy, 2006; Mäkelä, 2007; Smith & Dean, 2009), the practitioner/researcher can explore research problems through his own practice and created artefacts. According to Charmaz (2006), this approach is concerned with the nature of practice in order to gain new knowledge. Thus, a practitioner's activity in the context of academic research can generate new knowledge. Three main elements of the practice-led approach can contribute to this new knowledge: the practitioner's expertise, creative processes, and the artefact created to be used in the research.

The primary focus of this method is to advance knowledge about *practice* or *operational* significance within that practice. Compared to other practice-related research, the results of practice-led research may be in the form of a text description, often without the inclusion of the creative outcome (Candy, 2006). Practice is an integral part of this method and falls within the general area of action research (Candy, 2006; McNiff, 1998). The body of work produced by practice-led research is not the same as practice-based research, as the latter includes aesthetic or artistic works, but rather, uses artefacts as the material for investigating new processes within the practice (Smith & Dean, 2009). The creative process and the artefact are inseparable in practice-led research. While the artefact serves as a testing object for an assumptive theory or a method for collecting and preserving information, the making of the artefact drives the direction of the research process (Candy, 2006; Mäkelä, 2007). According to Scrivener & Chapman (2004), the understanding of creative processes during artefact creation and the artefact itself also represent a body of knowledge.

4.3.1 **Practice-led Research in Other Disciplines**

The practice-led research method is not new. Fields such as psychology and counselling, health care, pharmacology, nursing and education all adopted this type of research much earlier than art and design (Green, 2007; Houser & Bokovoy, 2006). Most definitions of practice-led research in these fields share similar characteristics as:

> "science-based inquiry that occurs in practice setting…, systematic reflection on the practice experience, and laboratory analysis – to the extent that such inquiry produces generalizable knowledge to improve the outcomes of practice or to inform policy making" (Potter, et al., 2006, p. 3).

While experimental research focuses on testing hypotheses, practice-led research focuses on how the practice operates in its real-life settings, positioning the practitioner researcher as a critical thinker (Houser & Bokovoy, 2006).

The reason we employed a practice-led approach is due to its potential to leverage creative artefacts as core research outputs (Biggs, 2007). Designers and artists show an increased ability to give form to design or artefact ideas through sketching and drawing (Goel, 1995). The goal in using the practice-led method in this research is to explore ways of creating visual analogies that are capable of supporting the incubation effect in the problem solving process, and this approach seems the most appropriate. In contrast to a practice-based method where the artwork is considered the key academic contribution, here, the practitioner's process and created artefact helps the scientific inquiry into how visual analogies for problem solving should be constructed.

The method for generating and revising the visual analogies was iterative. It started with an initial exploration to understand the problem, and was followed by generating, creating and revising the visual analogies. The practice-led method allows the practitioner to explore different qualities or elements of the visual analogies which help uncover the "possible" variables and relationships between them that may be studied quantitatively (Kroll, Neri, & Miller, 2005). The practice of generating artefacts provides an opportunity to manipulate such elements in different formats such as 2D, 3D, or animation.

4.3.2 Documentation

While some previous work has shown that practical knowledge and artefacts may be communicated through writing (Candy, 2006; Klein, 2010), other scholars (Goel, 1995; Mäkelä, 2007; Niedderer & Roworth-Stokes, 2007) have argued that knowledge is embodied in the artwork/artefact itself. We argue for the value of the former, and the documentation process in the practice-led research approach followed in this thesis consisted of three key activities: 1) generation of visual analogies consisting of ideation, sketching and developing complete illustrations or animations, 2) capture of and reflection on the process of generating visual analogies, 3) expert selection of the most promising analogies to be revised, refined, and tested.

4.3.2.1 Diary Method for Capturing the Generation of Visual Analogies and for Reflecting on this Generation Process

We employed diary methods for collecting data on the researcher's/artist's process of generating visual analogies. From the beginning of this research, I was meticulous in documenting each action in the visual analogy development process.

The first notes were related to the earliest stage of designing visual analogies, in particular, to the mental phase, conceptual planning and the intended use of mechanisms that initialise the flow of the design process. These notes were taken no later than the end of the day in which the new visual analogies were conceptualised. Reading and reflecting on these notes helped us to identify the problems and the relevant features of visual analogies, which could be manipulated and could subsequently impact on the success rate for solving these problems. Also, reading and the analogy-making process in the generation stage of visual analogies for problem solving captured in these diaries were the main drivers of the direction of this research.
These diaries are included in the materials/stimuli subsection of the method section for each experiment along with the produced sketches.

The second types of notes consisted of structured questions (Appendix 14-12) for which the researcher/artist completed a diary entry of each developed sketch of a visual analogy. The questions were informed by the literature on creative processes. The diaries were completed with written statements on the practitioner's first-person experience of his creative process, notes on the evaluation process, as well as ideas, feelings, or preferences for shapes or forms (e.g., Appendix 14-13).

Post hoc diary entries were used, as soon as possible after a sketch was generated (i.e., no later than an hour), in order to avoid the overshadowing effect (Schooler, Ohlsson, & Brooks, 1993) of completing the diary during the sketching process. Thus, this approach facilitated reflection-on-action rather than reflection-in-action (Schön, 1983). The data gathered through this diary method consisted of over 22 entries, and over 10,000 words. The analysis of this data was used to shed light on how the visual analogy concepts were generated.

For analysis of data collected using this method, we used "HyperRESEARCH" (ResearchWare, Inc., 1997-2012) software for coding the text in the notes and preparing the data for qualitative analysis; in addition, a theoretical sampling technique was used to generate categories of collected data (Charmaz, 2006). Theoretical sampling narrows down the emerging categories, and by filling out the properties of a category, the researcher can create analytic definitions and rules for that category, describe and explain it, and specify the links and relationships between other categories and subcategories.

In order to account for my own identity in the description and analysis of my reflection-on-action practice, I need to make explicit my own expertise and values through a brief self-identity audit (Tracy, 2012). I have a background in fine arts in the areas of movie stage design, painting, graphics and computer arts, and have worked as an artist painter (Luchian, 2012) for over 30 years, and as an art educator in US higher education for over 14 years.

4.3.2.2 **Expert Selection of Most Promising Analogies**

Once a reasonably sized pool of visual analogies was generated, an expert evaluation method was employed (described in detail in the *Preselecting Analogical Concepts* of the *Stimuli* subsection in the *Materials* sections for each experiment) to select the most promising visual analogies for further development and testing through experimental studies. Such a selection method was followed by a refining the selected analogies stage and a pilot study to test how the identified analogies are perceived by a small group of participants.

4.4 Experimental Method

An experimental method is commonly used to test the impact of analogies on insight problem solving. An experimental method follows a fixed documented procedure offering the advantage of being easily replicated by other researchers. Indeed, this thesis builds strongly on such previous work by replacing the experimental study testing the impact of analogies on the *8-coin* insight problem solving, and their generalization to solving the *cheap necklace* problem. The value of analogies for solving these two insight problems has been previously explored. For instance, (Ormerod, MacGregor, & Chronicle, 2002; Fioratou, 2005) used both verbal and visual hints.

Experimental studies allow for hypotheses testing and for controlling variables, particularly extraneous ones. Indeed, in an experimental study, a researcher has one or more hypotheses, which are being tested by methodically changing the conditions of independent variables (IVs) and by measuring their impact on dependent variables (DVs). We used the experimental method to test the effectiveness of constructed analogies for five laboratory studies. Another reason for using the experimental method is that visual material is fluid and its visual elements can be manipulated and integrated into variables which can be tested experimentally. Thus, the strength of the experimental method resides in the flexibility to manipulate and the control over the independent and extraneous variables in the experiment, which helps the researcher to explore causal relationships, while allowing for replication.

The analysis of experimental data involved descriptive statistics, and inferential ones, such as mixed-factorial analysis of variance (ANOVA), and was conducted in SPSS Statistics software; it is described in detail in each experiment.

Additional data such as demographics, visual style, preferences on visual elements, visual analogy helpfulness, number of attempts made to solve the problem, and feelings of warmth self-ratings were also gathered to improve the quality of each constructed analogy. The results from the additional data are discussed and reported in the General Discussion (Chapter 11) of this thesis in the context of the whole body of work.

Ethics: Over 540 undergraduate and postgraduate students from Lancaster University, UK, and Arizona State University, USA, participated in five experiments designed to test the effects of the developed visual analogies in the problem solving processes. All experiments received Institutional Ethics approval, and all participants consented to participate voluntarily in the experiments.

Limitations: Because experimental research seeks the objective view of participants and practice-led research seeks the subjective view of the artist/researcher, replication of the latter may be problematic. For example, there is no guarantee that a later researcher trying to replicate the study will be able to generate the same number and quality of visual analogy concepts. However, the rigour of the experimental method employed to test the visual material produced is replicable; this is evidenced by the fact that previous experimental designs of the *8-coin* and *cheap necklace* problems were replicated. In addition, many researchers stated that a mixed-method type of design provides the most accurate interpretation (Tashakkori & Teddlie, 2008; Creswell & Creswell, 2017).

5 Depth and Problem Insights Representation in Visual Analogy

This chapter describes the first of a series of five experiments, which begins to investigate visual analogies as support for insight problem solving and their role in analogical reasoning. The main aim of the research is to identify appropriate elements, mechanisms, and tools that lead to the construction of useful analogies. The first experiment is a partial replication of Ormerod et al.'s (2002) study which investigated insight performance in the *8-coin* problem, providing participants with verbal hints.

To test our constructed visual analogies as hints for insight problems, we used the same *8-coin* problem, choosing the most difficult initial stimulus configuration for the coins from Ormerod et al.'s (2002) Experiment 1 which had generated only 6 out of 14 correct solutions after the verbal 3D hint. A similar procedure was used in both in terms of instruction and timing, except that we developed and provided visual analogies printed on paper as hints to the *8-coin* problem.

The reason for choosing to use the most difficult initial configuration (see the configuration from Tight/Move Avaible condition from Table 1) from Ormerod et al.'s (2002) experiment is that our focus is on visual analogies development. We create visual analogies, then consistently test and evaluate them to determine which ones work and why, and our study's focus is not on the type of effect of the initial configuration on participants' performance. Thus, we replaced the verbal hints for grouping and stacking insights with the developed visual analogies that are described in the materials section.

The reason for the replication is twofold: no image-based visual analogies have been used for this problem, and it involves a small set of identical items, i.e. coins, which can be consistently mapped.

5.1 Chapter Overview

This chapter begins with a description of the experiment using visual analogies as hints in the insight *8-coin* problem solving. It also presents the preliminary work to construct a set of more than ten visual analogies, some in a few variations, and evaluates their impact on solving the *8-coin* problem.

Findings suggest that in visual analogies, the insight hints are the most beneficial ones, especially when integrated, and that depth cues are essential surface aspects in facilitating an incubation effect. Our findings support the facilitative cue theory and replicate previous outcomes on the importance of impasse experience as a prerequisite for analogical transfer.

5.1.1 **Experiment 1: Rationale and Research Questions**

Much research has focused on the impact of analogies in insight problem solving, but less work has investigated how the visual analogies for insight are being constructed. Thus, it appears that in the search for their facilitative impact on the incubation effect, the understanding of what makes good visual analogies has somehow been lost.

We argue that a systematic construction and rigorous evaluation of a series of visual analogies within the same experimental design can offer a different perspective in the study of visual insight. The chapter presents an initial empirical study which aims to address the following research questions:

- What aspects of the visual analogies are most relevant for incubation effect in visual insight problems?
- How can the surface and structural aspects of visual material be represented in visual analogies?

5.2 Method

This section offers a description of participants, physical materials, including the construction of visual analogies, and experimental design following the procedure.

5.2.1 **Participants**

A total of 66 undergraduate and postgraduate students were enrolled in the study. They were all from Lancaster University, and the overall sample consisted of 40 (60%) males and 26 (40%) females with a median age of 24. Over 75% of them were between 21 and 30 years of age.

5.2.2 **Materials**

In this section, we describe the physical materials and the visual analogies that were provided as hints, along with the process of developing and selecting them for the *8-coin* problem solving.

5.2.2.1 Stimuli - Development of Visual Analogies

This section offers a description of the construction of the visual analogies together with a reflection on the developed artefacts. The following subsection focuses on the experimental study for comparing and evaluating the visual analogies. The process of constructing the visual analogies for this experimental study has been a lengthy and iterative one, involving over ten concept sketches of hints. An important aspect in developing the hints for the *8-coin* problem was identifying the relevant features, which could be manipulated and subsequently expected to impact on the success rate for solving this problem.

The process of designing a concept or a product involves a mental phase followed by a form creation phase. The critical aspect of the mental phase (Johnson M. , 1987) is the search process where the thinker sets a goal to find a mental representation of how to solve a problem.

The strategies guiding the search for such representations involve the use of external aids and recall of internal memory aids. External representations such as sketches serve not only as memory aids, but they also facilitate (Kristensen, 1999; Larkin & Simon, 1987; Kosslyn, 2006; Do & Gross, 1996; Goldschmidt G. , 1991) and constrain inference (Tversky B. , 1999), understanding (Casakin & Goldschmidt, 1999; Cheng & Lane-Cumming, 2004) and problem solving (Dominowski & Dallob, 1995; Clement J. J., 2008).

Initial Ideation

In practice-based fields like industrial and interior design, architecture, painting, sculpture, and graphics, the conceptual planning is considered the earliest stage of design. A schematic description of a mechanism initialises the flow of the design process. The following brainstorming techniques and sketching processes were used in generating concepts for this experiment:

- Understanding of the problem and generating mental images (as we all do before proceeding to plan anything on paper)
- Looking for inspiration
- Designer's methods
- Associations arising from similarities with previous experiences
- Themes and subjects related to the problem

- First ideas that come to mind when applying imagination and intuition
- Processes of transferring mental images into sketches
- Coordinating mapping of mental images with the actual drawings, changes and additions
- Evaluating and reflecting on the outcome
- Making changes and re-evaluating the drawings
- Polishing the drawings for experimental study

The Generation of Visual Analogies

The generation process started with thoughts about scenarios underlined by a similar structure of a source-target for the *8-coin* problem. The critical issue here was to identify analogies that present easy to understand situations, i.e., configurations of items or entities which limit irrelevant information.

Here we applied the principle of *one-to-one* mapping (Gentner, 1983), and the spatial scale concept proposed by Montello (1993).

Broader Exploration of Visual Analogies through Sketching

This section offers reflective diaries on the large number of generated sketches in order to decide which to implement as per the principles outlined in the previous section.

The first idea consisted of a triangular pyramid: a three-point triangular base that connects its perimeter with the fourth point above. This was inspired by the value of a point, which through its material geometric form, marks the location of things in space and, according to Kandinsky (1979), "belongs to the signs and writings and signifies silence". No matter how much we increase its size, in relation to other shapes of larger dimensions (i.e. a circle or a sphere), it would be viewed and interpreted as a point by the majority. It was felt that the point would be taken as a whole unit of the coin in the problem solving experiment.

Arranging the points in the same structural aspect as the target seemed to offer a good hint to finding the solution, indicating that the 2D hints might work well. The reflection on the structure led to the realisation that connecting the points that represent the structural aspect of each whole would create a triangular shape that might confuse the solvers. Sketching encourages a multitude of interpretations and reinterpretations (Suwa & Tversky, 1997), so projecting the triangular pyramid from the top view is seen as a perfect triangle divided into three equal parts (Table 2) creating the ambiguity.

Also, the real coins are of hexagonal shapes and looking at the drawing hint as a whole object.

Table 2 Pyramid concept (from above)

This suggests little of the structural aspect of the target arrangement or the number of the coins in the problem. The other weakness of this concept is the ambiguity of objects composition in a psychological space. By how the objects are represented in the sketch, this representation cannot be classified either as *figural*, *vista* or an instance of *pictorial space* capturing the information of a *geographical space* (Montello, 1993).

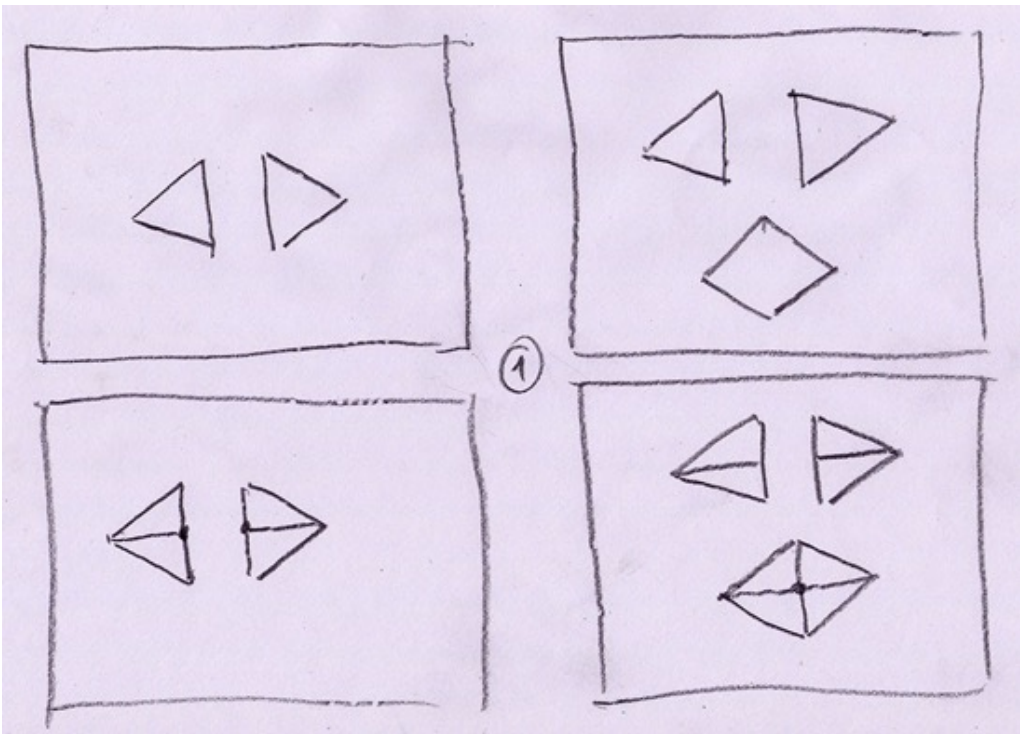


Figure 5.1 The triangle

The idea of representing the unity of coins through geometrical points and connecting them through lines was dropped as it might direct participants down the wrong path in terms of structuring the problem. In this case, taking into account the structural aspect of *one-to-one* object mapping (triangle) and *one-to-one* object parts mapping (e.g., corner point) in the sketch-target was found to be somewhat challenging in terms of matching the arrangement of coins in two separate groups. The elements had to be presented in both 2D and 3D views to fulfil the intended experimental conditions.

In order to create compelling, less ambiguous hints, the decision was made to return all drawings to their basic geometrical shapes like rectangles, squares, pentagons, hexagons and octagons that could be extruded and represented in a 3D form while recognising their 2D primitive base. For the second set of hints, the square was chosen (Figure 5.2) as a 2D representation of the unit, and the cube as a 3D extruded square that would match the mapping of the elements from the source to the target configuration.

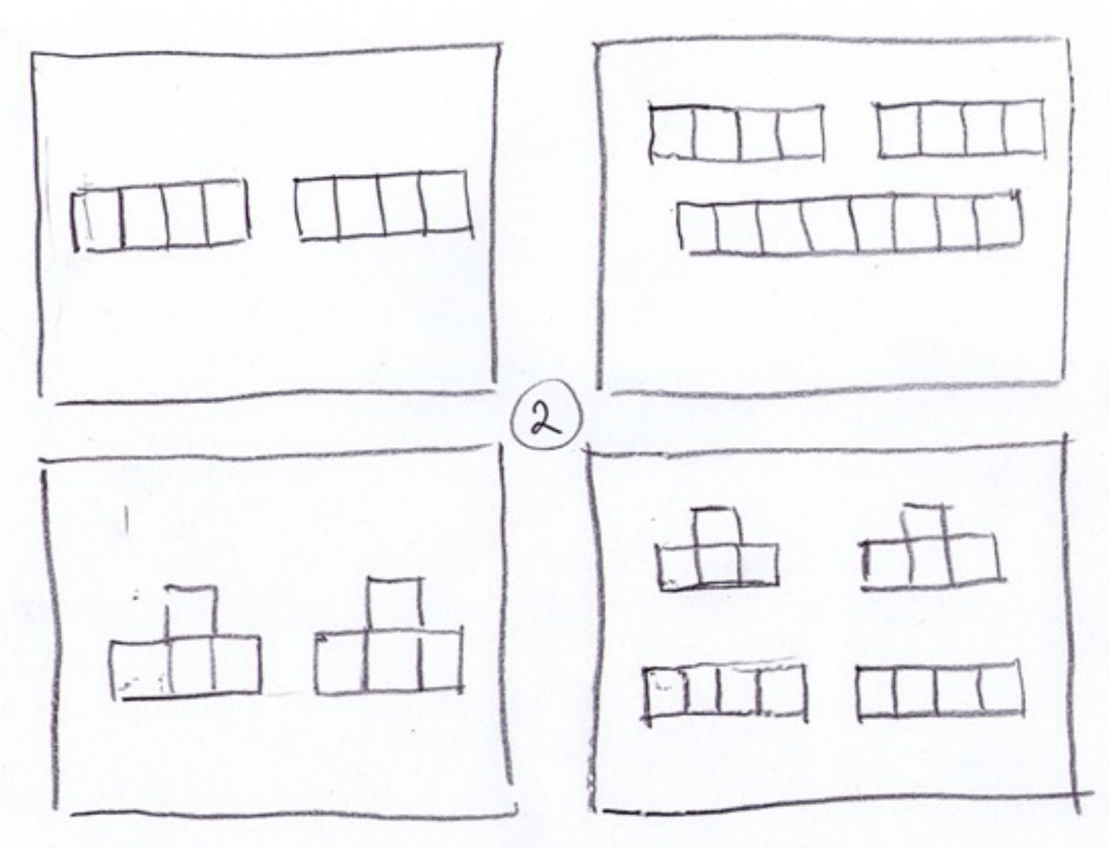


Figure 5.2 The square

The images from the upper part of Figure 5.2 illustrate the grouping (splitting) hints for the *8-coin* problem. The representation incorporates the same number of units, (e.g., 8) and two groups (splitting) of four units capturing the grouping hint. The elements are shown from a frontal view aligned on a horizontal line. Compared to the pyramid concept (Table 2), here, the composition (positive and negative space relationship) suggests a *figural space* that is perceptual and more familiar to the human eye.

The stacking hint for the 2D experimental condition was represented with the same consistency as in the grouping hint design and consisted of flat square shapes (Figure 5.2 – bottom row), with three squares aligned symmetrically and the fourth square on top. We used the same similarities of structural mapping as for the grouping hint. Even though geometrical sketches or diagrams convey abstract concepts, they guide solvers to look for visual inference paths (Gelernter, 1959), facilitate the retrieval of perceptual-chunks and provide visual hints for extracting new chunks for future use (Suwa & Motoda, 1994), and constantly refining and revising them (Goldschmidt G. , 1991) by giving access to new mental images and ideas; consequently, I came up with the hexagon idea.

The hexagon shape was dropped very quickly after we realised that we were using hexagonal coins too, so that mapping 100% of the elements of the source with the elements of the target would instruct the subjects on how to solve the problem and moreover would show them the final solution. This reflects an important tension in constructing the hints: providing enough information to facilitate insight but not too much to deliver it straight away.

Car tyres (Figure 5.3) came to mind when I was looking out of a window at a car shop across the street, and a mechanic was changing the tyres on a vehicle. Seeing him throw one tyre on top of a pile of old ones, I thought that this would be a worthwhile theme to explore. I took a pencil and started sketching my ideas, placing the tyres close to the coin arrangement. We often see tyres left on roadsides, and the road could be used in the problem as a splitting hint. The shop itself seemed irrelevant to the problem, so instead, I was attracted to the mechanic's actions performed earlier; it was more important, in the future analogy, to capture the action of lifting a tyre up and putting it on top of others. Tyres are as round as the coins, and in the analogical image, they could be arranged in different configurations and the same number of items and the actions could be used; thus, the movement of the human body on the surface could be simulated, as could lifting up and dropping down to capture the grouping and stacking hints. All four versions of the sketches offer some indication of searches for new ideas on this subject. The man and the moving of tyres from the vehicle are instruments suggesting the actions in the analogy. We expect that the viewer's attention will be focused on objects and characters that share features with the target such as arrangement, number, form, the road as a dividing symbol, and the human as the instrument by which the layout of space is transformed.

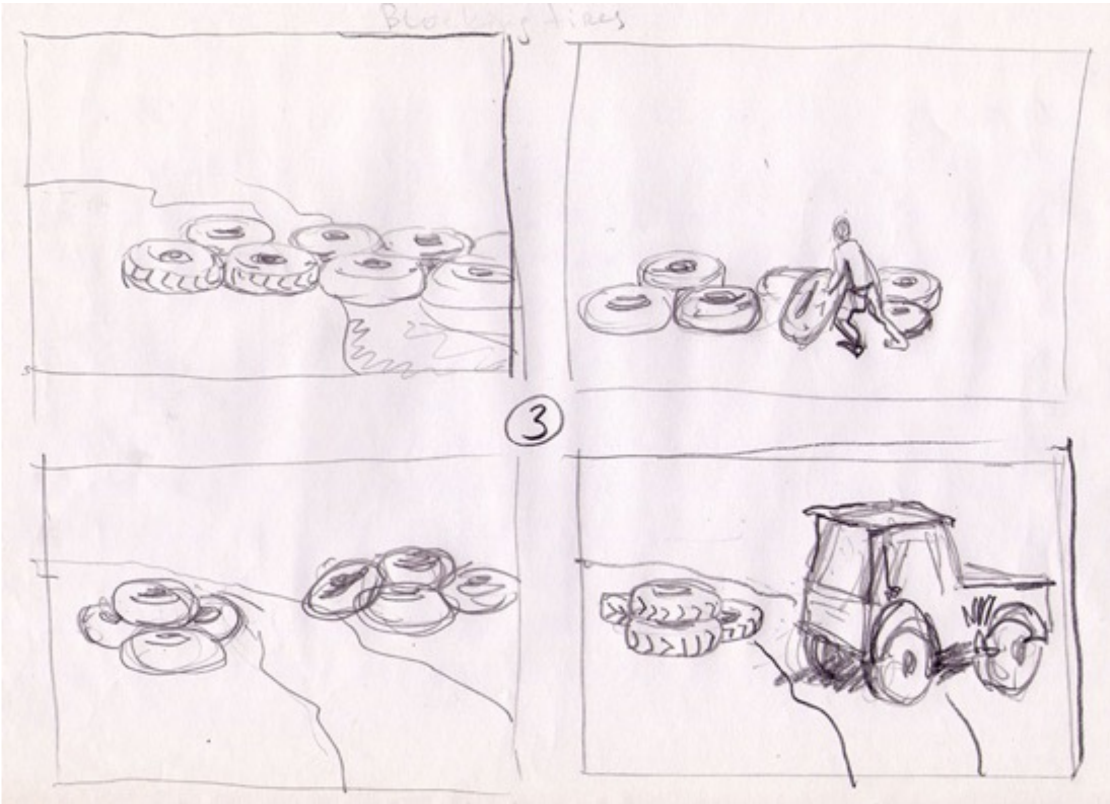


Figure 5.3 Car tyres

The compositional choice for this sketch suggests a *vista psychological space* (Montello, 1993) that is projected so that it is larger than the human body and surrounds it and can be apprehended by acquiring the information over periods of time without significant locomotion.

Specifically, a natural and familiar scene depicted in such a layout with its compositional structure directed to expand the visual field (e.g., through use of background and objects in the middle field) might focus visual attention towards these objects and actors for selection, relationship recognition and control of action (Chun &

Jiang, 1998). The road divides an area in two and thus, might suggest separating the initial configurations of coins into two groups.

After passing by a flower shop on a daily basis, I noticed that the merchants changed the outdoor displays very frequently. After observing one of the workers arranging the displays for about an hour, I became aware of the limited space they had, and this meant that the shop worker had to be meticulous about thinking how to use the space to fit in all the flowers for sale each day. Selecting the best-looking flowers and creating a harmonious arrangement were his main aims at that time.

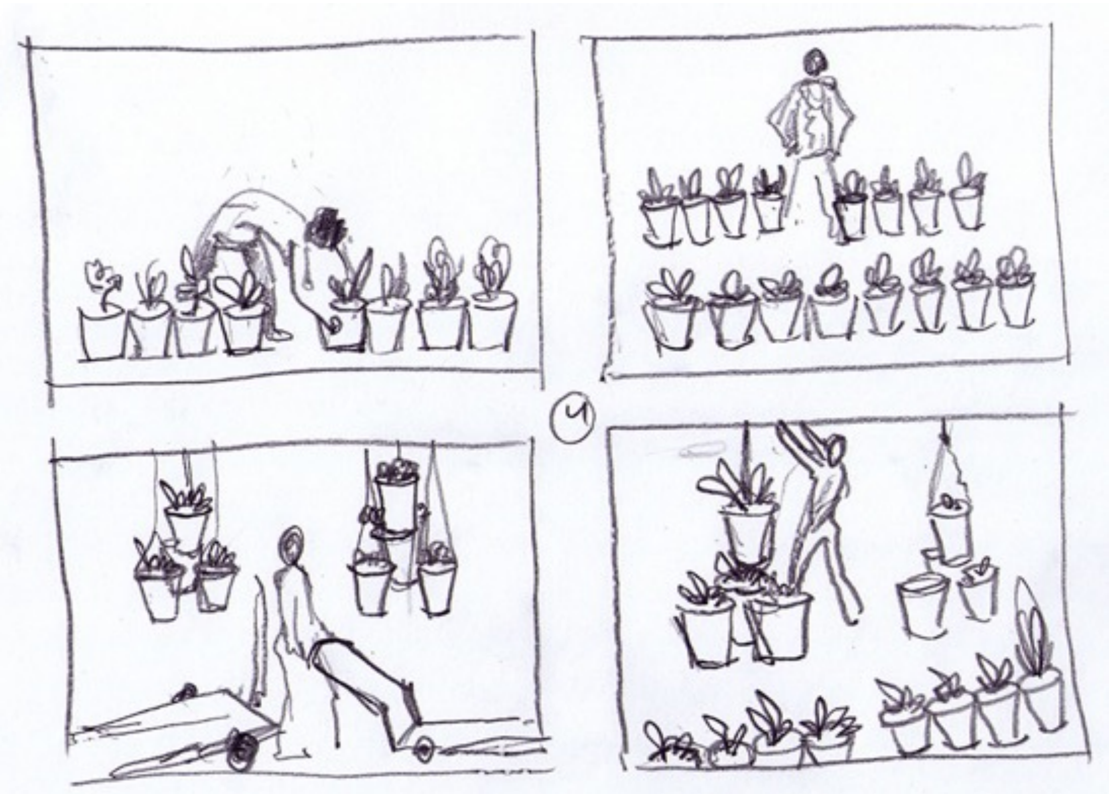


Figure 5.4 Flower arrangement (Version 1)

We have the same kinds of tasks when constructing visual analogies for the *8-coin* problem and representing it visually. In fact, this is a continuous process to direct attention towards a limited set of things and events (Eriksen & Yeh, 1985; Treisman & Gelade, 1980) in such a way that the content of the created image and its compositionality facilitate the deployment of attention and the observer's behaviour.

After we extended the design upward, by placing some pots on top of others, some hanging by wires from the terrace ceiling, some suspended from the interior ceiling, we considered that this situation was a good solution for our problem too. One hour of observation and doodling at the flower shop gave me enough ideas to explore this theme as a potential visual analogy.

A couple of sets of sketches were generated, and two versions of this idea are shown in Figure 5.4 and Figure 5.5, where the actions of grouping, lifting and dropping on top are captured through the actors and objects in the composition.

Figure 5.5 Flower arrangement (Version 2)

Naturalistic images (the ones on which I base my searches) could be extended to spatially continuous stimuli (Wolfe, 1994) where the source location is more likely to correspond to the elements, relationships or actions of interest in the target location. Analogies can be encountered in daily life surroundings and situations. Figure 5.6 captures a kitchen scenario with an arrangement of plates. The plates are similar in shape to the coins, and similar in their flatness.

They could be manipulated as a number, could be laid out on a flat surface (table with the coins on it), could be haptically manipulated, put on top of each other and could suggest grouping through the cabinet drawers.

The whole scene is depicted and classified as a *figural psychological space* where no considerable movement of the entire body is required (Montello, 1993), thus, all the source correspondences could be captured in the image.

The inspiration for the concept with the chairs in Figure 5.7 came to me after I attended a meeting. A custodian had started to rearrange an untidy room that had been left by the attendees. She quickly moved all the chairs to the side of the room, cleaned the floor, and then arranged the chairs neatly into two groups, leaving a space between them to allow people to walk through. Every now and then, she lifted a chair that was touching the side walls and dropped it on top of another chair from the same row to make space and clean the area underneath.

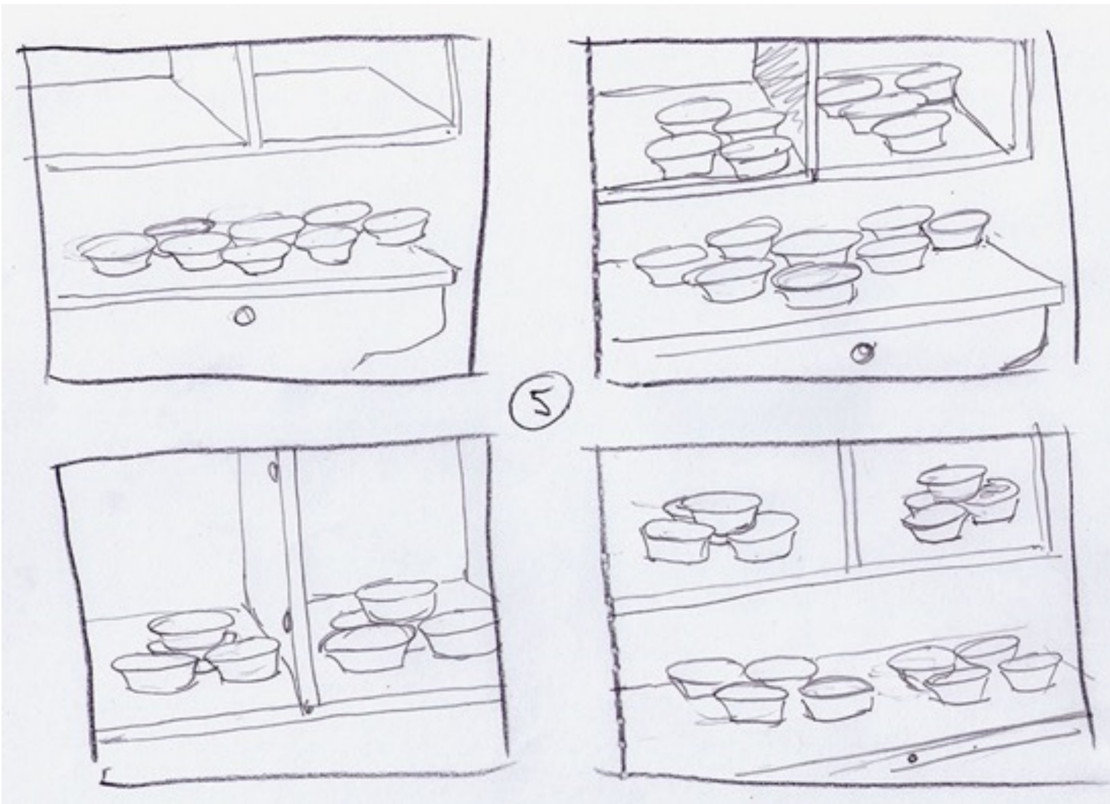


Figure 5.6 Washing dishes

In these sketches, I decided to try neglecting the similarities in shape and form, looking at the chair as a whole unit. The custodian's actions seemed more important than the resemblance of object forms with the coins.

The lower right version from the sketch in Figure 5.7 was generated spontaneously, using the form decomposition and reconstruction method that might lead to new ideas for this theme. An effective facilitation by a natural room arrangement comes from interacting with the objects and cognitive processes of interpreting it (Miyake & Hatano, 1991). So, attempting to depict the spatial properties of the room and what took place in it in a 2D picture is a difficult task. Scanning the room can be done only when you are in a natural space, and obtaining more information about that space one needs to move and see it from different angles.

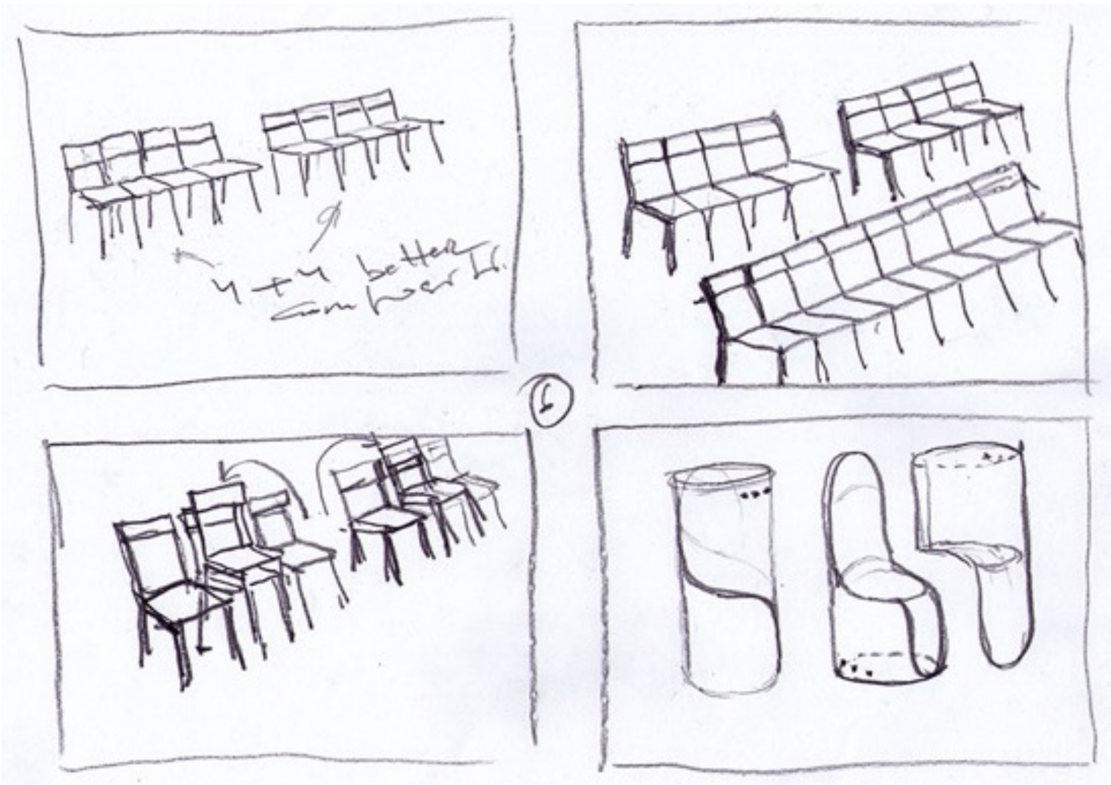


Figure 5.7 Chairs

Nevertheless, the produced image does capture the properties of the room from one point of view only. Also, capturing only the hints for the layout, splitting and stacking actions, by ignoring the structural mapping of shapes and forms of objects between the source and target, might generate multiple interpretations, mostly biased, according to individuals' past experiences and knowledge. However, our focus is primarily on investigating how to construct effective visual analogies for problem solving and less on individuals' performances.

Another idea for a possible visual analogy (Figure 5.8) to use in the *8-coin* problem came about one evening, as I prepared a salad for dinner. Cutting a piece of cucumber directed my attention to the similarities in shape and form and the ability to touch and manipulate the round pieces as easily as the coins. Both the source problem and the target solution and their objects and relationships belong to the *figural psychological space*, and this allows the participant to relate and map the involved objects and relationships in a more familiar way than in the previous concept with chairs from Figure 5.7. Here, the arrangement can be designed to fit the requirements for visual cueing, as well suggesting through the implicit instruments the actions which need to be performed.

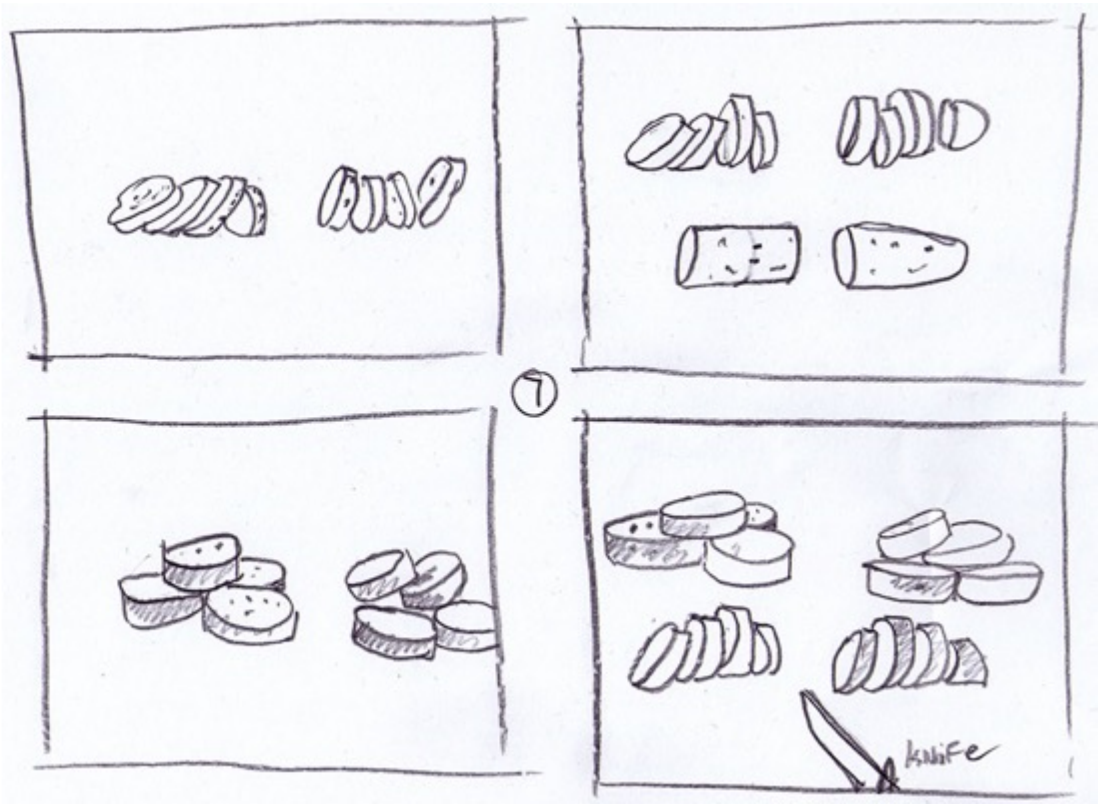


Figure 5.8 Cutting cucumbers

The next sketch representing a potential analogy to the *8-coin* problem captures the growth of four-petal flowers in wooden boxes (Figure 5.9). The soiled top box from the left column was intended to capture the splitting hint for the *8-coin* problem and the one from the bottom to capture splitting and stacking insights. The right column versions were intended for the same hints, but include the additional process insight as an independent variable in the experiment. All the objects used in this concept are in the *figural space*, and you can touch and examine them; only the boxes can be moved, not the petals. On the other hand, the design of flower petals might offer a powerful insight into the problem solution.

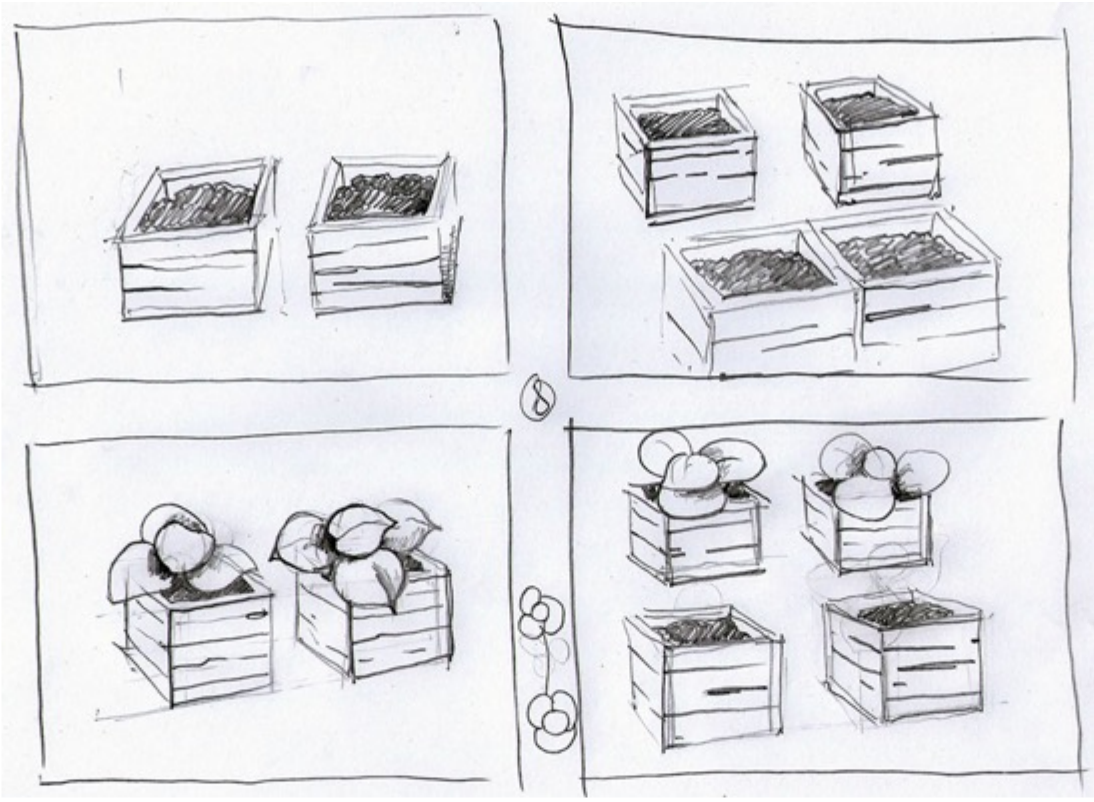


Figure 5.9 Flower pots

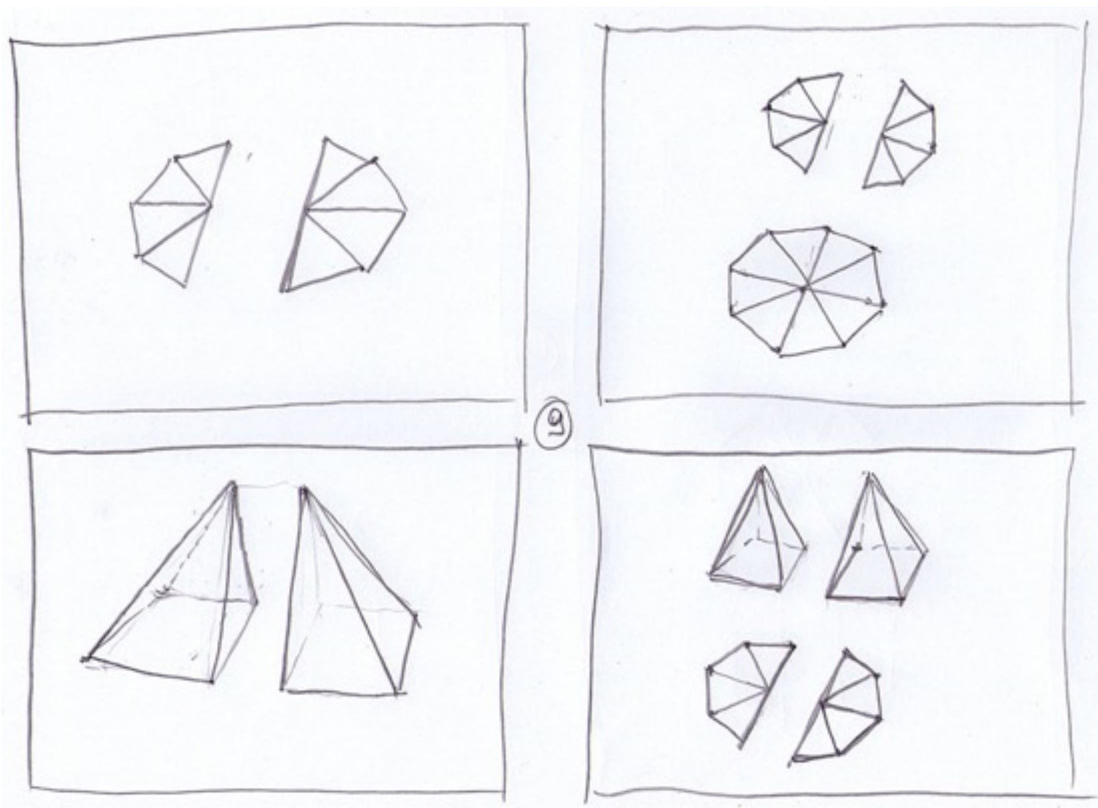


Figure 5.10 Octagon decomposition

Figure 5.10, shows the kind of sketch produced when I was less engaged directly with the insight problem. Instead, I am using the search for new ideas by playing with the decomposition of form and recomposing it from its chunks in a different way; this is a very useful technique in the fields of ceramics, sculpture and architectural.

The sketch of the irregular pyramid gave birth to a new idea of extending the search to the construction domain (Figure 5.11). The bricklayer manipulates bricks just as the problem solver handles the coins. Even though there are many metaphorical similarities in the source and the target, it is difficult to represent their best correspondences.

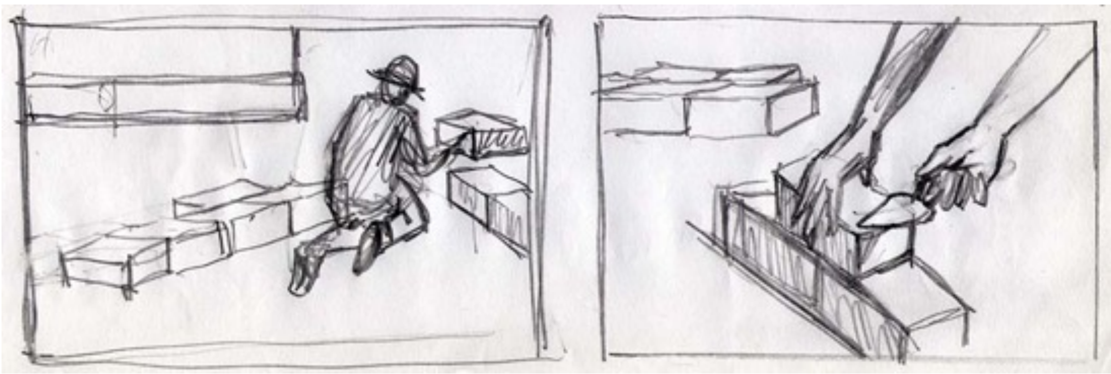


Figure 5.11 Laying bricks

Preselecting Analogical Concepts

The ten sets of concepts generated for visual analogies (Figure 5.1 - Figure 5.11) for the *8-coin* problem were assessed by three experts (Appendix 14-2 – 1, 3 & 4) in visual analogies who were familiar with the Ormerod et al. (2002) study and the *8-coin* problem by employing the expert examination technique. The preliminary experimental design was submitted for evaluation along with these sets of sketches and diary notes. Two concepts were chosen: "The Square" (Figure 5.2) and "Cutting Cucumbers" (Figure 5.8) as the best candidates for the experiment. A decision was made to adapt and implement the elements from these two concepts for the experimental conditions for the presented design.

Implementation

In the construction of the analogies, we employed a distinction between their surface and structural aspects, as well as the two principles from Gentner's (1983) structure-mapping theory. Figure 5.12 captures the unique problem solution, while Table 3 presents an overview of the created visual analogies, which are further discussed.

The *surface aspects* of the problem relevant to representation include the physical artefacts (coins) and their attributes such as number (8), shape (hexagonal), and colour (grey); their spatial organisation (topology), and the perspective from which they can be seen (above). Among these aspects, we decided to discard the less salient ones such as shape and colour while including in the analogy the number of objects and their spatial relationships.

Figure 5.12 8-coin problem solution

With respect to the artefact representation, we introduced an additional surface aspect, i.e. depth. The rationale for this choice is twofold: (i) findings suggest that depth cues can improve object recognition within pictures (Biederman, Mezzanotte, & Rabinowitz, 1982) and (ii) solving the *8-coin* problem involves physical manipulations of coins and, therefore, their pictorial and abstract representations may be better recognised when offered in 3D rather than 2D.

Additionally, although designers often appear to draw 3D sketches (Do & Gross, 1996) and arguably may benefit from 3D hints, there has been limited work on the role of depth cues in visual analogies. For example, in a study focused on the role of visual analogies for creative design problems, Casakin and Goldschmidt (1999) use both 2D and 3D representational images as visual hints. Unfortunately, the findings do not report the different impact these two sets of hints have on the performance scores.

In order to account for the considered surface aspects, we constructed three types of analogies: abstract 2D, abstract 3D and representational 3D.

At this stage, it is necessary to disambiguate the meaning of 3D hints. Throughout this study, the 3D hints are the ones which involve cast shadows and perspective, as opposed to those that suggest stacking, and which in Ormerod et al.'s paper (2002) were referred to as 3D hints. The latter hints were used with the aim of supporting the solver in moving from the unsuccessful attempts to solve the problem in 2D, towards considering the problem in 3D by placing one coin on top of others. In the experiment, these hints are called stacking hints.

The 2D analogies have surface similarities with the problem such as identical elements (squares), an identical number of elements (two groups of four items each), and their spatial organisation (elements in an array on a flat surface). The different shape of the element (square rather than hexagon) and their placement in a straight-line position are *alignable* differences.

The 3D analogies have the same surface similarities for the problem as the 2D ones except that the elements are cubes. The different shapes and colours of the items as well as their placement in a straight-line position are *alignable* differences.

Representational 3D analogies are pictorial representations of everyday objects, which share the same surface similarities of the problem as the abstract analogies. Slices of cut cucumber, which are similar to the shape and form of the coins, placed in groups and stacked on each other, offer stronger surface similarities than the abstract analogies. The different colour is an *alignable* difference. For both abstract and representational 3D hints, the depth was suggested through cast shadows and perspective. In order to test the role of depth in visual analogies, we formulated the *depth hypothesis*: the 3D representations support better incubation effect than 2D ones.

The developed analogies are consistent with the *structural consistency* principle involving *one-to-one* mapping between each part of the target and each part of the source, as well as between each of these parts' attributes.

The *structural aspects* of the problem include the primary and secondary insights, i.e. the verbal hints in Ormerod's experiments (2002). Thus, the concepts of grouping and stacking were visually represented through spatial configurations such as two groups of four items each (for the **grouping** hint), and groups of four elements with three on the base and one on top (for the **stacking** hint).

There appears to be a temporal dependency between these structural aspects so that one has to perform grouping before the primary insight of stacking can be reached.

This interdependency is captured in Ormerod et al.'s (2002) study through the order in which hints are provided, i.e. grouping hint followed by the stacking hint.

We kept the same order of hints, but the stacking hint was provided together with the grouping hint. This decision ensured that the *systematicity* principle (Gentner, 1983) was respected so that the stacking hint involved two groups of two items, each of them with three items as a base and one item on top (rather than one group only).

This way, the stacking is actually a stacking plus grouping hint, thus representing extended mapping (Gentner & Medina, 1998).

Refinement and Execution

Selected sketches for use in the experimental study were refined and produced so that they were consistent throughout the experimental conditions. Firstly, we looked at the ways we could represent these different concepts through imagery so that they could be mapped consistently to capture the principles of analogical similarities. We described this process in detail in the previous subsection. Secondly, we looked at how to present these concepts compositionally so that they could be seen for "what they are" (Rose, 2007) rather than as a piece of art. Gillian Rose calls this critical approach a "compositional interpretation" in visual imagery (2007), as opposed to Irit Rogoff's (2002) approach of the "good eye" which is focused more on a kind of visual connoisseurship and what is regarded as High Art. The "good eye" requires expertise in the field, extensive knowledge, and information about painters, their techniques, what kind of paintings they created, what subjects and imagery they looked at, and who inspired them. Based on all these criteria, a painting was assessed for its quality. Compositional interpretation neglects the ways the imagery is produced, as well as the roots of its cultural or social formation.

One could start to look at the content of the image by trying to see what is captured in it, then, by looking at the colour, spatial organisation, the logic of configuration, emphasis, light, texture and its expressive content (the feel - a harmony of all the factors).

The reason we chose to refine and execute our future visual analogies according to the "compositional interpretation" method is that our concepts for visual analogies are inspired mostly by real-life situations by capturing objects, relationships between objects and humans, relationships between relationships, actions and gestures that occur and surround us. Compared to the "good eye" approach to understanding an image , the compositional interpretation approach allows the viewer his/her interpretation of the image and might reveal, "what the audience brings to the image" (Rose, 2007). Our visual analogy could be categorised, codified, and its content analysed, thus allowing us to investigate viewers' preferences regarding image compositionality and its contents regardless of whether they are immersed in fine arts or not.

Our goal is to investigate the created visual analogy that are recognised and which elements of the imagery make an impact on participants' performance in solving the *8-coin* problem. Nigel Whitely (1998) insisted on taking this approach more seriously and being "conjoined to other types of analysis so that the visual scrutiny of what can literally be seen can be studied in relation to perception, meaning and content".

Each chosen concept-sketch for the visual analogy was accurately drawn using graphics software and the finished versions were printed on a sheet of A4 photo paper (see Table 3 images A -> L) and used in this experiment.

5.2.2.2 **Materials**

Before the test, each participant was provided with a Participant Information Sheet: Part I (Appendix 14-3), and Part II (Appendix 14-4) including a consent form to be signed by both the participant and investigator.

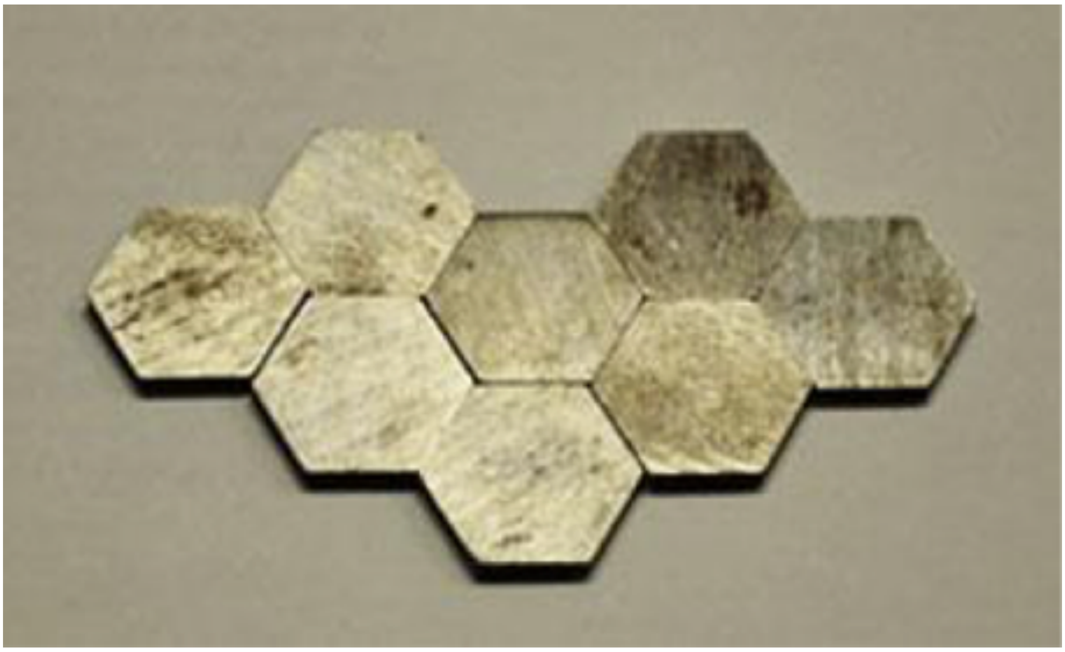


Figure 5.13 Initial configuration of the coins

Visual Analogies (cues)

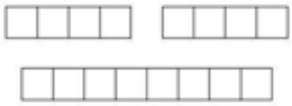
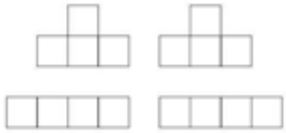
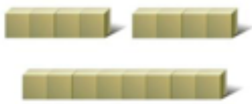
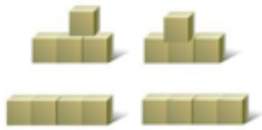
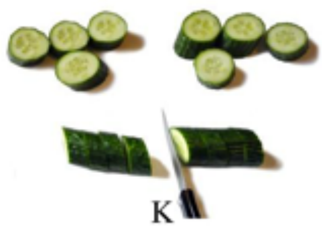
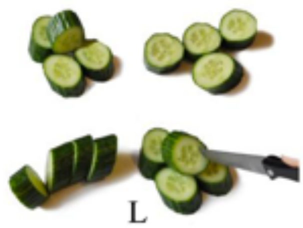
Conditions	Structural aspect:	Insight	
Surface aspect: Depth	**Process**	Grouping	Stacking + Grouping
Abstract Two Dimensional (A-2D)	No process **(gr. 1)**	 A	 B
	Process **(gr. 2)**	 C	 D
Abstract Three Dimensional (A-3D)	No process **(gr. 3)**	 E	 F
	Process **(gr. 4)**	 G	 H
Representational Three Dimensional (R-3D)	No process **(gr. 5)**	 I	 J
	Process **(gr. 6)**	 K	 L

Table 3 The constructed visual analogies vary with respect to both aspects

Study instruction sheets for control (Appendix 14-5) and experimental groups (Appendix 14-6) were given to participants individually. Participants' consent to being video recorded during the problem solving session was included in the consent form.

The eight coins were positioned in the initial configuration (Figure 5.13), and a sheet of paper with an image of this arrangement was placed on the table to serve the participants as a reminder to reposition the coins in the initial configuration after each attempt to solve the problem with two moves.

As suggested by Ormerod et al. (2002), we used regular steel hexagons, with the length of each side being 15 mm and the thickness being 3 mm, to make it easier for participants to assess the number of mutual contacts between them. Participants in the experimental groups (see groups AB, CD, EF, GH, IJ, and KL in Table 3) also received two additional sheets during the experiment, each with a different printed image-hint, provided after two and four minutes respectively (i.e. for conditional group AB, the participant received a printed image A if s/he did not solve the problem during the no-hint period, and was allowed to work for two more minutes with this image in front of her/him, then if s/he still failed to find the solution, the participant was provided with image B and left to work for an additional two minutes).

For the entire set of selected visual hints for each experimental group, see Table 3.

5.2.3 **Study Design**

The IVs for our experimental design are introduced in the description of the implementation of visual analogies development subsection (5.2.2.1) since they were purposely manipulated during the analogy construction. Thus, we have three IVs (see Table 4).

The first IV relates to the structural aspect of insight and has two levels: grouping only, and grouping plus stacking. The second IV relates to the structural aspects of process or transformation and has two levels: no process, and process. The third IV relates to the surface aspects of depth and has three levels: abstract 2D, abstract 3D, and representational 3D.

Thus, the experiment involves a mixed factorial design with two between factors and one within factor. Between factors are surface and process aspects, and the within factor is the insight or structural aspect, i.e. 3 x 2 x 2. Each visual hint was presented as an image (A to L) on a piece of printed paper 8 x 10 inches in size in the order shown in Table 3.

<table>
<tr><th colspan="2" rowspan="3">Conditions
Ctrl. Group = 16
Cond. Group(s) = 8 in each</th><th colspan="4">Structural aspect:</th></tr>
<tr><th rowspan="2">Process</th><th colspan="2">Insight</th><th rowspan="2">Total:</th></tr>
<tr><th>Grouping</th><th>Stacking + Grouping</th></tr>
<tr><td colspan="2">Control Group</td><td>N/A</td><td>-</td><td>-</td><td>?</td></tr>
<tr><td rowspan="6">Surface aspect: Depth</td><td rowspan="2">Abstract 2D cue</td><td>No process</td><td>A</td><td>B</td><td rowspan="2">?</td></tr>
<tr><td>Process</td><td>C</td><td>D</td></tr>
<tr><td rowspan="2">Abstract 3D cue</td><td>No process</td><td>E</td><td>F</td><td rowspan="2">?</td></tr>
<tr><td>Process</td><td>G</td><td>H</td></tr>
<tr><td rowspan="2">Representational 3D cue</td><td>No process</td><td>I</td><td>J</td><td rowspan="2">?</td></tr>
<tr><td>Process</td><td>K</td><td>L</td></tr>
<tr><td colspan="3">Total:</td><td>?</td><td>?</td><td></td></tr>
</table>

Table 4 Design / Experiment 1

During the experiment, the researcher manually recorded on paper the participants' self-reported feelings of warmth and the number of attempts (Appendix 14-7) made by each participant at solving the problem.

The Dependent Variable [DV] was the success or failure in solving the problem.

At the end of the session, each participant was provided with: a) Santa Barbara Learning Style Questionnaire (SBCSQ, Version 1.0 - Appendix 14-8), b) a brief questionnaire including demographic questions and questions about familiarity with the problem (Appendix 14-9); and c) several questions on the effectiveness of the provided visual material (Appendix 14-10).

Hypotheses

H1 Extended hint hypothesis: Visual analogies capturing structural aspects of insight such as both stacking and grouping support better incubation effect than those capturing grouping only.

H2 Process hypothesis: Visual analogies capturing structural aspects such as process or transformational representations support better incubation effect than those without.

H3 Depth hypothesis: Visual analogies capturing surface aspects such as 3D representations support better incubation effect than those capturing 2D ones.

5.2.4 Procedure

The procedure section includes how participants were recruited for the experiment, a description of the location and layout of the laboratory in which the experiment took place, and the procedure and data collection.

Recruitment

Throughout the campus flyers were posted (Appendix 14-1) inviting students to participate in an experimental study on problem solving. To prevent potential signees from preparing for the study, the details of the types of problems or tests involved in this experiment were not communicated prior to the study. They were told only that the study would last around ~25 minutes and that participants would be compensated for their time and participation with £7.

Experimental Setting

The experiment took place in a laboratory which was about 3 X 3 meters in size.
Two tables, a desktop computer table for the participant and a coffee table for the researcher were positioned face-to-face so that the researcher could observe each participant during the experiment (see Figure 5.14).

On the participant's table were the eight coins positioned in the initial configuration (Figure 5.13) and above this workspace was attached an image of the initial configuration as a reminder to reposition the coins after each unsuccessful attempt of two moves (Figure 5.15).

The researcher sat across from the participant's table. He started the experiment by activating the online stopwatch on the laptop. During the experiment, he asked the participant to rate his/her feelings after each attempt of two moves.
Also, the investigator provided the participant with the hints at the designated time, made notes, monitored if the instructions were properly followed, recorded the results and stopped the experiment after a total of six minutes.

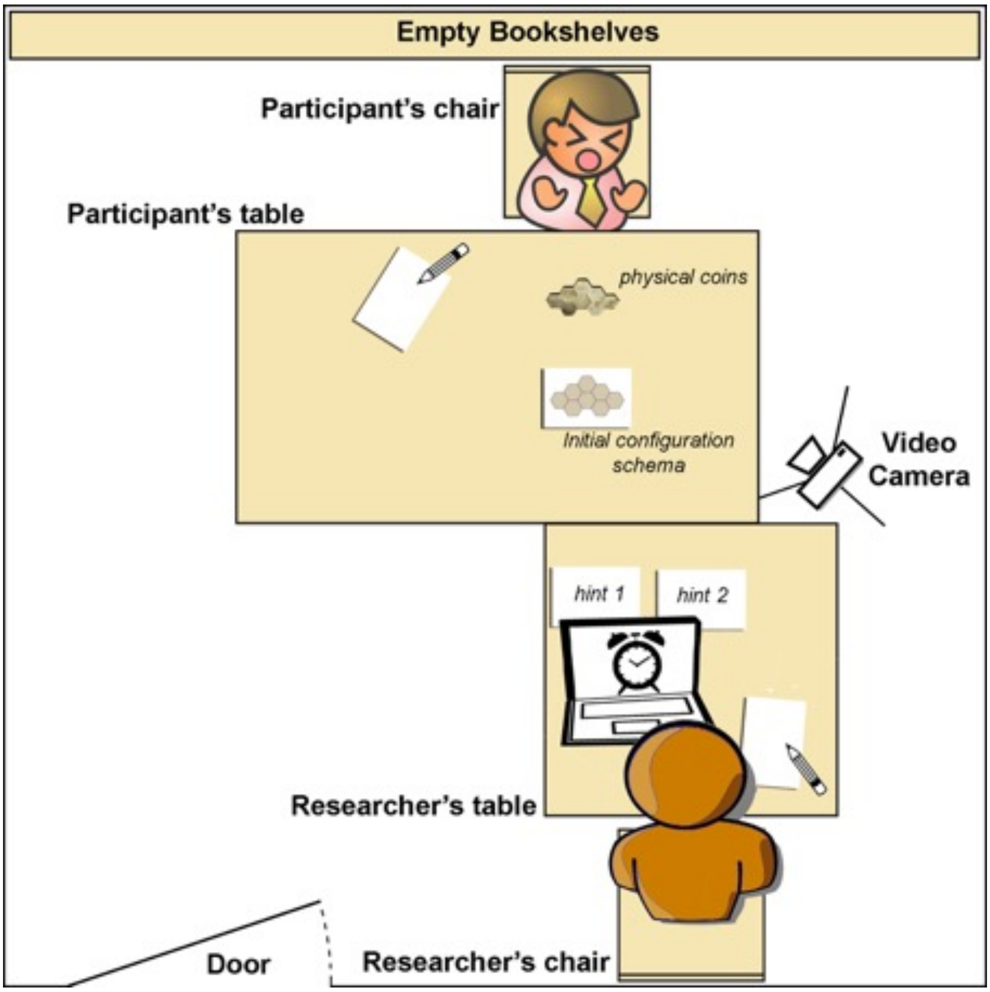


Figure 5.14 Layout of the room for experimental study

Figure 5.15 Room setting with coins in the initial configuration

Experimental Procedure

Before the test, each participant was handed two sheets of paper with a brief amount of information about the study (Appendix 14-3 and Appendix 14-4). Each participant left to read both pages and asked to sign the consent form if they agreed to participate in the study. Participants were randomly assigned to one of the six experimental conditions (Table 3) or the control group, and each was tested individually.

Participants were given a sheet of paper with printed text (for subjects in conditional groups see Appendix 14-6 and those in the control group see Appendix 14-5). They were instructed to rearrange the eight coins by moving two coins only (defined as a solution attempt) so that the correct solution would result in each coin touching exactly three others.

All participants were given a total of six minutes to work on the problem and were allowed to make as many solution attempts as they wished with the condition that for each new attempt they must start with the original coin arrangement (Figure 5.13).

After each attempt of two moves to solve the problem, participants were also asked to rate their feelings in terms of how close they were to the solution, i.e. feelings of warmth (Metcalfe, 1986). Based on a scale of 0 to 10 (i.e. “0” being completely stuck and “10” extremely close) their responses were filled in on the template (Appendix 14-7) by the researcher along with the number of attempts made at the time at which each attempt was completed.

Participants in the six experimental conditions were provided with two visual hints (*“grouping”* and *“stacking + grouping”*), one every two minutes after the initial no hint period of two minutes. For example, participants in the conditional group **Abstract 2D / No process (gr. 1)**, after two minutes of unsuccessful attempts to solve the problem in the no hint period, received image **A** (see Table 3), printed on a 10 X 8 inch sheet of paper as a visual hint to the problem, and they were then allowed to work for two more minutes with the hint in front of them. If they had still failed to find the solution in this period, they were provided with image **B** in the same format and left to work on the problem for two additional minutes.

Participants in the control group were left to work on the problem for a total of six minutes without any hints.

The time intervals from the beginning of the experiment to the end were guided by a set of sounds from an online stopwatch (http://www.online-stopwatch.com/full-screen-interval-timer/?c=r48wfggiyj) customised for this experiment. After each period of two minutes, the stopwatch played an alarm sound reminding the researcher to provide the participant with the designed visual hint and after a total of six minutes working on the problem, there was a clapping sound to end the experiment.

Participants who solved the problem during the experiment were scored as successful and the time at which they found the solution to the problem was recorded, and those who did not solve it in the period of six minutes were stopped and scored as unsuccessful.

Participants who solved the problem in the first two minutes without receiving the hints were scored as successful and were excluded from analyses along with the ones who did not correctly follow the study instructions or who were previously aware of the *8-coin* problem (Appendix 14-9).

Of the total of sixty-six participants, two of them solved the problem in the first two minutes, and they were excluded from further analyses. This left sixteen participants for the control group and eight participants for each of the six between conditions.

5.3 Results

The main results are illustrated in Table 5, which shows the percentage of participants who produced correct solutions for the control group and each of the six conditions. The numbers of times that each participant produced a correct solution was processed with an analysis of variance, with surface hints and structural process hints as between factors, and structural insight hints as the within factor.

Although the use of ANOVA for binary data has been previously criticised (Gabrielsson & Seeger, 1971), ANOVA analysis used by Ormerod et al. (2002) has led to almost identical patterns of results to the ones employing the recommended factorial design for binary data (Cox & Snell, 1989).

Our findings suggest two significant main effects and an interaction effect. There appears to be a main effect of structural insight hints with grouping plus stacking hints leading to significantly more correct solutions (M = .19) than grouping only hints (M = .04), (F (1, 42) = 6.72, *MSE* = .51, p < .05).

The other main effect regards the surface cues (F (1, 42) = 4,26, *MSE* = .32, p < .05) and the post-hoc Tukey's HSD tests showed that abstract 3D hints lead to significantly more correct solutions (M = .19) than abstract 2D hints (M = .00) at .05 level of significance. Without being significant, post-hoc Tukey's HSD tests suggest that the representational 3D hints also lead to more correct solutions (M = .16) than abstract 2D hints (M = .07). The other comparison was not significant.

Visual Analogy					
Conditions Ctrl. Group = 16 Cond. Group(s) = 8 in each		**Structural aspect:**			
		Process	**Insight**		Total:
			Grouping	Stacking + Grouping	
Control Group		N/A	N/A	N/A	0
Surface aspect: Depth	Abstract 2D hint	No process	0	0	0
		Process	0	0	0
	Abstract 3D hint	No process	0	4 (50)	4 (50)
		Process	2 (25)	0	2 (25)
	Representational 3D hint	No process	0	1 (12.5)	1 (12.5)
		Process	0	4 (50)	4 (50)
Total:			2 (4.16)	9 (18.75)	11

Table 5 Number of problem solvers in each condition after the visual hints

There also appears to be an interaction effect between all three factors: surface cue and both structural cues (F (2, 42) = 8.65, *MSE* = .66, p < .05). Thus the most successful hints, both with a success rate of 50%, are stacking hints without process information and in abstract 3D representational format, together with stacking hints with process information and in representational 3D format. Furthermore, representational 3D hints only work, and work well, together with stacking insight hints rather than grouping ones. On the other hand, abstract 3D hints work with grouping hints with process information.

5.4 Discussion

Whereas the overall success rate for all the visual hints is about 23% (11 out of 48 participants in the conditional groups), an in-depth analysis shows that different features of the visual hints can, in fact, considerably improve this result. When comparing this overall finding with outcomes on the impact of visual hints from previous studies (Table 6), two things emerge. Firstly, the success of visual hints appears to be connected to task difficulty. Indeed, both our *8-coin* problem and the nine dots problem are particularly difficult, and they lead to similarly low success rates (above 20%). Secondly, when compared with the original experiment in the same initial spatial configuration (Ormerod, MacGregor, & Chronicle, 2002), it appears that the verbal hints support insights better than our visual hints.

Problem	**Sample size**	**Success rate** (%)	**Incubation time** (min)
Farm (Dreistadt, 1969)	40	70	20
Farm (Olton, 1979)	160	38	20
Nine dots (Chronicle, Ormerod, & MacGregor, 2001)	58	24	3
Nine dots (Chronicle, Ormerod, & MacGregor, 2001)	110	24	3
8-coin Exp. 1 (Ormerod, MacGregor, & Chronicle, 2002)	56	42	6
8-coin Exp. 2 (Ormerod, MacGregor, & Chronicle, 2002)	52	33	8

Table 6 Success rates for using hints to facilitate incubation effect

As previously suggested, this may be due to moderator variables such as the experience of impasse (Chronicle, Ormerod, & MacGregor, 2001; Sio & Ormerod, 2009) the level of cue processing (Olton & Johnson, 1976), the problem difficulty or domain (Christensen, 2005), and pre-incubation period (Sio & Ormerod, 2009). While the level of difficulty has been addressed, and the pre-incubation period has not been manipulated, we will further discuss the experience of the impasse.

Study findings suggest a significant impact of impasse on success rate. We ran independent t-tests and the findings suggest that during the four minutes when hints were provided, the solvers experienced impasse for significantly longer periods of time

(M = 59 sec) than non-solvers (M = 20 sec) ($t(46) = 3.83$, $p < .05$), as well as significantly more moments of impasse (M = 4 times) than non-solvers (M = 1 time) ($t(46) = 4.97$, $p < .05$). In addition, the mean impasse duration for the entire sample was 30 sec and the findings suggest that over 52% of those experiencing impasse for at least 30 sec succeeded in solving the problem, whereas only 3.4% of those experiencing impasse for less than 30 sec solved the problem. Sadly, almost 69% of participants experienced less than 30 sec of impasse, and 74% of non-solvers did not have a single moment of impasse.

These outcomes are particularly relevant in supporting the importance of reaching impasse before the visual hints are processed and could prove useful. These findings support facilitative cue theories while emphasising the prerequisite condition of reaching impasse.

A significant contribution of this study is based on the findings, which show that some of the employed visual hints did work, and we will turn our attention to them while revisiting the study hypotheses.

H1 Extended hint hypothesis is validated by the main effect of structural insight cues, with the grouping plus stacking hints leading to significantly more correct solutions than grouping only hints.

This is a particularly important outcome for the construction of visual analogies. We argue that seamless integration of distinct insight cues and their parallel processing can be better achieved through pictures than words. This is supported by findings in brain science on hemisphere specialisation, with the left hemisphere being superior at language processing and sequential organisation and the right hemisphere being superior at perceiving relationships, the whole configuration and performing spatial visual transformations (Bradshaw & Nettleton, 1981).

H2 Process hypothesis is refuted by the failure to identify the main effect of structural process aspects. However, structural process cues have a significant impact when they are integrated together with surface cues and structural insights cues (see the interaction effect in the Results 5.3 section). Findings suggest that the most successful hints are a mix of 3D hints, stacking hints and no process hints; and a mix of representational 3D hints, stacking hints and process hints.

What is interesting is the fact that process hints do not appear to work in the case of abstract 3D hints (H cell Table 3), albeit that they work for representational 3D hints (L cell in Table 3). Process hints were designed to provide information about the initial problem state and about the transformation process from that to the solution state. The major distinction between the hints in cells H and L in Table 3 is that the transformation process is tacit in the former and explicit in the latter, i.e. from each of the bottom arrays, one element is supposed to be moved on top of the array. In other words, without being explicit about the transformation process, the process hints can be detrimental for problem solving, probably because of failure of mapping. The transformation process can be made explicit by providing a means of extracting the operation needed to move from the initial to the final state of the problem.

H3 Depth hypothesis is validated by the main effect of surface cues, with 3D representations better supporting incubation effect than those capturing 2D ones.

This is another significant outcome for constructing visual analogies, especially since most of the previously employed visual hints are 2D. It is possible that 3D hints are particularly suitable for the *8-coin* problem, and future work could explore if their impact on the success rate of solving other visual insight problems, which require manipulations of physical artefacts, can be replicated. If that is the case, then 3D visual analogies may be particularly beneficial for design practices involving manipulation and production of physical artefacts. Future work could further explore this research question.

5.4.1 **Observations During the Experiment**

The first moves of participants were observed both during the experiment and while analysing the video recordings. Most of the participants clearly understood the grouping hint; however, they found the problem of how to group the coins somehow ambiguous. Some participants tried to separate the initial configuration into two groups, assuming they needed to have the same linear arrangement presented in the hints, others tried to divide the configuration by moving four coins at once and later taking a coin in one hand and another coin in the other hand, trying to place them in the top row of the initial configuration.

Some participants asked me what the relationship was between “these squares” and the problem, which suggests that they did not understand any associations between the designed grouping hint and the target problem.

Also, participants failed to see, with this hint, the suggestion of working in a 3D space by moving one coin on top of the other three. Firstly, one reason for failing to see this could be that when suggesting the depth through 2D shapes, in particular, when that depth is constructed from non-overlapped symmetrical lines, the spatiality of those objects is difficult to interpret. Secondly, when presented on a horizontal surface (placed on a working table), the shapes are seen from above as flat maps or diagrams.

5.5 Conclusion

This chapter has presented the construction of a set of visual analogies, the selection process for the best concepts for experimental study together with their empirical evaluation.

In the reflective practice of constructing the analogies, we draw support from structure-mapping theory. We made use of the constructs of surface and structural aspects, *alignable* and *nonalignable* differences, as well as of the principles of *structural consistency* and *systematicity*.

The experimental findings suggest that, in visual analogies, insight cues are the most beneficial, especially when integrated, and that depth cues are important surface aspects in facilitating incubation effect.

Our findings support the facilitative cue theory and replicate previous outcomes on the importance of impasse as a prerequisite for analogical transfer. Our work makes important theoretical contributions to the understanding of visual analogies and insight problem solving. In addition, the visual hints that we constructed could also be extended to other visual insight problems that share similar insight, i.e. three trees or six matches. Finally, our findings support the benefit of our novel methodological approach consisting of the systematic construction, interpretation, selection and evaluation of a set of visual analogies within the same experimental design. The long-term benefits of such an approach is that it allows for a shift of emphasis from exploring if the hints work to *which* ones work and, more importantly, *why*.

6 Static Versus Dynamic and Realistic Versus Schematic Visual Analogy

Our findings from first experimental study showed that 3D representations led to a significantly higher success rate than 2D ones and that when grouping and stacking hints were provided together, they led to a significantly higher success rate than just the grouping hint alone. This chapter starts with an overview of the second experiment describing the general intent of the study, followed by a section describing the presentation of the study method, including a detailed description of the developed visual analogies, design and procedure. The subsequent section introduces the study results that are later interpreted. Some final remarks conclude the chapter.

6.1 Chapter Overview

The experiment investigates the role of depth, realism and dynamism in visual analogies for cueing the insight problem solving process. To match the visual-kinaesthetic feature of the *8-coin* problem, the developed analogies represent the insight cues, both kinetically and kinaesthetically. Our experimental study shows the superiority of visual analogies as realistic and continuous animations over schematic and discrete animation ones. The outcomes emphasise the importance of image schema for visual-kinaesthetic tasks and are discussed in the light of analogical reasoning and embodied cognition theory (2.2.1.2).

6.1.1 **Experiment 2: Rationale and Research Questions**

By capturing the similarities between two domains, metaphors and analogies, the transfer of meaning from the source to the target is supported. Different types of analogies and predominantly conceptual ones have been investigated for their role in perception, learning, problem solving and creativity. Not much work has focused on the role of nonverbal analogies in insight problem solving, a domain that could greatly benefit from the development of visual insight cues.

The existing work into insight problems offers conflicting findings on the effectiveness of the different types of visual analogies, agreeing, however, that levels of dynamism and realism are important factors to be considered. Visual analogies appear to be particularly successful when augmented with kinetic or kinaesthetic information, but no study has compared their effectiveness when such information is captured in the analogy's content rather than its form of delivery.

The chapter presents an experimental study addressing the following questions:

- What kind of visual analogies are more effective: continuously animated or discrete ones?
- What kind of visual analogies are more effective: realistic or schematic?
- What kind of visual analogies are more effective: kinetic or kinaesthetic ones?
- How could visual analogies capture the changes in the process of solving the insight problem?

To answer these questions, this work innovatively brings together research from four distinct areas: (i) analogical reasoning theory emphasising the role of hints in learning and understanding, (ii) cognitive principles for static and animated visual representations in supporting understanding, (iii) analogies and their effectiveness in cueing insight problem solving, and (iv) embodied cognition theory focusing on the role of image schema in perceiving and comprehending visual representations of action forces and gestures.

6.2 Method

The method for this experiment is similar to that for the first experiment. The section includes a description of participants, the process of visual analogy development and the physical materials together with the design and experimental procedure.

6.2.1 **Participants**

A total of 136 undergraduate and graduate students from Lancaster University acted as participants in this experiment and were paid £5 each. The sample consisted of 72 (53%) males and 64 (47%) females with a median age of 24; 46% of the total participants were younger than 21, 46% were between 21 and 30 and 8% were over 30 years of age.

6.2.2 **Materials**

The materials section includes a subsection with the description of stimuli for visual analogy development that are used to test their effectiveness in the *8-coin* problem. The materials and apparatus subsections describe the physical materials and the equipment and technology utilised in the study, following the experimental design and its procedure.

6.2.2.1 **Stimuli – Development of Visual Analogies**

Based on the previous findings, for this experiment, we focused on generating new concepts of visual analogies that may be developed and offered in a time-based media format. Even though analogical thought includes an active construction of consistent relational mappings, the qualities of these mappings may be affected by a multitude of other considerations. The nature of these mappings depends on their distinct features in terms of the constructs or categories. Thus, new instances, typically prototypic patterns will have a strong influence on the nature of the mapping outcomes. The typical features used in organising these prototypic patterns may play a distinct role in mapping analogical transfer by moderating the links between relations and setting the structuring constraints.

In addition to the analogy features captured in relevant concepts or ideas, people will construct the kind of relational mapping according to the type of relations that were applied in these patterns. One can form relational statements based on general principles, and shared similarities of attributes to indicate only a few noteworthy references for identifying relationships, and others will look into the cause, purpose, or time. These various types of relational frameworks will, in turn, affect how people draw conclusions about their relational mappings, and thus the kind of solutions they generate.

To create the stimuli for this experiment, we integrated the artistic (practiced by artists and designers) and the scientific analysis-oriented visualisation (practiced by people in computer science) cultures. This concept is not only employed to use the knowledge and ideas from these fields but also to integrate them through an interdisciplinary approach by interchanging the ideas between the artistic and scientific fields.

Simon (2006) argues that both the process of seeing and interpretation are subjective and what and how people see depends on personal background and experience. Research in problem solving shows that when visual hints are presented at the beginning of the problem, they are not as effective as when they are presented after a period of working on it (Christensen, 2005; Christensen & Schunn, 2005; Ormerod, MacGregor, & Chronicle, 2002; Sio & Ormerod, 2009). They suggest that once they have been working on the problem for an initial period, people are more likely to reach impasse and make use of the hints. Does time have the same impact on problem solvers as the way a hint is exposed to them? Research on the animation effects in learning and problem solving yields mixed results. To test the effectiveness of graphics in teaching Newton's laws of motion to elementary school students, Rieber and Hannafin (1988), and Rieber (1989) used text, static diagrams and diagrams that animated the path in their experimental studies. They found no differences between the static and the animated diagrams. Byrne et al.'s (1999) experiment on the effectiveness of animated graphics shows that animations were equivalent to static graphics in terms of teaching algorithms to college students. In contrast, according to Tversky et al. (2002), animation has an advantage over static images in that it conveys extra information and additional procedures. It appears that this media is ideal for conveying change over time (Schnotz & Grzondziel, 1999). However, the animation must be carefully constructed and used. For this reason the *congruence* principle, which holds that "The structure and the content of the external representation should correspond to the desired structure of the internal representation" (Tversky, Morrison, & Betancourt, 2002, p. 249) would be applied so that the transformations would convey naturally the change expressed in the analogy.

Many complex animations are difficult to perceive and understand, especially as they relate to the concepts they address, even for emerging professionals; thus, following *the apprehension* principle when creating animated graphics would ensure the effectiveness of an analogy in learning, teaching and problem solving. The animations must show the objects/characters at a slow speed, and be clearly drawn/modelled so the viewers will observe their movement and changes over time.

According to the *apprehension* principle (Tversky, Morrison, & Betancourt, 2002), the structure and the content of the animation should be readily perceived and comprehended, thus a prerequisite to its constructions is that it conveys only the essential information for the concept and eliminates extraneous ones.

Pictorial images were used in the previous experimental studies as a source of investigation on visual analogies in problem solving. Giving explicit instructions to use analogy and exposing the subjects to visual displays, Casakin and Goldschmidt (1999) examined how this method could contribute to the enhancement of design for problem solving. The goal in their investigation was to consider the effect in the performance of expert-novice designers involved in a creative design problem while stimulated by visual analogy. In the experiment, a group of experts and a group of novice designers participated; 12 images related to the architectural domain and 12 images related to other fields such as visual analogy stimuli were used for solving the three creative design problems. In their paper, they report on only one example that was used in the experiment as a source for solving one of the three problems, although four more pictorial and three 2D images are mentioned as constituting the visual display in the study. Therefore, it is unclear and difficult to deduce from the report which visual displays worked better. Firstly, this is because the ratio of used pictorial 2D images and the effect size on the problem solution were not mentioned. Secondly, the result was scored on a scale as a creative solution and not as a well-defined problem with a definite outcome in which it was recorded whether the solution was found or not found.

The figure-ground relation represents the perception of dimensionality on a flat surface, and no more than two planes are considered. Both of them have to be boundless, and one lies in front of the other (Arnheim, 1974). The simplicity of their shapes and symmetry, predisposes an area to function as the figure and the other as the ground. Adding more information to the image, we tend to see, at a different level depending on our knowledge and experience, three-dimensionality. Artists use the relative size of an object, its occlusion, orientation, elevation, shadows, texture gradients, colours, linear and atmospheric perspective to show the illusion of depth on a 2D surface (e.g., canvas, paper). Robert Solso (1994) classifies these elements of depth perception as pictorial cues.

It appears that the *extraneous information* shifts human attention; for example, the American commentator Weinberger (2009, p. 122) stated that slicing your attention is like slicing a plum – "You lose some of the juice." Rubinstein et al. (2001) reported strong evidence in this direction, also, by showing that the cost of adding ambiguous and extraneous information could be very high. They indicate that the task performance was approximately 50% slower on average (especially when the tasks were relatively complex) when two tasks were involved compared to single task performance (Eysenck M. W., 2006).

We argue that implementing the image schemas in the early stages of visual analogy development for our experimental study will give us a better understanding not only of how to construct them to be effective but also in terms of what extraneous or ambiguous information to eliminate from them that might distract solvers from the problem.

Initial Ideation

The initial stage of developing the visual analogies involved over twelve distinct sets of representational sketches created by the researcher. He explored splitting and verticality schemas in real-life contexts (Tversky B. , 2011) including a lottery machine (Figure 6.1), a billiard game (Figure 6.2), stacking buckets (Figure 6.3), photography sessions (Figure 6.4 & Figure 6.5), a car park (Figure 6.6), a paper design (Figure 6.7), a wooden bench (Figure 6.8), and others (Figure 6.9 to Figure 6.13).

Sketching Analogies

For this experiment, I decided to explore other new ideas and concepts of visual analogies that could be implemented in a richer pool of image schemas that relate to the *8-coin* problem. Research in industrial design practice suggests that there are strong links between sketching and the design outcome (Schrage & Peters, 2000) and practitioners who use sketching during the design process generate better quality solutions than those who do not (Schütze, Sachse, & Römer, 2003).

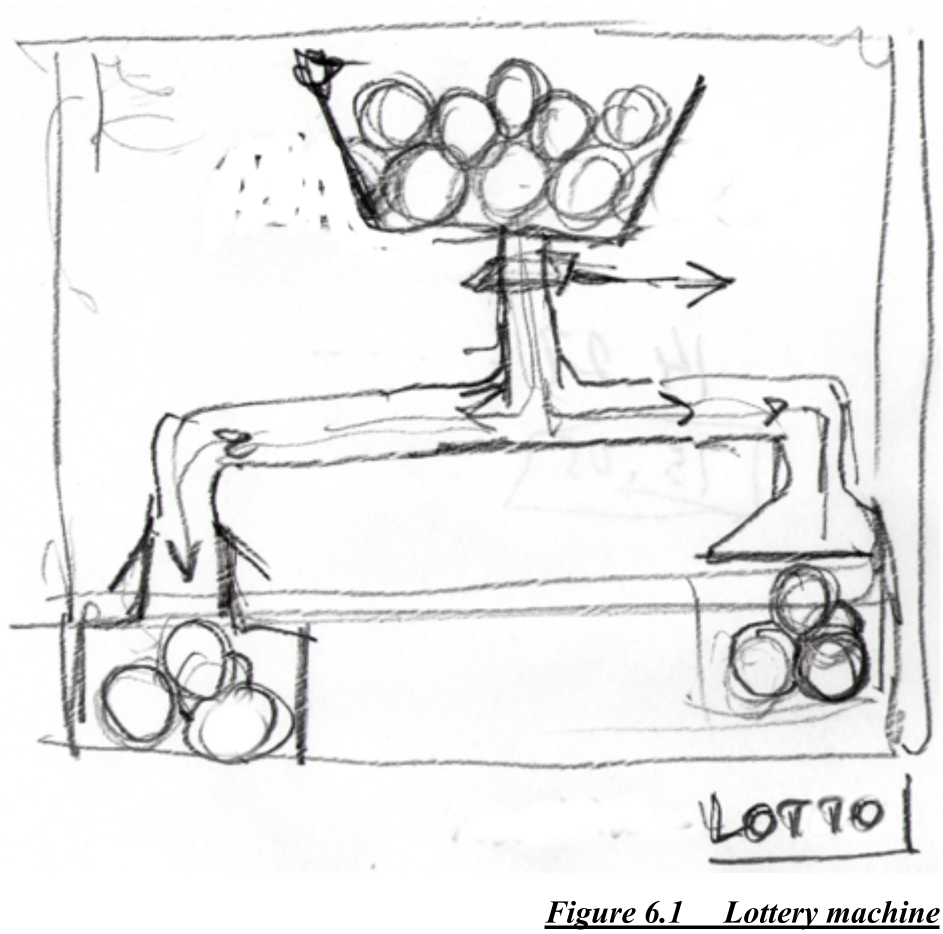


Figure 6.1 Lottery machine

The result of sketching can be unpredictable, but one thing is clear: an increased quantity of sketches yields a better quality design (Yang, 2009).

The first rough sketch for this experiment was merely an invented lottery machine (Figure 6.1). Usually, the designs of these machines are pretty compact, mostly in a spherical form, with some being rectangular prisms or cylinders. Shuffled balls fall out through a round tube slightly larger than the balls. The tube is divided into two and directs the rolling ball to the left or to the right. The idea of stacking, as well as that of dividing (grouping) in this concept is clear if look at it from a structural point of view; however, conceptually, the lottery machine might draw more attention to its purpose due to its association with the idea of competition or a reward to viewers. Artists often use techniques to draw attention to the viewers by placing objects or characters that seem brighter or out of context in their works of art.

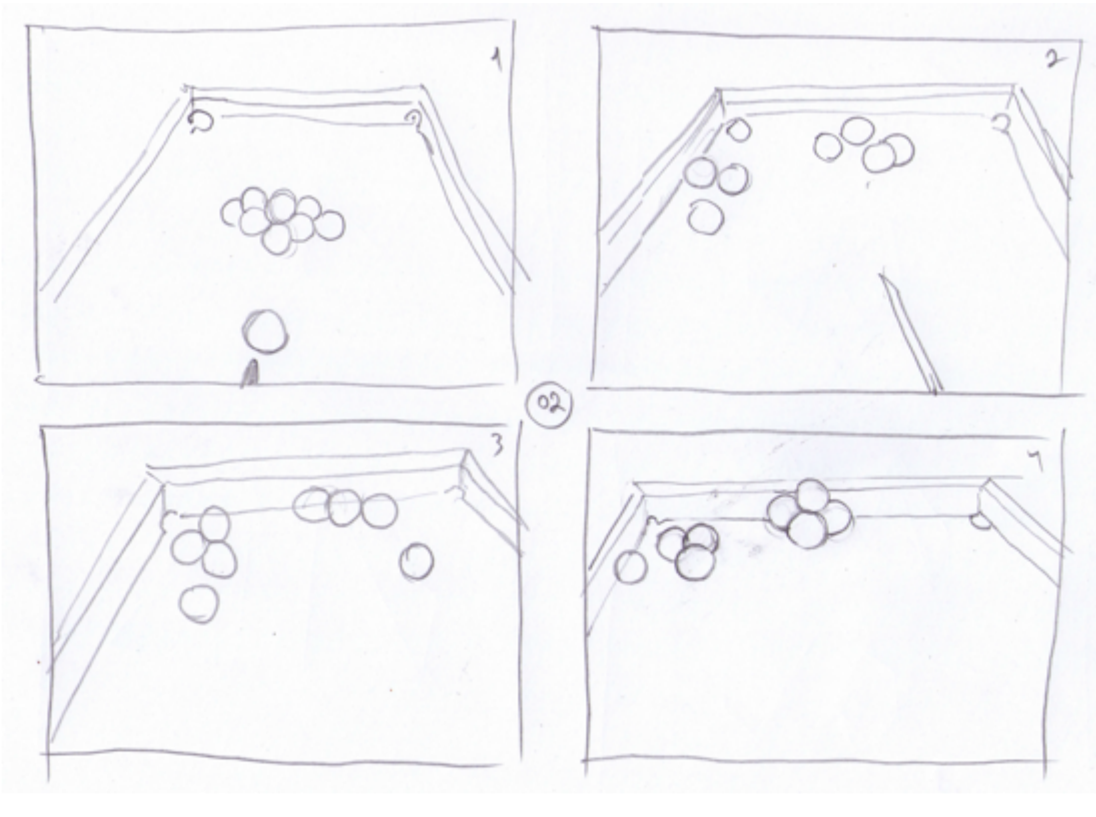


Figure 6.2 Billiard game

The billiard game (Figure 6.2) is a sketch that employs the artist's trick to draw the viewer's attention. Billiard is a very common game and is recognised by most people. The billiard balls can be manipulated like the coins, and have a round shape like them, reminding the audience on a conceptual level to be playful while involved in the game.

In the four sketches of this concept, the balls' placement suggests the splitting and stacking hints for the *8-coin* problem. If the scenario is considered carefully, a strange depiction in the placement of the balls in the bottom right image can be noticed. In real life, it would be impossible to drop a perfectly smooth ball on top of three other ones and not affect their layout. This is the artist's trick for drawing the viewer's attention to a particular or specific area of his/her work of art. We asked ten students what they saw in these four sketches, and six of them commented on the bottom right drawing by saying: "That cannot happen in real life." and asking: "Are the balls made from clay?" Creating this game simulation in an animation format could be more effective than a static version, as the effect of the balls' interaction is unexpected and unfamiliar to the viewers (i.e., the ball falling on top of the three other ones on the table), and thus this change could shift their focus to the newly produced layout on the table.

The fields of art and design research have a long history of studying situated learning and body-based knowing (Smith & Dean, 2009; Solso, 1994) through embodied cognition (Henning, 2003). The term "tacit knowledge" was coined by Michael Polanyi (2009) and is typically understood to refer to un-declarative practically-oriented knowledge, which is, by its very nature, very closely connected to experiential knowledge. This means that we form schemas in our minds through our experiences. The more experiences we have of a particular action or interaction, the better we are at anticipating and predicting possible outcomes from future similar actions and interactions. Simulation, which also points to our mind-reading capabilities, is another mechanism used to understand the mental states of others (Borghi & Cimatti, 2010). For example, visual perception is also one of the embodied skills that we acquire through interacting with other people and the environment, as vision alone does not make sense without human experiential knowledge about what is seen (Noë, 2006). Johnson (2007) goes on to explain that these image schemas are embodied in us as structures and patterns we have learned through action: "we learn what we can do in the same motions by which we learn how things can be for us" (p. 21). According to Lakoff and Johnson (1980), the image schemas are directly responsible for structuring concepts, often exemplified as metaphors which express our bodily experience in relation to space, time and direction (Johnson M. , 1987; Lakoff, 1993; Lakoff & Johnson, 1980).

Johnson listed the 27 “more important” image schemas including the notion that our body is a container that allows for inner and exterior space which we move between. Such action schemas are usually unconscious and automatic bodily knowing structures that allow us to operate our bodies while we are busy doing other things (Gallagher, 1986). By capturing the insights of the *8-coin* problem through depicted actions of human embodied schemas, the developed visual analogies would help to take the load off problem solvers’ minds (Van Merriënboer, Kirschner, & Kester, 2003). Their sensory experience of the environment in a direct and requested way would invite them to act upon situations accordingly.

Figure 6.3 Stacking buckets

Stacking buckets (Figure 6.3) is a refined version of a concept that was already explored in the first experiment. Here, we try to add executive action instruments that will show the change over time in the main frames of the storyboard and sequences of the future visual analogy animation. The concept, in addition to having a similar arrangement and number of coins, captures up and down (pick and drop), front and back (mirrored action between the character from the sketch and the solver), and gesture schemas.

The concept in Figure 6.4 is explored using different versions and styles, including a naïve style (Figure 6.5). The advantage of exploring this theme is in the use of people and their interaction with each other. Since visual analogies are based on visual and conceptual materials, we also plan to create candidates that offer the option of matching more of the conceptual content to see if supressing the surface bias can produce better results in insight problem solving. The concept may capture the insight for our problem through implementation of a natural use of gestures (image schemas). The photographer is guiding a family in a photography session. To take those unforgettable shots, he uses body gestures to move the family members into the best spots and position them to create interesting compositions. A similar number of people and arrangement were used in the concept to match these aspects to those from the problem.

Figure 6.4 Photography session (V 1)

The concept could be executed as a visual analogy in different formats: schematic and realistic static graphics, discrete and continuous animation, and even film. The start and end frames show the photographer interacting with the viewer, which might encourage the viewers to pay attention to his gestures in the frames or sequences which follow.

Figure 6.5 Photography session (V 2 – Naïve style)

The next concept which arose was an underground parking lot (Figure 6.6). Its construction included two levels and those were divided into small areas of three lots per section. The surface similarity in this concept is mostly ignored, structural similarity is difficult to read, and the cars are aligned in a straight line as opposed to the circle of the target of *8-coin* problem.

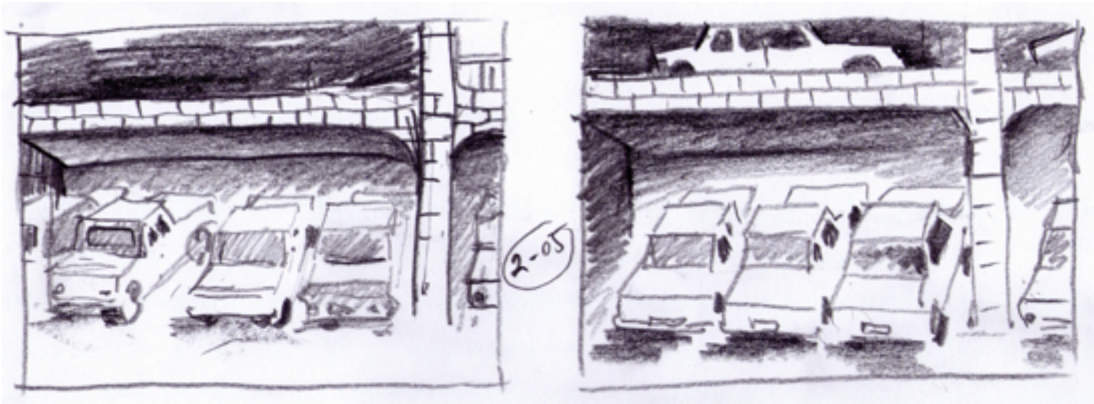


Figure 6.6 Parking lot

Working constantly on the same problem and moving from one concept to the next, means that it is easy to run out of new ideas, encouraging one to think laterally. Accordingly to Goel (1995), in the progress of a design project, especially in the initial stage of idea generation, there are two types of transformations between consecutive sketches made by designers.

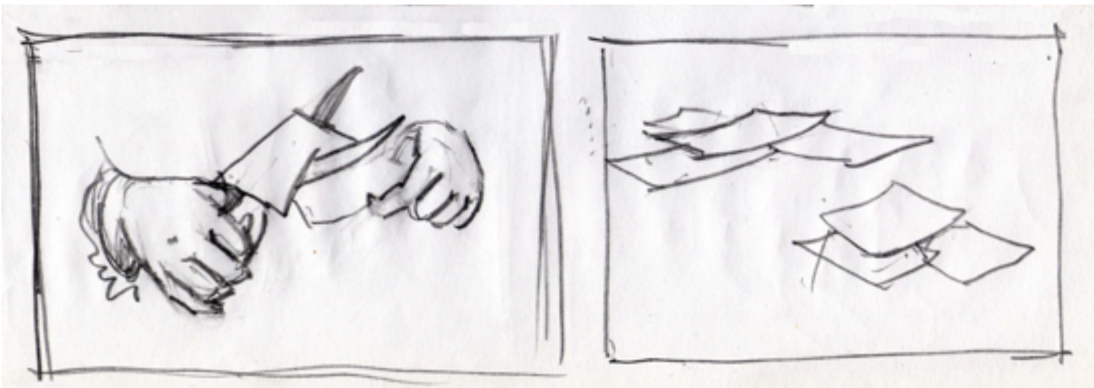


Figure 6.7 Paper cutting design

The lateral movement is when the designer moves from one idea to a slightly different one and the vertical movement refers to when the designer adds details to a previous version. In the next sketch (Figure 6.7) I decided to go with a different setting and change from a *vista* to *figural space*. I switched to a subject of human activity involving hand movement, a table and a tool (scissors) that might suggest a splitting hint in the problem.

The *paper-cut design* is intended to capture the idea of process. In the first sketch the splitting process of the insight is captured, and in the second sketch, both the splitting and stacking insights are captured. It is necessary to consider other issues such as shape, number, and arrangement to develop this concept further so that I can create a final version and use it in the experiment.

Wooden benches (Figure 6.8) reflects a kind of modern minimalist design, intended mostly for teenagers who get together in the park; it attracted my attention due to its arrangement which resembles the target arrangement of the *8-coin* in our study. Not so far to the left from those two functional benches were three more without their tops, so I thought that this kind of layout might serve as a hint for the initial configuration of the coins in our problem.

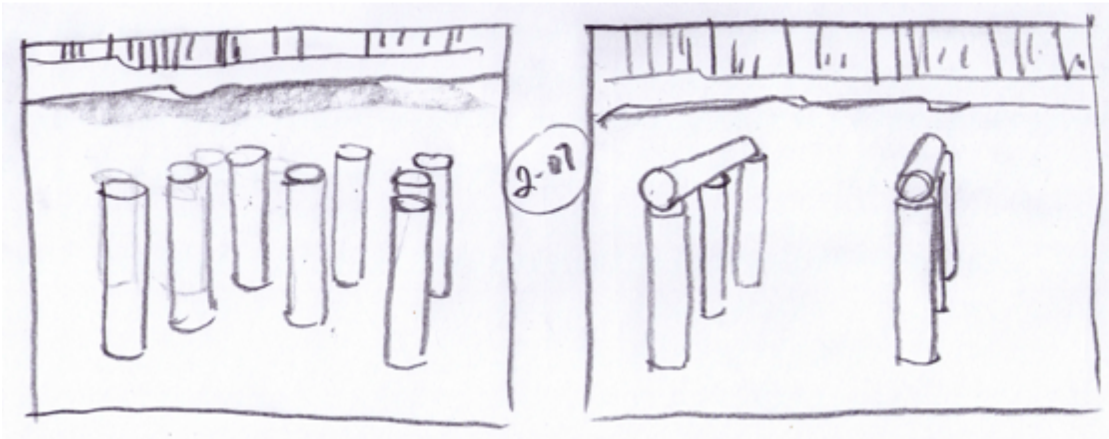


Figure 6.8 Wooden bench

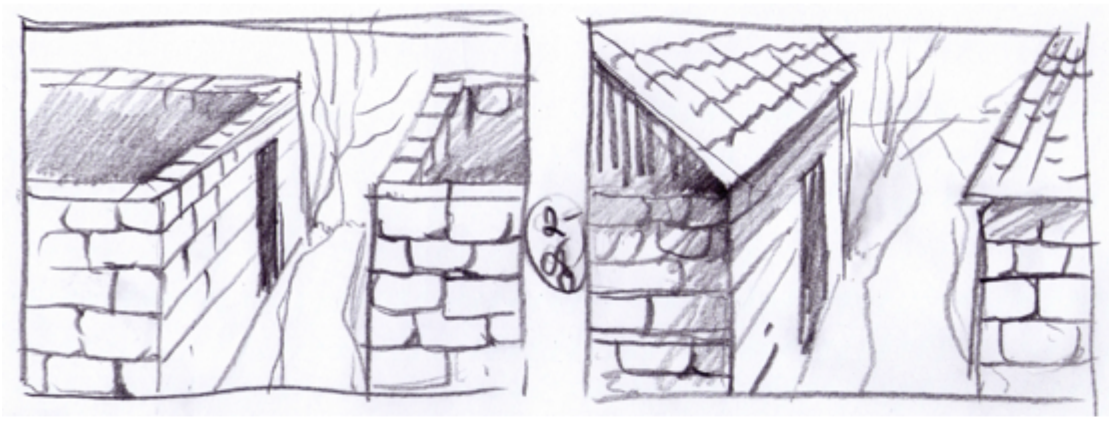


Figure 6.9 Roofing (two houses)

Roofing (two houses) from Figure 6.9 was generated spontaneously by looking for analogical links between the problem and surroundings. Of course, not all generated ideas lead to creative solutions, but at this point, getting to grasp with the network of links in this space, by sketching it, seemed a possible technique for suggesting new ways to look for potential subjects. In this concept, the similarities with the coin shapes and forms are totally ignored. The groups are seen as whole elements (two houses) that cannot be broken into small items like the coins in the problem. The road might suggest the grouping hint and the rooftops, the stacking hint; however, the similarity between actions to reach the solution is missing.

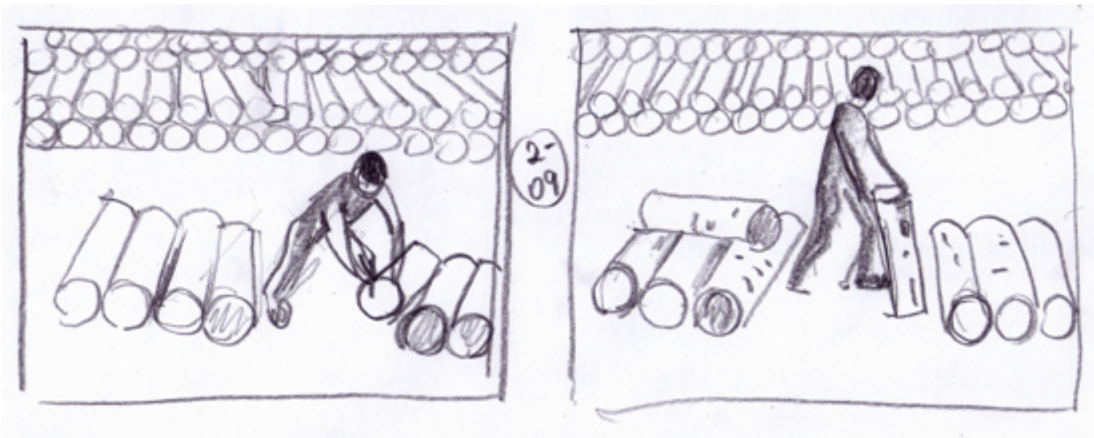


Figure 6.10 Cutting logs

I generated the *Cutting logs* (Figure 6.10) concept by transforming the earlier idea with the benches. Here, the operator was added with the intention of capturing the analogue process and action cues that are required in the *8-coin* problem.

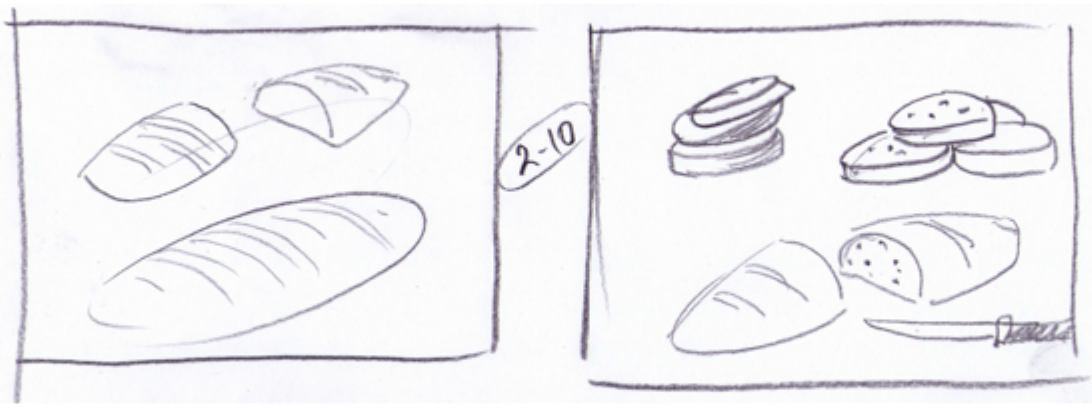


Figure 6.11 Loaves of bread

After sketching the *Loaves of bread* concept (Figure 6.11), we realised that it represents the same idea and features as the *Cutting cucumber* (Figure 5.8) analogy that was used in the previous experiment. We used the same matching features as in the cucumber-slicing concept, including the knife as the action operator.

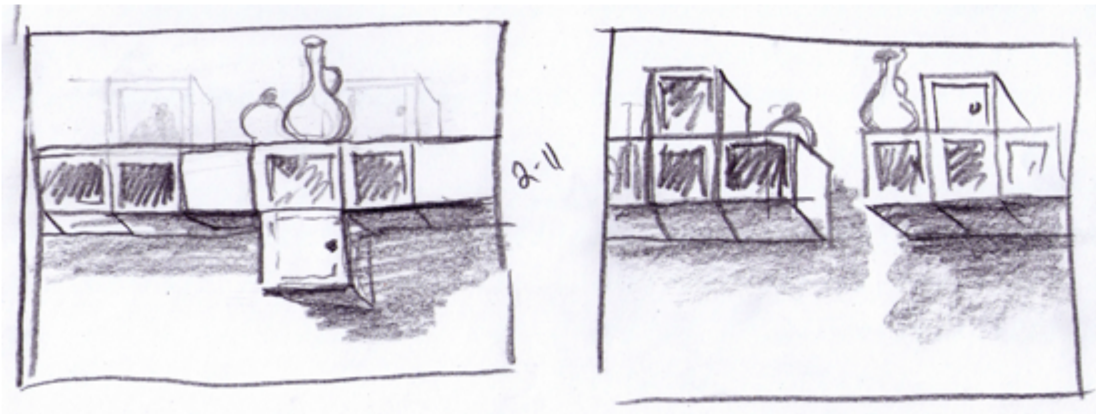


Figure 6.12   Decorative shelves

We do, from time-to-time, remodel homes. Again, this concept is inspired from a routine in daily life. The decorative design of the interchanging cabinets from Figure 6.12 could capture both the splitting and stacking insights of the *8-coin* problem. The layout of the left sketch suggests the concept as a whole – the cabinets are placed in one group and are roughly similar in structure to the initial configuration of the coins, while the one from the right is split into two groups, and shows a cabinet on top of the other three in each group. The glass vases were drawn as decorative objects on the cabinets to mimic real-life surroundings. These two vases are different in form and material than the cabinets, so they stand out more and capture the attention of the viewer even though they are not relevant to the problem, thus distracting them from the useful information that might help them to solve the problem. To focus the solvers' attention on the most important information in this analogy, we should drop the vases from this design and keep only the relevant objects.

The design (Figure 6.12) for analogy and the experimental setting (solver working at a table) are slightly different in their psychological space perception; the first belongs to the *vista* and the other to *figural space*. In addition, capturing different image schemas – one projecting verticality/out surface and the other, horizontality/in surface – makes this analogy even more difficult to perceive and apprehend.

The concept from Figure 6.13 was inspired from observing children playing in the park. The round table and the terrace frame seemed an attractive place for a children's competition. Aligned in a small hint, one by one children climbed onto the frame's horizontal bar, swinging their bodies back and forth as hard as they could, and jumping, trying to land on the table without falling onto the ground.

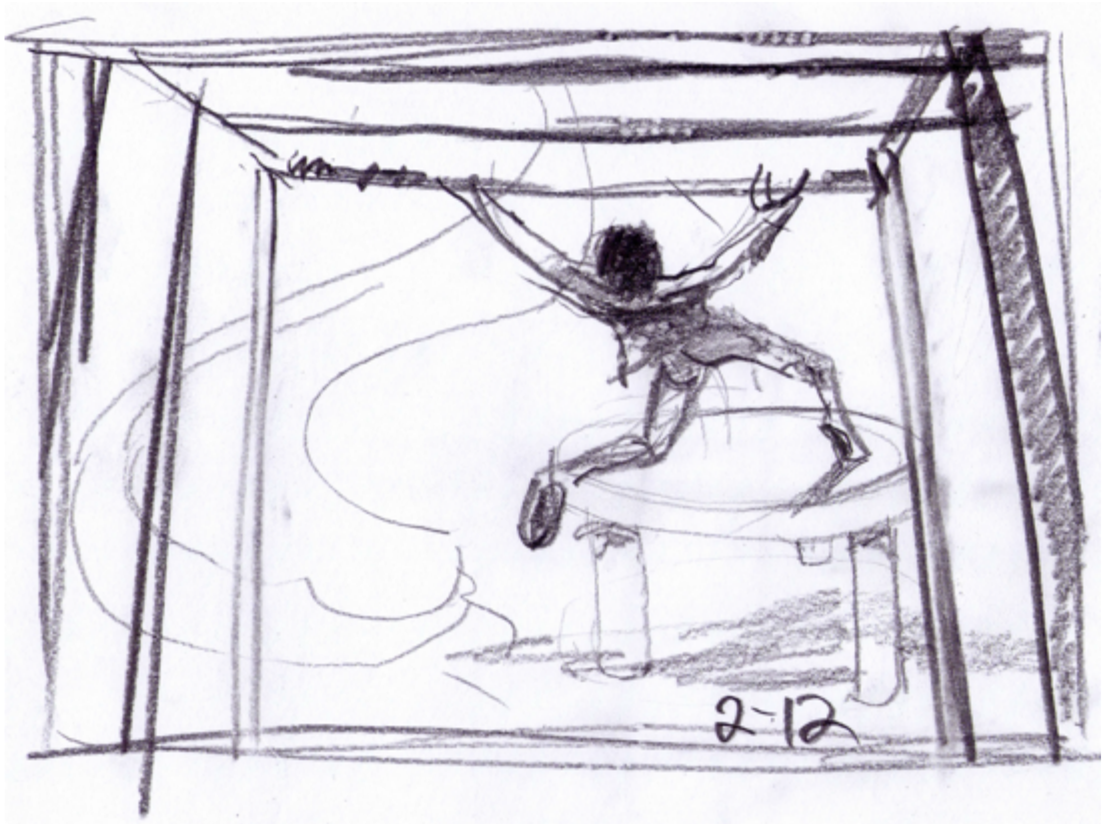


Figure 6.13 Children's playground

Landing, in terms of the top action (up and down schema), locomotion (path-goal), balance (equilibrium) and touching the table (interaction) actions, could guide the viewer's attention toward moving objects in a 3D space. The terrace frame could be shown from a frontal, familiar view; so applying one point of perspective to the surroundings directs the attention to the centre of the event and might reduce any distraction from it. For our problem, we could sketch an analogy to match the number of coins and give it a similar layout; however, the splitting hint might become less understood and even distracting in this scenario, in which the groups are in a state of perpetual change, while the problem solution requires only two moves. Although we consider it as a weak candidate for the current study, this sketch generated more mental concepts for our future studies.

Preselecting Analogical Concepts

The generated sets of sketches were evaluated in three stages. Firstly, an initial feasibility test ensured that the sketches could be further developed by applying both the principles of structure-mapping theory (Gentner, 1983) as well *consistency* and *apprehension* principles (Tversky B. , 2011). Secondly, the sketches were further evaluated by three experts (Appendix 14-2 – 1, 2, & 3) in analogical reasoning who selected two of them for further development, ("Photography session" – Figure 6.4, and "Billiard game" – Figure 6.2).

The different image schemas that these sketches entail allowed for the representations of forces and actions in the "billiard game" and for gestures in the "photography session". Thirdly, both selected sketches were piloted on a small group of students to assess their understanding of the two insight cues. After that, the sketches were developed through an iterative process that involved consistent evaluation according to the relevant principles from an understanding of analogies.

Implementation

To explore the benefits of visual representations for insight problem solving and in particular the role of animations, we compared computer-based simulations with a set of static pictures selected at the key moments within the animations. In this way, the critique of the lack of equivalence between animated and static graphics (Sweller & Sweller, 2006) has been carefully addressed. While building on previous work on the radiation problem (Beveridge & Parkins, 1987), we have also extended it by animating the entire picture (rather than the mere force vector represented by arrows), and by employing a longer sequence of pictures representing the different key states in the problem solving process. However, unlike Pedone, Hummel and Holyoak (2001) who provided more arrows in each picture to support the insight (i.e., convergence of forces to destroy the tumour), our sequence of pictures was selected at key moments within the process of solving the problem, (i.e., each picture represents either an action or a result of the previous action). The two main actions that we represented corresponded to the insights required for solving the problem as discussed and used by Ormerod et al. (2002) (i.e., grouping and stacking).

Realism in animation has emerged as an essential moderator from Höffler and Leutner's meta-analysis (2007) and their findings do not support the *apprehension* principle that requires that animations should be more schematic and less realistic. Michas and Berry (2000) also argued that static pictures could be more effective if they represent a set of key moments in the process or have a high level of realism.

The issue of realism is particularly relevant in relation to the surface attributes of analogies, which are more easily attended to as opposed to the structural ones (Novick

& Failures, 1988). On the other hand, as suggested by Doumas et al. (2008) and Hummel & Holyoak (2005), an effective presentation of relations, while minimising the features of the objects being displayed might boost analogical recognition. To further explore these outcomes, we considered two levels of realism for the set of static pictures and animations, (i.e., schematic and realistic). The schematic visual analogies were developed by applying only the primary depth cues (i.e., relative size, occlusion, orientation and elevation), whereas the realistic analogies benefited from both primary and secondary cues, (i.e., light, shadow, atmospheric perspective and gradients) (Finke, 1990; Ramachandran, 1988). We reduced the details in objects (i.e., human to a wooden mannequin figure) in the dynamic and static animations to avoid the extraneous element-specific features that can distract from the more important relational ones.

Previous findings have shown the significant impact of animations on the acquisition of procedural-motor knowledge (rather than problem solving or declarative knowledge), particularly when they are representational (Höffler & Leutner, 2007). Interestingly, the expected superiority of animations in supporting problem solving has not been identified (Mayer & Moreno, 2002), and the link between the observational learning of motor skills and cognitive skills has not been investigated.
Although the tied interdependence between image schemas and motor skills has already been advocated by Lakoff and Johnson (1980), the role of this interaction in insight problem solving has not been yet explored. A notable exception is Catrambrone et al. (2006) who investigated the role of perceptual kinaesthetic information in analogical reasoning.

This experiment is the first to investigate the role of animations in insight problem solving through visual representations of image schemas capturing both kinetic and kinaesthetic information. Unlike in Catrambone's study where participants were asked to act out the source story to activate the target image schemas, in this experiment, we provided the explicit visual representation of the image schemas.
We also extended this work by considering the representation of image schemas not just as actions and force vectors but also as gestures involving human arms and hands.

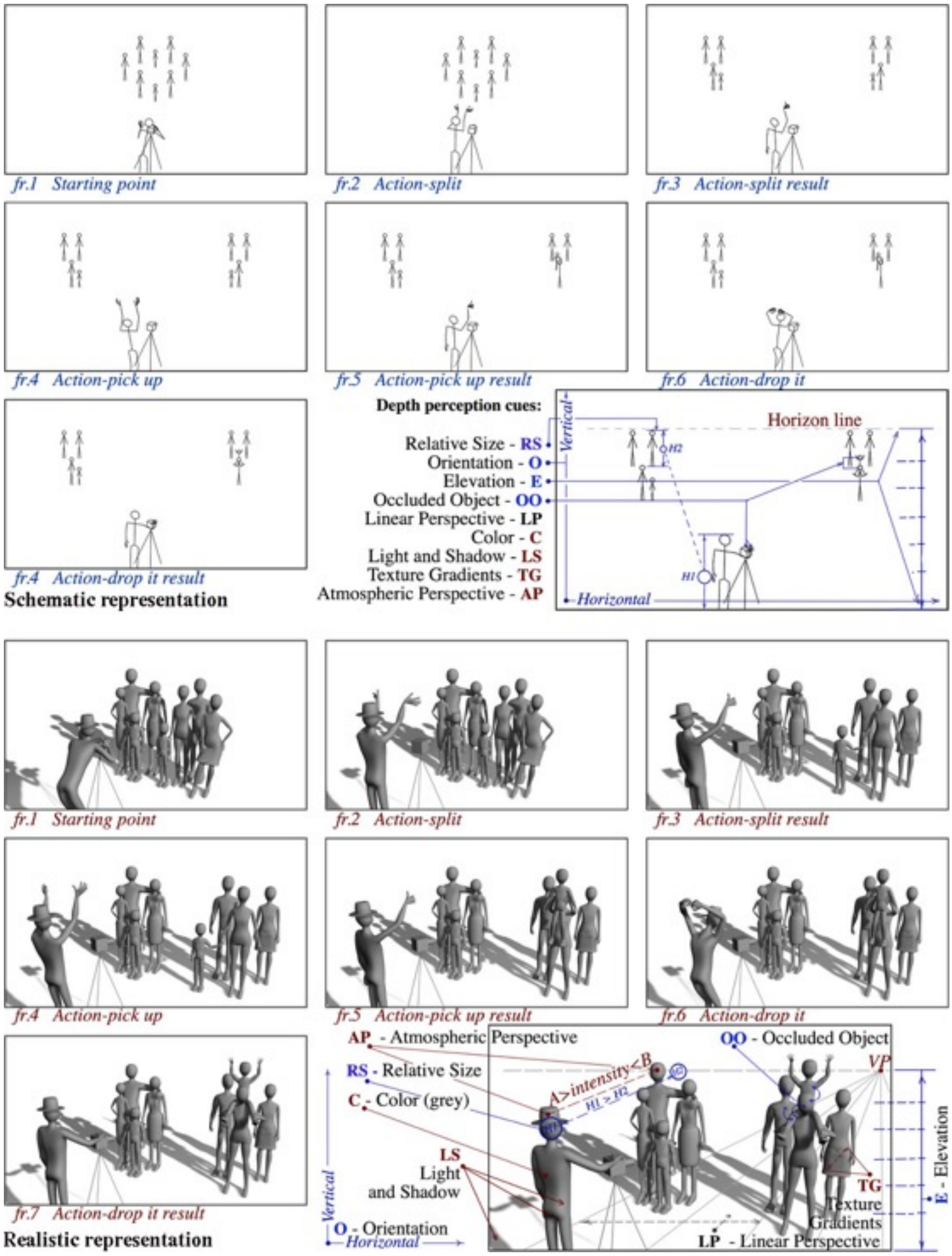


Figure 6.14 Photography session animation in schematic and realistic format

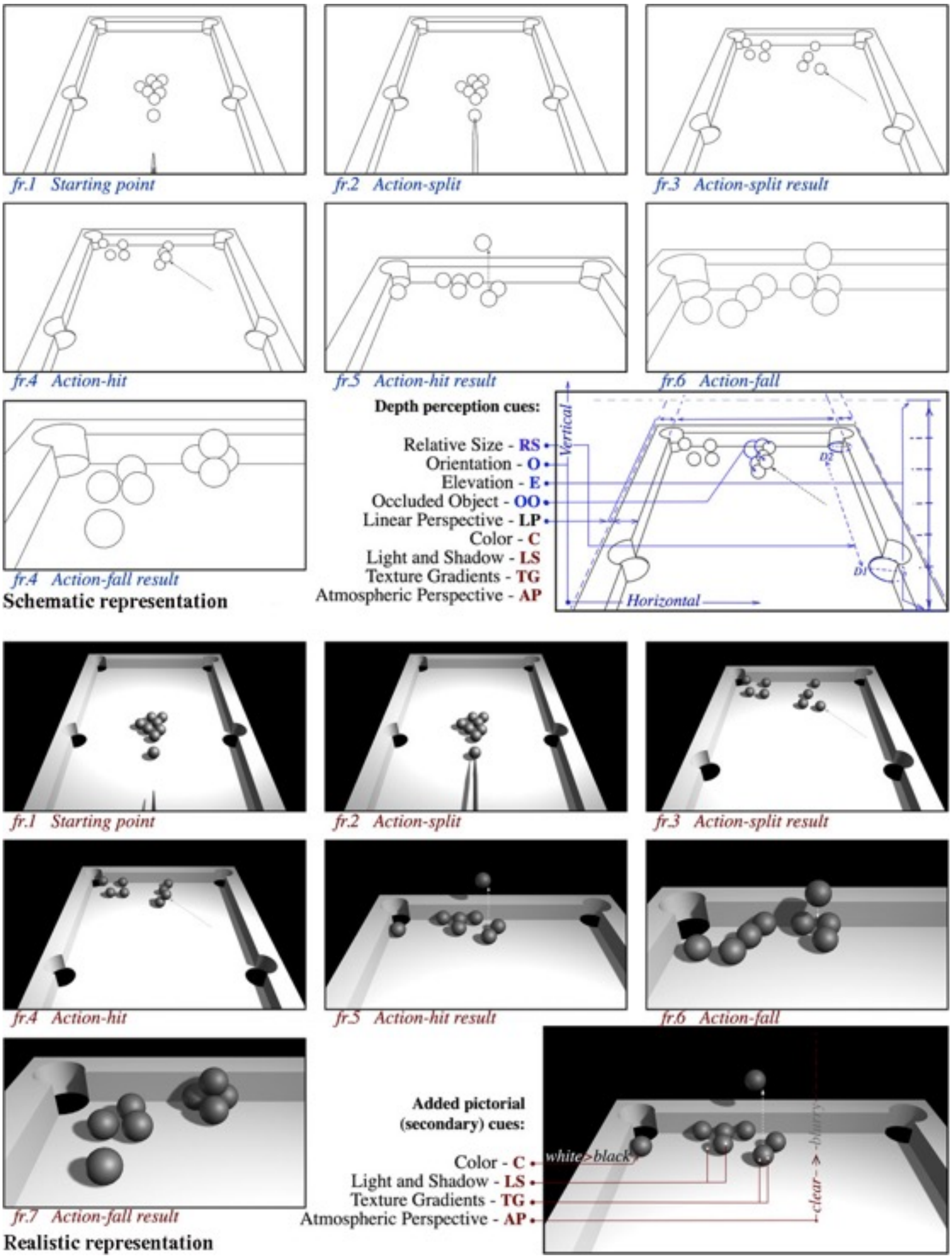


Figure 6.15 Billiard game animation in schematic and realistic format

The link between gestures and image schemas has only recently begun to be explored; it promises to be a fertile research area since gestures and image schemas share some basic qualities distinct from language: they both have physical form and involve motion;

they are both linked to spatiality, imagery and share a gestalt structure; they are both continuous, analogue and multidimensional or multi-modal respectively (Cienki, 2005). Previous findings suggest that gestures offer accessible manifestations of image schemas and that they can invoke different schemas to speech alone.

Refinement and Execution

Based on a preliminary storyboard that was generated after our pilot study, four computer-based animations were created using Autodesk Maya 2011 software. Each one was 38 seconds in length, with two of them capturing the "photography session" in schematic and realistic formats (Figure 6.14), respectively, and the other two capturing the "billiard game" in schematic and realistic formats (Figure 6.15) respectively.

According to the *systematicity* principle (Gentner, 1986), the arrangement and number of elements (i.e., people or billiard balls) in each condition directly corresponded with the target solution. Slight differences in the *nonalignable* structure relate to the people depicted in "photography session", who differ in terms of height, gender and age, as opposed to the balls in the "billiard game" which are all alike, thus providing an *alignable* structure to the set of identical coins in the target solution.

The differences between schematic and realistic representations are in added pictorial (secondary) cues such as colour, light and shadow, texture gradients and atmospheric perspective for the realistic formats, which can be seen in the Figure 6.14. For example, besides the application of depth perception cues such as relative size, orientation, elevation, occluded objects and linear perspective of the schematic representation were added pictorial cues such as colour, light and shadow, texture gradients and atmospheric perspective to capture the same analogies in a realistic format.

The animations were exported into an MP4 movie format at 25 fr/sec (standard ratio for PAL TV system) at HDTV 1920 x 1080 resolution.

The four computer simulations were created as continuous animations and used for the development of the four discrete animations by selecting seven key frames from each. This ensured that the equivalent information was provided in both continuous and discrete animations.

The seven key frames in each of the discrete animations included: (1) the initial frame; (2) the action/force or gesture capturing the grouping insight; (3) the outcome of the setting elements for the first action/force or gesture; (4) the action/force or gesture capturing the first component of the stacking insight, i.e., "up"; (5) the outcome of the setting elements for the action/force or gesture for stacking “up”; (6) the action/force or gesture capturing the second component of the stacking insight, i.e., “down”; and (7) the outcome of the setting elements for the action/force or gesture for stacking “down”.

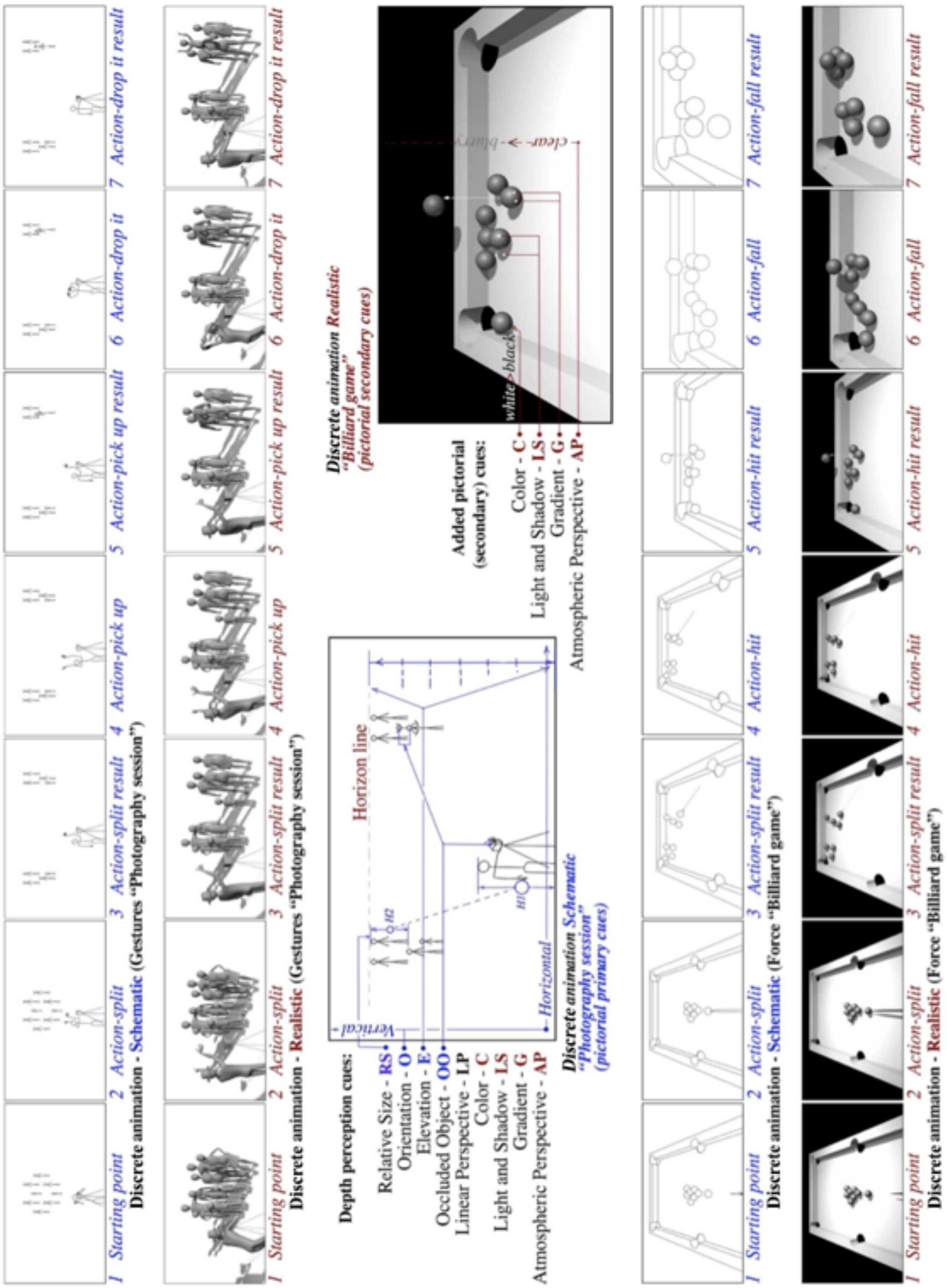


Table 7 Discrete animation layouts

Each one of the four discrete animations was provided on a strip of paper placed on the table, 35 inches long and 4 1/2 inches wide, with all seven frames in a row. Each frame was 2 1/2 x 4 1/2 inches (the same proportional rate of 9 x16 as the movies).

6.2.2.2 **Materials**

The same physical materials were used in this experiment as in the first experiment: two sheets of paper with information for participants, Part I (Appendix 14-3) and Part II (Appendix 14-4) including a consent form to be signed by both the participant and investigator, 8 coins positioned in the initial configuration (Figure 5.13), a single sheet with the study instructions (Appendix 14-5) for the control group and one (Appendix 14-6) for the conditional groups, a sheet of paper with an image of the initial configuration of coins as a reminder to reposition the coins in the shown position after every unsuccessful attempt of two moves. Participants in the continuous animation group received two hints in movie formats, while those in the discrete animation group received a different printed hint-image; the hints were provided after two and four minutes respectively.

For the entire set of selected visual hints, see Table 7. In the end, participants were asked to complete a demographic questionnaire and some questions about their familiarity with the problem (Appendix 14-9). With the consent (Appendix 14-4) of participants, the sessions were video recorded.

6.2.2.3 **Apparatus**

A total of four animations were created using Autodesk Maya 2011 software. The animations can be seen at www.luchian.info/html/02_01.html. Each one was 38 seconds in length, with two of them capturing the "photography session" in schematic and realistic formats (Figure 6.14), respectively, and the other two, capturing the "billiard game" (Figure 6.15).

The animations were exported into an MP4 movie format at 25 fr/sec (standard ratio for PAL TV system) at HDTV 1920 x 1080 resolution, and shown on a 24" HD TV screen via a MacBookPro notebook, equipped with a 2.4 GHz Intel Core 2 Duo Processor, with a memory of 4 GB 1067 MHz DDR3 and a VRAM 256 MB NVIDIA GeForce 9400M graphics card.

Each animation started to play on the 24" HDTV screen at the times designated for conditional groups and guided by the stopwatch sounds up to the end of the test.

6.2.3 Study Design

In order to test the study hypotheses, we had three IVs: dynamism on two levels through continuous and discrete animations; realism through depth hints on two levels – schematic and realistic – and insight cues capturing image schemas through force and gestures. The first two variables were between-participants, and the third one was within; they were thus counterbalanced to account for the order effect (see Table 8). The DV showed the success rate in solving the problem, leading to it being recorded as solved or unsolved.

Hypotheses

We have three hypotheses exploring the impact of visual analogies on insight problem solving. Two of them investigate the role of structural aspects, (i.e., the insight cues represented through image schemas and the changes in solving process from the initial to the final state of the problem captured by animations), while H2 refers to the changes in surface aspects (i.e., schematic, realism).

Conditions	Participants per		Image schema (within-) Order of providing visual analogies	
(between participants)	Group	Sub-group	Force “Billiard game”	Gesture “Photography session”
Control group	26		N/A	N/A
Discrete animation Schematic	26	13	1st (after 2 min)	2nd (after 4 min)
		13	2nd (after 4 min)	1st (after 2 min)
Discrete animation Realistic	26	13	1st (after 2 min)	2nd (after 4 min)
		13	2nd (after 4 min)	1st (after 2 min)
Continuous animation Schematic	26	13	1st (after 2 min)	2nd (after 4 min)
		13	2nd (after 4 min)	1st (after 2 min)
Continuous animation Realistic	26	13	1st (after 2 min)	2nd (after 4 min)
		13	2nd (after 4 min)	1st (after 2 min)

Notes on independent variables:
Dynamism – on 2 levels: Discrete and Continuous (between participants);
Depth – on 2 levels: Schematic and Realistic (between participants);
Image Schemata – on 2 levels: Force and Gesture (within participants).

Table 8 Design / Experiment 2

H1 Dynamism hypothesis: continuously animated visual analogies illustrated by computer simulations lead to a higher success rate in problem solving than discrete visual analogies illustrated by a sequence of key static pictures.

Graphics of all kinds, including animation, benefit comprehension and learning and foster insight (Larkin & Simon, 1987; Mayer & Moreno, 2002; Tversky, Morrison, & Betancourt, 2002); however, the literature has shown mixed results on the benefits of animation (Rieber & Hannafin, 1988; Byrne, Catrambone, & Stasko, 1999) even though it is, in principle, an ideal format for conveying change over time (Schnotz & Grzondziel, 1999). Paivio and Clark (1991) state that the distinction between dynamic and static processes is in the added symbolic movement system, suggesting that this implicates motor processes in the dynamic thought processes. Thus, perceptual action schemas embodied in our body may be the key to constructing effective animations. In their paper *Animation: can it facilitate?* Tversky, Morrison, and Betancourt (2002) suggest that, in order to be successful, the animated graphics should meet two conditions when constructed: 1) the structure and content of the external representation should correspond with the desired structure and content of the internal representation; and 2) the structure and the content of the external representation should be readily and accurately perceived and comprehended.

H2 Realism-depth hypothesis: realistic visual analogies capturing surface aspects through secondary depth cues lead to a higher success rate in problem solving than those of schematic analogies capturing surface aspects through primary depth cues only.

Cognitive load theory (Paas, Renkl, & Sweller, 2003) argues that due to working memory limitations, people may be unable to handle the high information load carried by animations, which might hinder problem solving and creativity. On the other hand, Höffler and Leutner (2007) showed that animations could be more effective in learning than static imagery. In their study (2002), Tversky et al. state that animations may slow down understanding because "the presented information cannot be accurately perceived and understood".

In the context of the *8-coin* problem, we consider that both insights (splitting and stacking) needed to solve the problem are visuospatial, thus cueing may be effective if animations capture the insights in 3D (see the added pictorial depth cues in Table 7) rather than 2D. Adding pictorial depth cues to the objects in our animations will cause these objects to be perceived as obvious "wholes" moving in space rather than being perceived as "wholes from parts" (additional task), thus considerably reducing the extraneous load (Mayer & Moreno, 2002).

H3 Image schema hypothesis: Visual analogies that capture the insights needed to solve the problem through image schemas lead to a higher success rate when represented through gestures rather than forces.

The image schemas that we have argued are key points in the visual analogy development process are abstractions from concrete; thus, at some deeper level, these schemas are represented as sensory-motor patterns that are, in turn, associated with existing things in the world. The choice of support for our analogies may be related to this sensory-motor experience. The relationship between visual analogy, gestures and embodied schemas is interesting, for example, even for abstract concepts like "What is truth?" Barsalou and Wiemer-Hastings (2005) have shown that explanations often involve scenarios: "It is when you…". Similarly, when someone is asked what a rectangle is, s/he may explain by gesturing the process of drawing a rectangle in the air. Therefore, gestures can provide much more accessible instances of image schemas than forces, which often have to be integrated with other types of schemas to have the same effect.

6.2.4 Procedure

Participant recruitment, laboratory setting and layout, and the procedure along with the generic data collection for this experiment are described in the following section.

Recruitment

Throughout the campus, flyers similar to the one in Appendix 14-1 were posted, inviting students to visit a web link to sign up and find out more information about the experiment. The details of the types of problems or tests involved in this experiment were not communicated prior to the study. The web page displayed a clear address for the experiment location and stated that each participant would be required to participate for approximately 25 minutes and would be compensated for their time and participation with £5. The web page was set up with a system showing available time slots for the experiment, which potential participants could choose and sign up for.

Experimental Setting

The experiment took place in the laboratory and is described in detail in the experimental setting subsection of the procedure section for Experiment 1 (5.2.4).

The layout of the room can be seen in Figure 6.16, as well as a photograph depicting a participant starting to work on the problem as an example of the real-life setting (Figure

5.15). On the participant's table, there were eight steel hexagonal coins in the initial configuration (Figure 5.13), and above the workspace, there was an image of this configuration as a reminder to participants to reposition the coins after each unsuccessful attempt of two moves.

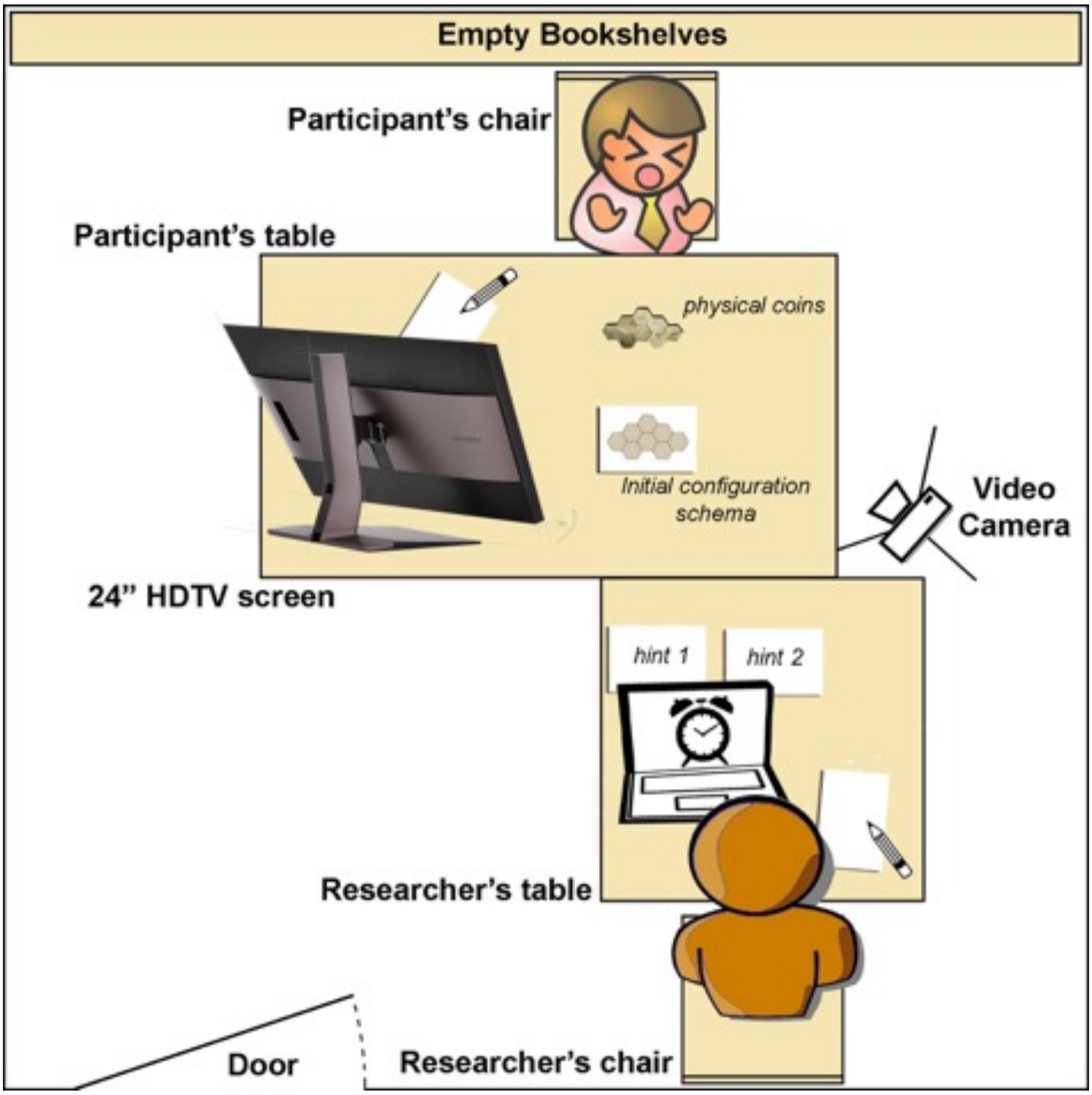


Figure 6.16 The layout of the room for experimental studies 2, 3, 4, and 5

Experimental Procedure

The procedure in this experiment was similar to the procedure for our first experimental study (5.2.4). Participants were randomly assigned to one of the four conditions or to the control group and each subject was tested individually and initially provided with two sheets of detailed explanations about the study and a consent form (see Appendix 14-3 and Appendix 14-4), and printed instructions, as for the previous experiment. They were guided by the sounds of a customised web stopwatch timer to ensure that participants spent the same allowed time per slot (i.e., no-hint, 1st hint, and 2nd hint periods) while working on the problem. After each two consecutive movements of coins, participants had to return the coins to their original configuration before making another attempt; during this task they were also asked to rate their feelings of warmth Appendix 14-7). Participants were allowed to make as many solution attempts as they wished. After two minutes of working on the problem, participants were alerted by the sounds of the stopwatch interval timer to stop and advised to watch the first provided visual analogy, either as a continuous animation lasting for 38 seconds or as a discrete one presented on a paper strip on the table in front of each participant. To ensure equivalent exposure, after 38 seconds of watching the hints, participants were instructed to restart working on the problem and they each did so for another two minutes. In this time, the continuous animation was looping on the screen and the paper strip was left on the table until the second analogy was similarly provided. Each experimental group was divided in two subgroups.

The first subgroup received the visual analogy capturing the force and actions schema (*Billiard game* – Figure 6.15) as their first hint after two minutes of working on the problem; then, after four minutes, they received their second hint of visual analogy capturing the gesture schema (*Photography session* – Figure 6.14).

The second subgroup received the visual analogies in a reversed order: firstly the gesture schema and secondly the force and actions schema. After a total of six minutes of solution attempts, the test ended and the result was marked as successful or unsuccessful. After that, the participants were asked to fill in the forms and surveys used in all our studies on insight problem solving.

Participants solving the problem at any time were recorded as successful and proceeded to the next stage of the experiment. The control group worked on the problem without any hints for the entire six minutes.

Generic Data Gathering

We used the same template to record information about the participants' performance and their self-ratings of feelings about how close they were to the solution (Appendix 14-7) during this experiment, as well the one for gathering the demographic data (Appendix 14-9), the same survey on helpfulness of the provided visual analogy as hints to the problem (Appendix 14-10), and the Santa Barbara Learning Style Questionnaire

(SBCSQ Version 1.0 - Appendix 14-8) survey to measure each participant's learning style. Participants were video recorded during the test for further analyses.

Out of the total of one hundred and thirty-six participants in this experiment, two participants solved the problem in the first two minutes (no hint period) so they were not given the hints and were excluded from further analyses. An additional four participants were excluded as well (i.e., three participants who were not naïve about the problem and one who did not follow the instructions properly).

This left a total of 130 participants: 26 subjects for each of the four experimental groups and 26 subjects for the control group.

6.3 Results

The solution percentages in the various conditions outlined in Table 9 were compared using the non-parametric binomial test which estimates the probability of a dichotomous variable's distribution being significantly different to the observed distribution (Siegel, 1956). Similar goodness of fit statistics for categorical variables such as maximum likelihood Chi-square, i.e. G2 (Bishop, Frienberg, & Holland, 1978) were used to analyse the impact of visual analogies in the radiation problem (Beveridge & Parkins, 1987; Pedone, Hummel, & Holyoak, 2001).

Conditions	**Force** “Billiard game”	**Gestures** “Photography Session”	**Total:**	
Control group	N/A	N/A	2 (7.7)	
Discrete animation Schematic	5 (38.5)	8 (61.5)	13 (50.0)	28 (53.8)
Discrete animation Realistic	5 (33.3)	10 (66.7)	15 (57.7)	
Continuous animation Schematic	8 (53.3)	7 (46.7)	15 (57.7)	34 (65.4)
Continuous animation Realistic	8 (42.0)	11 (58.0)	19 (73.1)	
Note: Numbers in parentheses are percentages, n=26 in each condition				

Table 9 Number of participants who solved the problem

However, the binomial test was preferred since it is specifically suited for dichotomous data. All tests of significance are one-tailed in the direction of the observed effect.

An exact binomial sign test showed that significantly more participants solved the problem when exposed to visual analogies presented as continuous animations (65.4%) as opposed to those exposed to visual analogies presented as discrete animations (53.8%) ($p = .03$).

Findings also suggest that there is a significant difference in success rate facilitated by the realistic metaphors (65.4%) as opposed to the schematic ones (53.8%) ($p = .03$). An exact binomial sign test indicated that metaphors which offered realistic representations delivered as continuous animations have led to a significantly higher success rate (73.1%) than the metaphors depicting schematic images delivered as discrete animations (53.8%) ($p = .01$).

For the image schema condition, once participants solved the problem in the first condition (19 for the force hint and 14 for the gesture hint), they were no longer exposed to the second condition. Thus, 26 out of 85 participants solved the problem after seeing the force hint, and 36 out of 91 after the gestures hint. In terms of image schema, the findings suggest that the gesture-based visual analogies lead to a significantly higher success rate (39.6%) than force-based visual analogy hints (30.6%), ($p = .018$).

Each of the four types of metaphors enabled a significantly higher success rate than was seen in the control group (7.7%) ($p < .01$) which provided a baseline success rate previously unavailable for the *8-coin* problem. While comparison between static and animated representations has been discouraged in the absence of equivalent information (Tversky, Morrison, & Betancourt, 2002), we have also performed comparisons with the success rate on the *8-coin* problem facilitated by the verbal hints in Ormerod et al. (2002) and static pictures in the first experiment. The rationale for this is that each experiment uses the same two insight cues (i.e., grouping and stacking) within the same time interval (2 + 2 + 2 minutes). They do differ in content since the change process is captured in a limited way through the static pictures but this is an inherent limitation of static representations. The findings showed that visual analogies represented either as continuous animations or as realistic visualisations offered a significant advantage over the static pictures (50%) and verbal hints (Ormerod, MacGregor, & Chronicle, 2002) ($p < .018$).

6.4 Discussion

The most important outcome of this study is that each of the four conditions has led to success rates above 50%, with the highest value being 75% for the continuous realistic animation. This is impressive given participants' limited engagement with the analogies. The findings are better understood when contrasted with the current understanding of the role of visual analogies in cuing insight problems.

Previous work has shown that visual insight problems are notoriously difficult to solve with a success rate for the control group seldom higher than 10%: 13% for the radiation problem (Pedone, Hummel, & Holyoak, 2001); 9.4% for nine dots (Lung & Dominowski, 1985); and 7% for the *8-coin* problem as shown in our study.

Different types of visual analogies appear to differ in their effectiveness. Static visual ones enable a 50% success rate for the *8-coin* problem (Sas, Luchian, & Ball, 2010), and for the radiation problem, static analogies augmented with kinetic (Beveridge & Parkins, 1987; Pedone, Hummel, & Holyoak, 2001) or kinaesthetic (Pedone, Hummel, & Holyoak, 2001) information, allow for success rates of 60%, 82% and 95% respectively. A sequence of static visual analogies can lead to a 67% success rate and above 90% when augmented with kinetic or kinaesthetic information (Pedone, Hummel, & Holyoak, 2001). Most notably, when kinetic or kinaesthetic information are part of the analogy content or its form of delivery, their success is above 90%.

The later outcome pertains to the radiation problem, which is arguably easier than the *8-coin* problem (13% vs. 7% baseline success rate), and requires only one rather than two insights, (i.e., convergence versus grouping and stacking). In comparison, the success rate of over 80% for the radiation problem (Pedone, Hummel, & Holyoak, 2001) may also be due to higher levels of engagement with the metaphors, (i.e., participants had to recall each analogy through written descriptions).

In our study, participants were actively exposed to each of the two analogies for only 38 seconds per analogy (i.e., "Photography session" and "Billiard game") without being asked to recall either of them. Finally, the 80% success rates in Beveridge & Parkins study (1987) may be due to the procedure of delivering the metaphor by demonstration. Since the authors offered no details on the time and instructions for delivery, it is possible that the outcomes were facilitated by the confounded variables. Subsequently, each of the study hypotheses will be reintroduced and discussed.

H1 Dynamism hypothesis: continuously animated visual analogies illustrated by computer simulations lead to a higher success rate in problem solving than discrete visual analogies illustrated by a sequence of key static pictures. This outcome is both interesting and important. Both continuous and discrete animations captured key moments in the problem solving process involving actions and their outcomes to hint the insights needed to solve the problem (i.e., grouping and stacking). For this reason, they were both more successful than the static visual analogies, which captured no more than the initial and final state of the problem solving process (Sas, Luchian, & Ball, 2010). The findings validate H1, which is in line with Höffler and Leutner's meta-analysis (2007). Both continuous and discrete animations align with the *systematicity* principle (Gentner, 1986) which states that high-order relations, such as causality, facilitate mapping. While both continuous and discrete animations reflect high-order causality relations through the depiction of actions and their effect on the elements of the settings, discrete animations can increase the cognitive load because they demand inferences of motions, (i.e. mental animation (Hegarty, 1992)).

Similarly, while both continuous and discrete animations align with the *structural consistency* principle by providing *one-to-one* mapping between their components (source) and the ones involved in the problem solution (target), we argue that the continuous animations adhere to this principle to a larger extent (i.e., for each one of the more than 800 frames in the continuous animation rather than only for the seven frames of the discrete animations.

The outcome is also in line with the *congruence* principle since the continuous animations offer a more natural mapping of the target solution. While it is true that both types of animations capture the changes in the process of solving the problem, the continuous ones also capture the changes in the action/forces or gestures – as operators allowing the process to unfold (i.e., in continuous animations, the raising of a hand is shown through a continuous movement whereas in discrete animations, the hand is shown only in its final raised position).

The *apprehension* principle requires that the analogies are accurately understood and predicts that discrete animations are better candidates since they adhere to how humans conceive motion; they can also be re-inspected if necessary as opposed to fleeting continuous animations. The fleeting nature of continuous animations was addressed in the procedure for this study by looping each animation for the two minutes of problem solving. We argue that this increased exposure to the continuous animations was particular facilitative in terms of allowing participants to benefit from the advantages of the continuous animations discussed above.

H2 Realism-depth hypothesis: realistic visual analogies capturing surface aspects through secondary depth cues lead to higher success rate in problem solving than those of schematic analogies capturing surface aspects through primary depth cues only.

The findings validate H2; this is in line with Höffler and Leutner's (2007) meta-analysis and previous outcomes regarding static visual analogies for the *8-coin* problem.

On the one hand, realistic animations can be more challenging to understand, (i.e., due to the *apprehension* principle (Tversky, Morrison, & Betancourt, 2002)), and thus more taxing in terms of working memory. On the other hand, the structure-mapping theory (Gentner, 1983) predicts that increased realism makes the surface attributes of analogies easier to perceive and understand. This may facilitate the mapping between the problem's initial state and the analogy, even more so when the content of the analogy is representational rather than abstract. In our study, simply adding secondary depth cues to the elements depicted in pictures without including any new elements or details provided increased realism. This added depth information could, in fact, be more beneficial when the analogical transfer is about the spatial relationship, (i.e., forces or gesture taking place in time and space). Thus, any increase in cognitive load due to complexity may have been compensated for.

H3 Image schema hypothesis: Visual analogies capturing the insights needed to solve the problem through image schemas lead to higher success rate when represented through gestures rather than forces.

The findings validate H3 and build on previous findings showing the significant impact of animations on the acquisition of procedural-motor knowledge (Höffler & Leutner, 2007). Since image schema were used to capture the insight cues of grouping and stacking, their impact extends beyond the comparison between gestures and forces. Indeed, the findings show the impact of animations on motor knowledge for insight problem solving. An important aspect in this respect is the nature of the *8-coin* problem both in terms of content (i.e., visual, spatial, 3D) and its form of delivery (i.e., visual kinaesthetic perception and object manipulation). It is this nature of the problem and the process of solving it, involving forces and gestures, that makes image schemas suitable for representing the insight cues.

The findings also replicate previous work on the role of kinaesthetic information in engaging with the analogies (Catrambone, Craig, & Nersessian, 2006). However rather than using this information for the enactment of visual analogy, we harnessed it within the content of the analogies themselves.

The findings support embodied cognition theory (Lakoff & Johnson, 1980) while extending its application to insight problem solving. They also offer a suitable diagrammatic representation for the splitting schemas, which has not yet been developed. Image schemas are spatially structured representations usually unconsciously employed (Rennie & Fergus, 2006) and directly relevant in terms of perceiving and comprehending visual representations. It is these qualities of image schemas which has ensured their success as hints for insight problem solving, particularly when they are considered in terms of cognitive load theory. This theory has been broadly applied in instruction and learning and central to the theory is the notion of limited working memory capacity (Baddeley & Mehrabian, 1976). The theory assumes that knowledge is stored in mental schema which, once automated, can be processed without demands on working memory (Shiffrin & Schneider, 1977) and that learning by observing what other people do is more effective (Sweller & Sweller, 2006). Previous findings have suggested that working memory is involved in the encoding of implicitly learned material (i.e., image schemas), but not in its retrieval (Yurovsky, 2007). Thus, the content to be transferred from the source to the target does not have to be constructed (i.e., the image schema is already acquired), and can be recognised rather than recalled, thus supporting the idea of less burden on working memory.

6.5 Conclusion

This experiment explored the impact of different forms of animations and their levels of realism in terms of cueing the process of solving the visual-kinaesthetic *8-coin* problem.

The findings suggested that the grouping and stacking hints needed for insight could be suitably visualised as forces and gestures. The study outcomes showed that the two analogies for kinetic and kinaesthetic cueing were more effective when delivered as realistic and continuous animations as opposed to schematic and discrete ones.

The results of the experiment also showed that added secondary depth (pictorial) cues in the image or the animation work much better than the 2D ones, which suggests that depth plays a significant role in designing hints for problem solving. Subtracting the structural and componential elements of 2D from 3D images used in the experiment, a clear conclusion can be drawn that using depth as the source may facilitate the identification or retrieval of similarity between possible relations in the target.

Designers and architects widely use visual simulation of artefacts. Designs are imagined, represented, and communicated pictorially in art, architecture, and engineering. It is clear that there is a need for pictorial representations and symbolic representations to coexist in design systems. A great use of mental images is seen in the simulation of design proposals, but they also play a role in making models for solving problems.

The findings also validated the structure-mapping theory and the *congruence* principle by suggesting that the visual kinaesthetic nature of the *8-coin* problem may be responsible for the findings' failure to confirm the predictions of the *apprehension* principle. This was discussed in light of the embodied cognition and cognitive load theories.

Future work will test the suitability of image schemas for developing metaphors for other visual-kinaesthetic insight problems and will look into how different levels of participant engagement with the visual analogies may impact on their success rate. Our outcomes could also be tested for creative design problems with strong potential implications for creativity support tools for design tasks rich in kinetic or kinaesthetic content.

7 Representation of Integrated Problem Insights in Visual Analogy

This chapter begins with an overview including the aims of the third experiment using visual analogies as hints in the insight *8-coin* problem solving. It presents the preliminary work carried out to reconstruct a set of animations for this study and analyses their impact on solving the *8-coin* problem.

Findings in behavioural psychology, neuropsychology and neuroimaging suggest that conceptual representations of objects in long term memory contribute to perception, language, thought, and action. The object concepts are hierarchically organised patterns of activation dealing with multiple properties, including motoric (e.g., manipulation mode, gesturing), perceptual (e.g., shape, size, depth), and abstract (e.g., function, relational) information. Thus, stimuli in a pictorial format may allow for direct access to action-related information (e.g., the way manipulation occurs, the use of gestures, the object movement attributes), functional information (e.g., relating to the purpose of the represented object and its specific role), and relational information (e.g., large-small, near-far, dark-light).

7.1 Chapter Overview

This experiment investigates the role of order in capturing the insights in visual analogies for cueing the problem solving process. The results of previous experiments showed that animated analogies can be effective in problem solving; however, it was not clear if the order in which the insights were delivered influenced the outcome, nor did the previous experiments determine which image schema works better with the problem insights. We created two similar sets of animated analogies for the *8-coin* problem and extended our studies to investigate this phenomenon. The chapter describes the rationale, research questions, method, and the outcome of the study, a discussion section and concluding notes.

7.1.1 Experiment 3: Rationale and Research Questions

Rather than being an entirely new experiment, this experiment is rather and extension of the previous experiment. Although our hypotheses were validated by the results, some additional questions arose and the answers to them remained unclear.

This chapter presents an experiment addressing the following questions:

- Is the order important as it relates to which type of hint is provided first in the *8-coin* problem solving task: the visual analogies capturing the insights through force image schemas or those capturing the insights through gesture image schemas?
- Are the hints more effective when they capture both insights in a sequential order or when they partially capture the insights and are presented in a reverse mode?

To answer these questions, we recreated four animated sets of analogies to test our hypotheses.

7.2 Method

This section describes the participants for this experiment, the process of developing visual analogy stimuli, materials and apparatus, design, and the experimental procedure.

7.2.1 Participants

Ninety-six undergraduate and graduate students participated in this experimental study. They were all from Lancaster University. The sample consisted of 47 (49%) males and 49 (51%) females with a median age of 23.57; 28% of the participants were younger than 21, 63% were between 21 and 30, and 9% were over 30 years of age.

7.2.2 Materials

The same physical materials, the same concepts of visual analogies, and the same processes of developing them were used in this experiment as in second experiment. The added elements and the differences between used materials in this and the previous experiments are highlighted in the following subsections.

7.2.2.1 Stimuli - Development of Visual Analogies

The construction of the visual analogy animations for this experiment adopted the same concept-sketches as in second experiment. We explored the grouping and stacking schemas in a multimedia context including three other theme-concepts used previously;

however, the same "Billiard game" and "Photography session" sketches (Figure 6.2 and Figure 6.4) were chosen as the basis for further development of multimedia analogy for this experimental study.

The evaluation stage and the criteria for selection of the best concepts for animations were similar to those for Experiment 2. Firstly, two experts (Appendix 14-2 – 1 & 3) in analogical reasoning and the researcher selected the best match from a portfolio of the eight sets for further development. Secondly, the feasibility test that resulted from the previous study ensured that the concepts successfully capture the principles of structure-mapping theory (Gentner, 1983) as well the *consistency* and *apprehension* principles (Tversky, Morrison, & Betancourt, 2002) in the future animations.

The two concepts allowed the image schemas to be captured in a multimedia format that represent forces and actions in the "Billiard game" and gestures and actions in the "Photography session". The multimedia animations were modified through an interactive process that involved consistent evaluation according to the relevant principles of our understanding of analogies, in addition to the experimental design variables.

We used the same objects, human characters, arrangements and number of elements in each condition as for second experiment to ensure the accuracy of the application of the *systematicity* principle (Gentner, 1986).

The results of Experiment 2 showed that visual analogies capturing the insights needed to solve the problem through image schemas lead to a higher success rate when represented through gestures rather than forces. However, because the presented visual analogies are capturing both insights (grouping and stacking) for the problem, it was not clear which insight works better with the force schema and which insight works better with the gesture schema. Therefore, we decided to recreate and purposely manipulate a set of visual analogies for this experiment, and test it to answer this question.

One group of two animations for this condition captures the insights acquired through force schema ("Billiard game") and the other group of two animations captures the problem insights acquired through gesture schema ("Photography session").

The second observation was that visual analogies capturing both insights and presented as continuous animations lead to a higher success rate in the *8-coin* problem than those presented as discrete sequences of static pictures. During the problem task, the animated version of the analogy was looping on the screen and participants were not able to control its speed or rewind it whenever they wished, while participants from the discrete condition could choose to look at any of the seven static pictures from the presented storyboard strip any time they wanted. Having been given the choice to select and use the visual analogy as a whole (all at once) may or may not have contributed to its superior readability and making a decision. This does not, however, mean that participants will retrieve analogy correspondences more easily and apply them to the target problem. For this reason we created another condition for the experiment, including a group of hints capturing the problem insights in reverse order and a group with hints capturing only the stacking insight. Out of the total of four animations created in a realistic style format, a set of two captures the *Only Up* (stacking) insight of the problem, and the second set captures the *Misleading* (grouping presented in a reverse order) insight.

The animations were created to simulate the concepts to be used in the study by the artist researcher using Autodesk Maya 2011 software. Each animation-analogy had a length of 25 seconds.

Developed multimedia hints can be seen at: http://www.luchian.info/html/03_01.html.

7.2.2.2 **Materials and Apparatus**

Each participant was initially provided with a single sheet with the study instructions. The experimental material also consisted of the same set of eight coins which were regular steel hexagons described and used in the previous studies (Figure 5.12). The coins were positioned on the table in the initial configuration position shown in Figure 5.13. Near the workspace was attached an image of the initial coin configuration as a reminder to reposition the coins in the initial configuration after each two-move attempt to solve the problem.

The animations were presented to participants in an MP4 movie format at 25 frames per second (standard ratio for PAL TV system) at a HDTV 1920 x 1080 resolution. The animations were shown on a 24" HD TV screen via a MacBookPro notebook. The four computer simulations were delivered as continuous animations. A Nikon D90 DSLR camera was used to video record the participants' activities during the problem solving sessions.

7.2.3 Study Design

The IVs for our experimental design are introduced in the description of the visual analogy development subsection since they were purposely manipulated during the analogy construction. Thus, we have three IVs. The first IV relates to the structural aspect of insight and has three between levels: control group, confusing hints and only up hints. The second IV relates to the order in which the image schemas were given to participants : no hints, force 1st and gesture 1st. The third IV is related to the time at which hints were provided to participants: first schema and second schema.

Experimental design – Visual Analogy / Animations

	Groups	Subgroups order of hints	Subjects	Time 0 [0>2 min]	Time 1 [2>4 min]	Time 2 [4>6 min]	
	Control group **[A]**	N/A	32	-	-	-	-
Conditions:				No hint period	**Within subjects** First schema **[D]**	Second schema **[E]**	Total:
Between subjects	Confusing hint group **[B]**	Force hint 1st **[b1]**	16	-	-	-	-
		Gesture hint 1st **[b2]**	16	-	-	-	-
	Only up hint group **[C]**	Force hint 1st **[c1]**	16	-	-	-	-
		Gesture hint 1st **[c2]**	16	-	-	-	-

Notes on independent variables:
***Type of insights** – 3 levels: Control* **[A]**, *Confusing* **[B]** *and Only up* **[C]** *(between subjects)*
***Order of schema** – 3 levels: Control* **[A]**, *Force 1st* **[b1+c1]** *and Gesture 1st* **[b2+c2]** *(between subjects)*
***Image schemas** – 2 levels: First schema* **[D]** *and Second schema* **[E]** *(within subjects)*

Table 10 Design / Experiment 3

Thus, the experiment involves a 3x3x2 mixed factorial design with two between factors, each with three levels and one within factor with two levels. Between are the structural aspects of the insight: the type and the order of provided hints, and the within factor is the time at which image schemas were provided.

Each visual analogy was presented as a continuous animation.

The DV was success or failure in solving the problem.

Hypotheses

H1 Order of schema hypothesis: individuals are more likely to solve the problem when they receive the hint capturing the insight through the gesture schema first rather than receiving the hint capturing the insights through the force schema first during the problem solving task.

H2 Type of insight hypothesis: Visual analogies capturing only the stacking insight for the *8-coin* problem and presented to participants in the forward sequential order support better incubation effect than those capturing the grouping insight and presented in a reversed mode (confusing/misleading hints).

7.2.4 Procedure

Participants for this experiment were recruited using the same criteria and methods as for second experiment. The experiment took place in the same room that was used to conduct the two previous experimental studies. The same layout (Figure 6.16), arrangement (Figure 5.15) and similar procedure (6.2.4) were all kept.

On the far right-hand side corner of the table was positioned the 24" TV flat screen to show participants the hints for the problem at the established time. On the table (Figure 5.15) were placed the eight coins positioned in the initial configuration (Figure 5.13) and above this workspace was attached an image of the initial configuration as a reminder to reposition the coins after each unsuccessful two-move attempt to solve the problem. Also, participants were given a blank sheet of paper and a pen to make notes during the experiment if they wished to do so.

The MacBookPro laptop was placed on the researcher's table to provide participants with multimedia hints at the designated time, monitor if they were properly following the instructions, and observe their behaviour and make notes.

Participants were randomly assigned to one of the two conditional groups or the control group. Each participant was provided with two sheets containing a detailed explanation of the study and a consent form to be signed.

After agreeing to participate in the study, participants were randomly assigned to the control or one of the conditional groups and each subject was tested individually. Each participant was given a sheet of paper with the instructions for the assigned category: control or conditional. Thirty-two were assigned to the *control group*, thirty-two to the *misleading* hint group and thirty-two to the *only up* hint group. The *misleading* and *only up* hints groups were divided into two subgroups. Analogies capturing the force-embodied schemas were given to the first subgroups from each category after two minutes of working on the problem and the ones capturing gesture schemas after four minutes of working on it to the end of the test. To the second subgroups were given the gesture first then the force as a second hint.

We used the same instructions that were given to the group of participants in the continuous animation / realistic conditional group for second experiment, with the exception that multimedia hints of 25 sec each in length were provided for this experiment. The reason for shortening the sequences for this study related to its slow movement, and 30 seconds in the second experiment seemed too long when the actions were adapted to the conditions of our design.

At the end of the session, each participant was asked to complete the questionnaires with the same questions as for previous two studies. With the consent of participants, the sessions were video recorded for further analysis.

All ninety-six participants met the criteria for this experiment and were included in further analyses.

7.3 Results

Table 11 shows the number of participants who solved the problem in each condition during the experiment (first schema period and second schema period).

In order to test our hypotheses for this experiment, we conducted a 3x3x2 mixed factorial ANOVA test with the first two factors as between-subjects factors and the third factor as a within-subjects factor.

The 3 (Type of Insights) x 3 (Order of Schemas) x 2 (Image Schemas) mixed factorial ANOVA revealed that the main effect for the type of insights provided to participants in the *8-coin* problem solving task was statistically significant $F(1, 91) = 12.344$, $p < .001$, Partial eta-squared = .119. The magnitude of the differences in the effect size between the three groups was moderate approaching large.

A post hoc comparisons using the Tukey HSD test indicated that the combined mean score for the *only up* hint condition ($M = .50$, $SD = .508$) was significantly different to both the *control* condition ($M = .06$, $SD = .246$) and the c*onfusing/misleading* hint condition ($M = .16$, $SD = .369$) during both periods of time spent on the task (see Figure 7.1).

The comparison showed also that the *confusing* hint experimental group (M = .16, SD = .369) did not significantly differ from the *control* group condition.

A non-significant main effect for the order of schema type was obtained, F (1, 91) = .102, p > .05, Partial eta-squared = .001. The differences in the effect size between the groups were not significant.

Experiment 3 – Visual Analogy / Animations

	Groups	Subgroups - Order of hints	Subjects	Time 1 [2>4 min]	Time 2 [4>6 min]	
	Control group **[A]**	N/A	32	1	1	2
	Conditions:			**Within subjects** First schema **[D]**	Second schema **[E]**	Total solved:
Between subjects	Confusing hint group **[B]**	Force hint 1^{st} **[b1]**	16	1	2	5
		Gesture hint 1^{st} **[b2]**	16	1	1	
	Only up hint group **[C]**	Force hint 1^{st} **[c1]**	16	2	7	16
		Gesture hint 1^{st} **[c2]**	16	3	4	
	Total solved:			8	15	23

Notes on independent variables:
Type of insights *–3 levels: Control* **[A]**, *Confusing* **[B]** *and Only up* **[C]** *(between subjects)*
Order of schema *– 3 levels: Control* **[A]**, *Force* 1^{st} **[b1+c1]** *and Gesture* 1^{st} **[b2+c2]** *(between subjects)*
Image schemas *– 2 levels: First schema load* **[D]** *and Second schema load* **[E]** *(within subjects)*

Table 11 Results / Experiment 3

However, the generated plot (Figure 7.2) and post hoc Tukey HSD test indicated that the mean scores for both the *force 1st* (M = .34, SD = .483) and the *gesture 1st* conditions (M = .31, SD = .471) were different to the control condition (M = .06, SD = .246). On the other hand, the *force 1st* condition (M = .34, SD = .483) and *gesture 1st* condition (M = .31, SD = .471) did not significantly differ from one another.

These comparisons suggest that the presented animations embodying force and gesture schemas do have an effect on participants' performance in the *8-coin* problem solving task compared to the results for those who do not receive any schemas. In other words, our results suggest that when participants are presented with animations embodying image schemas such as force or gesture, their performance in problem solving increases. Nevertheless, it should be mentioned that regardless of the type of schema proposed for embodying in the animation content, these image schemas must capture the problem insights accurately and prevail over other present families of schemas that might obscure their visibility.

Additionally, the interaction effect between type of insights and order of schemas was not significant , F (1, 91) = .918, p > .05, Partial eta-squared = .01.

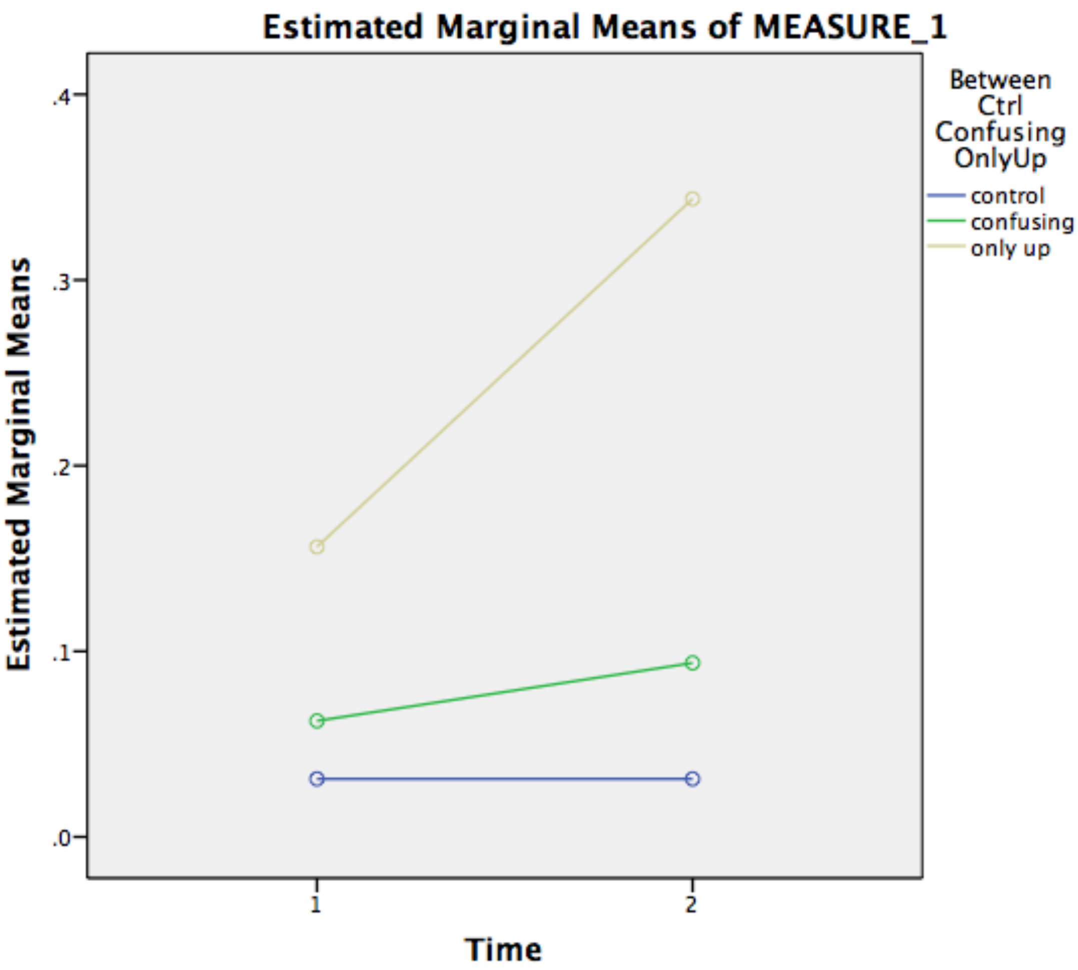


Figure 7.1 Plot of the results for the type of insights between IVs

The main effect for the image schemas as the within-subjects factor (first schema and second schema) conditions was not significant, F (1, 91) = 2.455, p > .05, Partial eta-squared = .026.

Also, the type of insights x order of schemas x image schemas interaction result was obtained, F (1, 91) = .068, p > .05, Partial eta-squared = .001 and showed no significant interaction effects between these IVs.

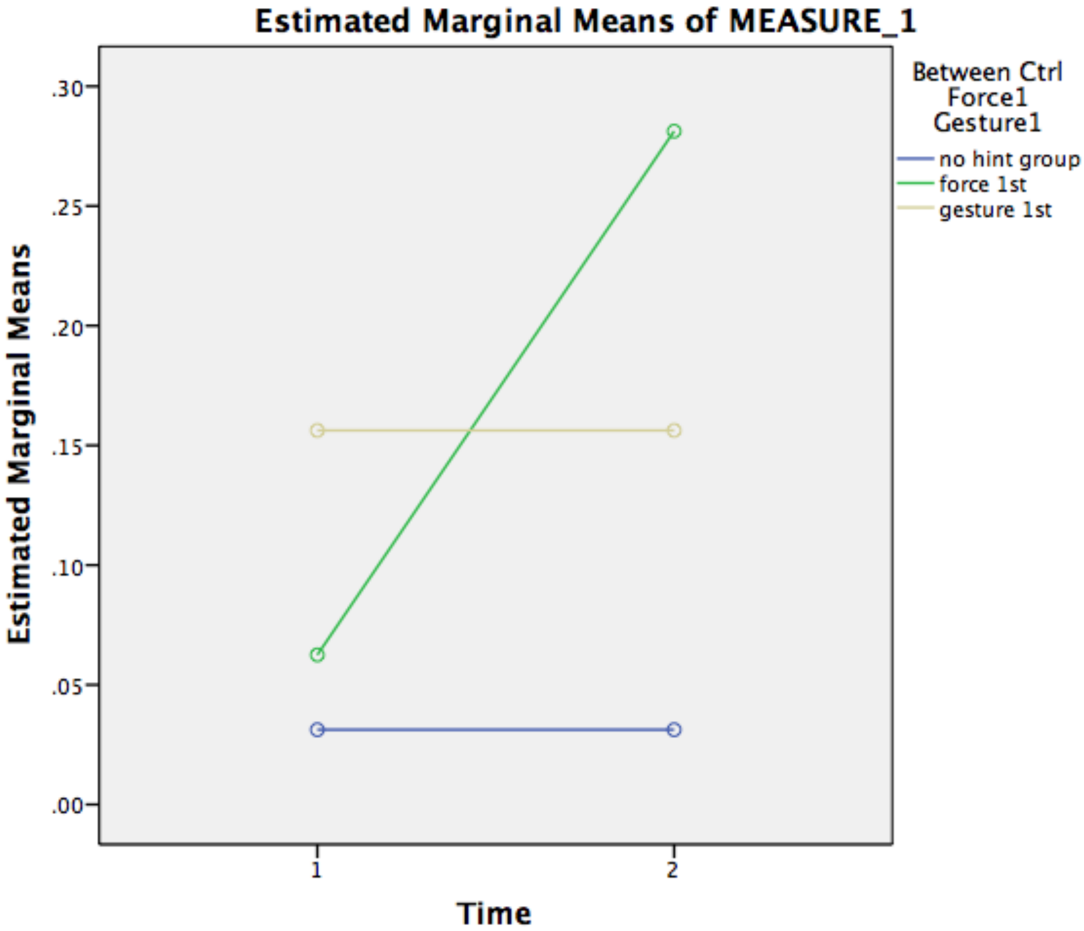


Figure 7.2 Plot of the results for the order of schema between IVs

Type of hints (between subjects)	Number of participants solving the problem		
	[2>4 min]	[4>6 min]	
Control group **[A]**	1	1	2
Conditions	First schema	Second schema	Total:
Confusing hint group **[B]**	2	3	5
Only up hint group **[C]**	5	11	16
*Number of participants per condition: Control **[A]** = 32, Confusing **[B]** = 32 and Only up **[C]** = 32*			

Table 12 Type of hints between subjects result for the experiment

7.4 Discussion

The prediction that participants receiving gesture schema first in the problem tasks are more likely to solve the problem compared to those receiving the force schema first was not supported by this study. However, taken together, the results of this experiment suggest that hints partially capturing the insights of the *8-coin* problem and presented in the proper sequential order in the animation do have an effect on participants' performance in terms of finding the correct solution. Specifically, our results suggest that when participants are presented with animations that partially capture the insights, they do solve the problem more often than those who are presented with confusing/misleading hints or no hints at all. Nonetheless, it should be noted that the animations must capture and present the insights in the proper sequential order for an effect to be apparent.

The prediction for **H1 Order of schema hypothesis:** individuals are more likely to solve the problem when they receive the hint capturing the insight through the gesture schema first rather than receiving the hint capturing the insights through the force schema first during the problem solving task was refuted by ANOVA analyses. Interestingly, this seems to contradict our findings from Experiment 2, where our **H3 Image schema hypothesis** predicted that visual analogies capturing the insights needed to solve the problem through image schemas lead to a higher success rate when represented through gestures rather than forces, which was validated in the previous experiment. We closely analysed the visual analogies provided in both experiments and speculate that the negative outcome in this experiment was due to the unequal match of correspondences in animations between groups. The variables of the reversed sequential order of insights and partial delivery of the insight conveyed the insights in a slightly different way. For example, in a comparison of how the insights were captured through the gesture and force image schemas in the provided animations, it was observed that in the "Photography session" scene an additional action was depicted. Towards the end of the animation that was provided to participants from the *misleading* group, the child is pushed down onto the floor; in the "Billiard game", it was not possible to convey the same visual effect, as the balls were rolling on a solid surface, and could not be distorted or made to go through the game table. Other differences between the animations used in the two experiments were that in this experiment we focused more on the impact of the order in which gesture and force schemas were provided and not on the separate success rate generated by these schemas. We purposely included the push-down-child action in the gesture schema to measure the effect of a misleading element in comparison to a force schema in which this element was not present. Thus, violating the *apprehension* and *congruence* principles (Tversky, Morrison, & Betancourt, 2002) in the construction of visual analogies may confuse participants in problem solving when presented with such analogies.

Our prediction for the **H2 Type of insight hypothesis:** Visual analogies capturing only the stacking insight for the *8-coin* problem and presented to participants in an adequate sequential order support better incubation effect than those capturing the grouping insight and presented in a reversed mode (*confusing/misleading* hints) is supported by ANOVA analyses.

When analysing the effect of provided visual analogies capturing only the stacking insight in this experiment, we observed similar patterns in participants' behaviour as during our first experiment, where we provided the insights in the same order in which they were provided in Ormerod et al.'s (2002) study, grouping first and stacking second, captured in separate images. Most participants were starting to make their first moves in the *8-coin* problem with the insights that were represented in the image, and then when presented with the second image, they were jumping to imitate the second insight and forgetting about their connectivity in the problem. Thus, a large number of the participants, in this experiment too, moved one coin on top of the rest, then counted how many other coins were touching, then moved the same coin to the edge of the group and counted again. Participants in this experiment had the same difficulties of overcoming the fixation as those in the first experiment where they were provided with static images instead of animations. Interestingly, both experiments generated a similar success rate: 50% of participants from the Representational 3D condition for the first experiment succeeded and 50% from the Only Up condition in this experiment were successful at solving the problem. This suggests that both insights are important in the *8-coin* problem solving task, and that they should be captured in the visual analogy in a synchronous manner in order to have an impact on participant success rates.

A significant contribution of this study is in validating the H2 hypothesis; this confirms the importance of integrating both insights in the visual analogy construction process.

7.5 Conclusion

The study explored the effects of the type of insight (i.e., grouping, stacking) captured in animations provided to hint the solving process on the solution rate for the *8-coin* problem and the impact of the order in which force ("Billiard game") and gesture ("Photography session") schemas were provided.

The findings confirm that visual analogies capturing the stacking insight are more effective in generating more correct solutions for the *8-coin* problem when they are provided in the appropriate sequential order. However, as per suggestions from the discussion notes for Experiment 1, a strong bond between the two insights appears to be a prerequisite for solving the *8-coin* problem. The assumption that the stacking insight is more important than the grouping one may be due to the fact that participants failed to detect the grouping hint presented in a reversed order through moving objects (balls, people). Thus, grouping may not be considered a determinant insight in finding the solution to the *8-coin* problem, but it is rather a result of the stacking insight action. When the stacking insight is prompted during the problem solving task, they both occur simultaneously depending on each other's next moves, thus both insights are important in successfully solving the problem.

Findings also suggest that participants who received both schemas captured into visual analogy cueing generated a higher solution rate for the *8-coin* problem than participants who did not receive hints. Thus, regardless of the type of schema provided, visual analogies partially capturing the problem insights may work well when presented in a proper sequential order.

8 Visual Analogy Represented from a Three-Dimensional Perspective

This chapter presents a preliminary work-study involving the construction of visual analogies to support the insight in problem solving and test their effectiveness. In this study, we are focusing on the effects on performance in problem solving when using visual analogies to capture the objects from two perspectives: Normal Eye View and Bird's Eye View. The correspondences of objects involved in a visual analogy representation (e. g., animation), and the quantity of correspondences in terms of the relations between objects and relations linked to capturing the insights for the *8-coin* problem are manipulated in this study, as well.

8.1 Chapter Overview

This chapter begins with a brief introduction of the background information about the topic under investigation, including some references to the published literature about the recognition of objects in space, in particular for the two points of view: Normal Eye View and Bird's Eye View. This is followed by a description of the rationale and research questions, method, results, discussion, and concluding notes sections.

8.1.1 Experiment 4: Rationale and Research Questions

Interpretation of imagery often relies on experiences from memory of where objects and things are located in the environment. This interpretation is produced by experiences of perceptual and motor systems, which usually have a particular perspective and are stored in long term memory: seeing, gaining, grasping, touching, and moving. Because they are mobile, people can approach the environment from many directions and points of view. The difficulty of recognising unfamiliar views of space will depend on how spatial relations are encoded. According to the claim that they are encoded independently of viewpoint, then both familiar and unfamiliar views of the space will be equally accessible for recognition (Marr, 1982; Biederman, 1987; Presson, DeLange, & Hazelrigg, 1989). However, some researchers, such as Rock and DiVita (1987), state that spatial relations are encoded in a view-specific manner, and that familiar views are more accessible than unfamiliar ones; they state that, in some cases, the latter may not be recognisable at all. Several studies (Rieser, 1989; Shelton & McNamara, 1997) on viewpoint dependence indicate that spatial relations are represented in a view-dependent mode, and that recognition of an object from an unfamiliar viewpoint is achieved by transforming the unfamiliar from the combination of multiple viewpoint-dependent representations retrieved from long term memory storage. The questions we asked in this study were to ascertain which view on the spatial relations of object recognition fits better into the visual analogy development process, and which point of view is more accessible for allowing recognition of the visual analogy objects in an animated clip.

To create animations for this experiment, we focused on the visual analogy objects' spatial placement, allowing us to explore the effect of angles and points of view, for which an analogy is presented to the solver. Spatial data of objects can be presented in both static and dynamic media. In the context of dynamic representation, as in our case, time and movement are involved; thus, the objects change their position.

Recent studies (Stevenson, Touw, & Resing, 2011; Siegler & Svetina, 2002) have shown that children of 4-5 years of age process objects and colour most easily in analogy features, and next most easily according to their size and orientation; however, the quantity and position information appeared to be the most difficult for them to process. Although findings (Stevenson, 2013; Pronk, 2014) suggest that this difficulty decreases with age and with training in analogical reasoning, limited work has explored whether the difficulty disappears with maturation and gained experience, and more importantly, with no special training in analogical reasoning.

The chapter presents an experimental study addressing the following research questions:

- Which point of view more effectively captures the insights in visual analogy for problem solving: Normal Eye View or Bird's Eye View?
- Which strategy is more effective in constructing visual analogies for problem solving: *one-to-one* mapping of numbers of items or *one-to-one* mapping of the problem insights?

To answer these questions, we designed eight short animated clips capturing the insights for the *8-coin* problem. The variations in the content and presentation of the animated hints provided are described in the following sections.

8.2 Method

In this experiment, a similar method as the one used in our previous experimental studies on the *8-coin* problem was employed. The differences are highlighted in the following subsections.

8.2.1 Participants

A total of 125 undergraduate and graduate students from Lancaster University participated in this experiment. The sample consisted of 51 (41%) males and 74 (59%) females with a median age of 23.5; 37% of the participants were younger than 21, 58% were between 21 and 30, and 5% were over 30 years of age.

8.2.2 Materials

This section describes in depth the visual analogy development of the stimuli that we used in this study, the materials, procedures, and methods used to gather the data in terms of the differences between the current and previous experiments and design along with our hypotheses.

8.2.2.1 Stimuli – Development of Visual Analogies

We employed the same techniques and methodology in the development of stimuli for this experiment as in the previous studies.

For this experimental study, we focused more on subjects that are closely related to the real world or that are inspired by real-life situations and are appropriate for a multimedia format. The reason for focusing on real-life situations is that people are more familiar with the objects that surround them; therefore, this can help unload memory and direct their mind-set towards reflecting on object relationships, activities/actions occurring in that situation and their conceptual relations.

Secondly, if one has an unfamiliar problem to solve and does not know how and where to find possible solutions, it would be easier for one to look for analogy in the surroundings than to become familiar with problem solving processes, to find similar cases in the literature with varying degrees of appropriateness, and then proceed to solve that problem. For example, it is easy to build something (e.g., an IKEA furniture piece) just by opening a box, finding instructions there, following them and building it. However, if one were to receive only several pieces of wood and a hand saw in a box, along with a sign with an invitation to “create your future chair”, a more general “mind-set” that calls for cross-domain analogising would be required to solve the problem.

Thus, in the process of generating this set of potential visual analogy candidates for this experiment, we focus on themes and subjects that evoke both object semantics and abstract relational reasoning.

Initial Ideation

At the ideation stage, we focused on generating new and varied content concepts for visual analogies with a view to increasing the performance in insight problem solving. For this experiment, a total of twelve sets of concept sketches were created as analogy candidates to investigate their role in the *8-coin* problem solving further. The ideation stage is continuous through the entire process of development. As one idea is transferred in the sketchbook, another can enter the mind. Most of the techniques employed in this ideation process are similar to the ones described in previous studies such as brainstorming, design-by-analogy, and designer methods.

Sketching Analogies

As for the previous practice of developing analogies, I begin by doodling my thoughts on paper first. Goel (1995) claims that mental states have certain properties (i.e. fluidity, ambiguity, impreciseness, amorphousness, etc.) that are shared by the symbol system of sketching. To move from these states to more constructive thinking, he suggests focusing on lateral transformations in the early stages of sketching so one can easily shift from one idea to entirely different ones and generate new concepts. At that point, ambiguity ensures the flow of ideas, so one does not want to determine the idea too early and freeze the design development. I start sketching the frames first, then, I think of objects, people, or relationships for my future analogies.

In the top left frame, I started sketching rectangular prisms, stacked on top of each other, resembling the second insight in the *8-coin* problem (Figure 8.1) I used a soft eraser as if it were a white drawing pencil to show contrast, and to interrupt or fix lines that I did not like. This led me to the idea of drawing Egyptian pyramids in the next frame.
Both types of pyramid have differences in structure and function, but they share symbolical similarities. Both of these types of pyramids symbolise a bridge between the earth and the heavens, which made me think about the human desire for connection with the divine.

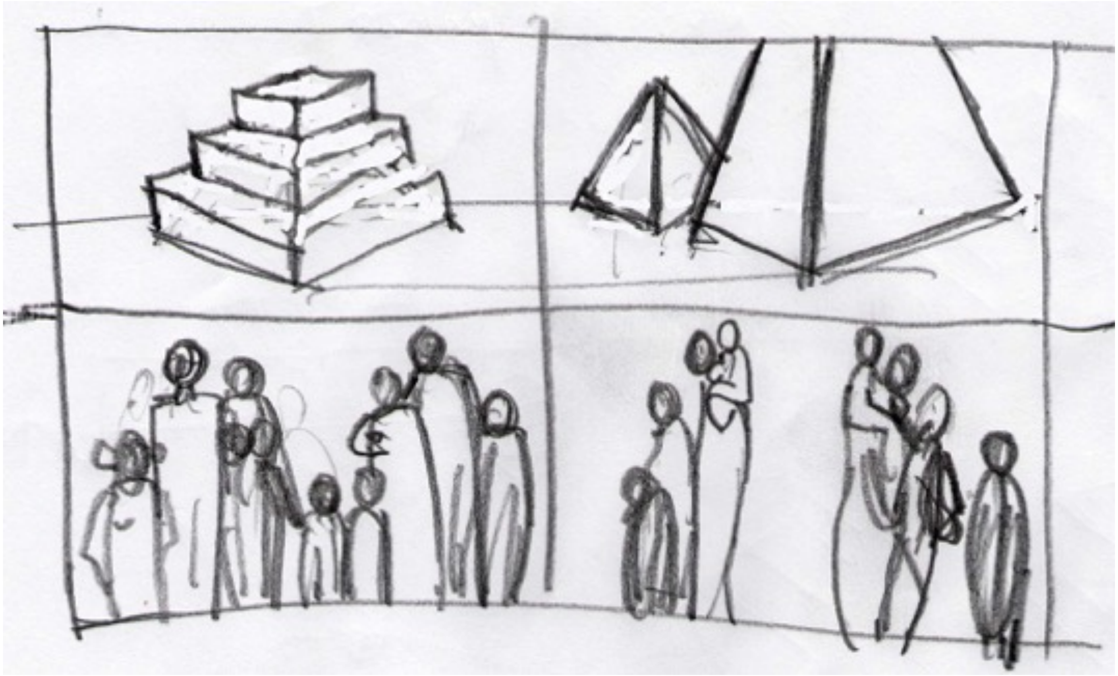


Figure 8.1 Ziggurat pyramid

The bottom frames of the figure represent humans forming a composition capturing the grouping insight. I decided to vary the objects' forms and the people's arrangement to give the concept a sort of movement and at the same time, to create a dialogue between them, like a bridge as mentioned above. In the frames at the bottom, I chose to depict people in different ways, whilst retaining structural mapping close to the idea of grouping in both frames, and adding stacking in the frame on the right. Could this be a family vacation in Egypt? Can it be represented in a multimedia format for an analogy as an aid in the *8-coin* problem solving? A possible combination of the upper concept with the bottom concept might generate an interesting analogy. As these two concepts (humans in the forefront and pyramids in the background) are arranged in different psychological spaces (*figural* and *vista)*, both subjects could independently capture the necessary insights to solve our problem, as well as suggesting the processes by showing them in the animated clip with a delay in time. I could also vary the number of family members used in the animated clip and create more IVs, to test its effectiveness in the problem solving task. The purpose of building such an architectural monument made me think about the tools the humans used in its construction.

The ones that were first retrieved were the ones I am very familiar with. So, the use of a caterpillar (Figure 8.2) as an operator tool came to my mind as the next theme in generating visual analogies. Regarding thematic relations, a caterpillar at work may capture the necessary transformations required for the insight so that one can move from one stage to the next to make progress in solving the problem. It also captures the action image schema (i.e. up-down, left-right, and front-back) through the caterpillar's movement in the scene. The future composition of the construction site and a caterpillar could be shown from different angles, but a frontal or a perspective (isomorphic) view is more familiar to viewers and may give information that is more accurate about the space they are in than would the top, bottom or side views.

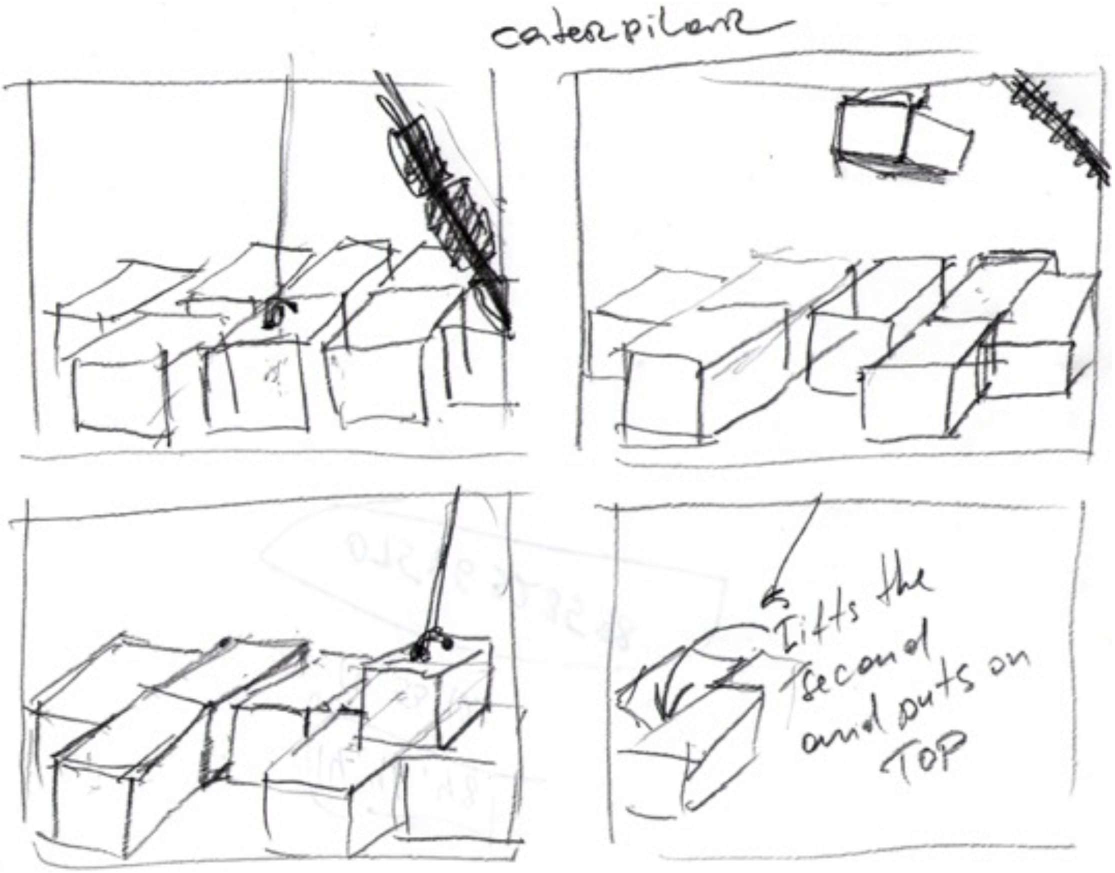


Figure 8.2 The caterpillar 1

The layout and arrangement of the concrete blocks can be mapped with the layout and arrangement of the target problem; additionally, the number of items can remain the same as for the problem. The movement of the blocks by the caterpillar will simulate a similar trajectory and the moves required to solve the *8-coin* problem.

While I tried to focus on similarities in both structural mapping and relations between objects and predicates in previous sketches with the caterpillar, in the *Family vacation*

(Figure 8.3), I decided to explore the relationship between concepts and attributes more, and possibly, their predicates (raining) through the actions of family members that could be captured in a time-based multimedia format (i.e., motion design, animation, movie, etc.).

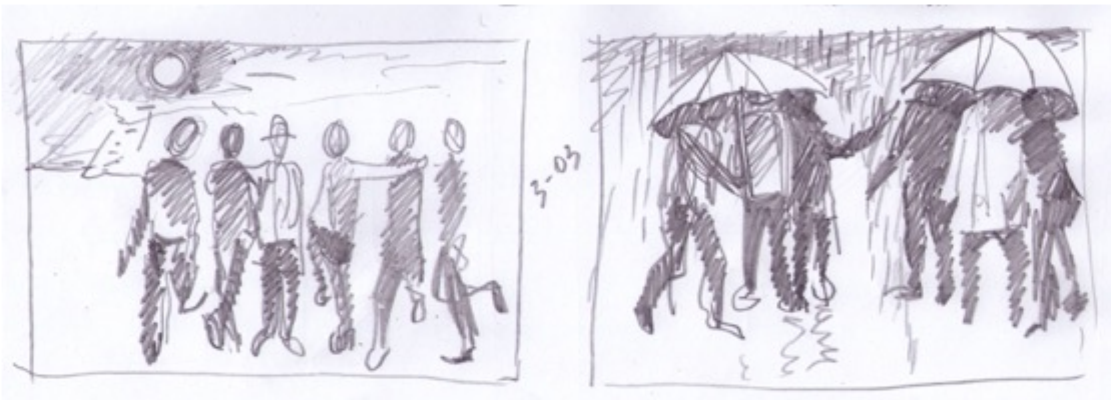


Figure 8.3 Family vacation

The first rough sketch with the sunset intention was done to capture the stacking hint (the sun goes down over the pyramid) while the entire family separates into two groups (grouping hint) for better viewing. We argue that the stacking hint in the *8-coin* problem generates the outcome of the grouping hint, so they are interdependent and both critical in reaching the correct solution.

The second concept with the rain might better capture this relation in the following scenario: family members are shown in a group. With only two umbrellas, they separate into two groups to avoid getting wet, once the rain starts. In both concepts, the first objects that move (the sun and the umbrellas) are intended to represent the movement of the first coins in the target problem. This may be somewhat confusing in terms of structural mapping similarity, as the sun (a single object) does not match the number of coins to be moved, and, the arrangement is unclear even though all compositional elements could be emphasised as a whole in further development.

It seems that an image captures objects located in different psychological spaces – the compositional elements are more likely to be perceived as groups depending on their location (family members in the foreground are in *vista space*, the pyramid is in *environmental space*, and the sun is in *geographical space*). The concept on the left seems to capture the insights through the similarities between the relations of elements, with the two umbrellas covering each group of three, but then, at the same time, the structural mapping is weak and confusing (one coin on top of three coins in the target vs. an umbrella over three humans in the source).

The next two versions of concepts in Figure 8.4 represent some searches for new ideas. The left is based on the actions performed by humans and intends to capture the stacking insight through image schema: pick it up, move it, and drop it down. The fourth person (on the far right) who separates from the group by moving and then dropping the brick on the construction wall was intended to capture both the separating and stacking insights simultaneously. Looking at the sketch after it was done, I thought that it would be better to depict the other people as being motionless, to retain accurate mapping in terms of the group of non-moving coins in the problem.

The second version is a simulated game my friends and I used to play as children after our football practices. As the stadium was under construction, we improvised games using objects that we found in the areas that surrounded it (we did not have the likes of iPhones or iPods back then). One such game required each of us to kick the ball through a set of bricks, while the goalkeeper tried stop it with a brick in his hands. The footballer could kick the ball just above either set of bricks that were arranged next to the goalposts. An image or short animated clip of the game as an analogical subject could be very difficult to interpret without prior knowledge of the rules of the game, and could further confuse the participants in our experiment. Even though I consider both concepts from Figure 8.4 as weak candidates for an analogy for the *8-coin* problem, they gave me new insights in terms of exploring other themes for this topic. For example, the search for the best visual analogy for our experiment takes place here in the frame space, often designers call it simply a search space, even though it is a combination of both problem space and solution space. The information that fuels these search acts originates from the knowledge base (i.e., analogies, art, science, etc.) stored in the memory which facilitates the retrieval of information through associations (a childhood dream, a game or something experienced at five years old, etc.). Externalising mental images in the physical world, the designer transforms them by adding or fixing relevant information about properties, functions, or relations between the sketched objects. In this way, the information is ready to ease the memory load and assist further in explorative thinking when analysing the images or generating new ideas later on. Such sketches do not necessarily have to be finished. Usually, professional artists do not bother to make them accurate or complete, as long as they capture the information stored in their minds. Some marks – and very often those that are not skilfully executed to match with the ones in mind – are exaggerated or lack scale and provide unexpected hints for further development.

Another benefit of these kinds of sketches is that they engage the creator in a cyclic dialogue with the self (the mind, the eyes, and the hand) facilitating a continuous feedback for further transformations in design.

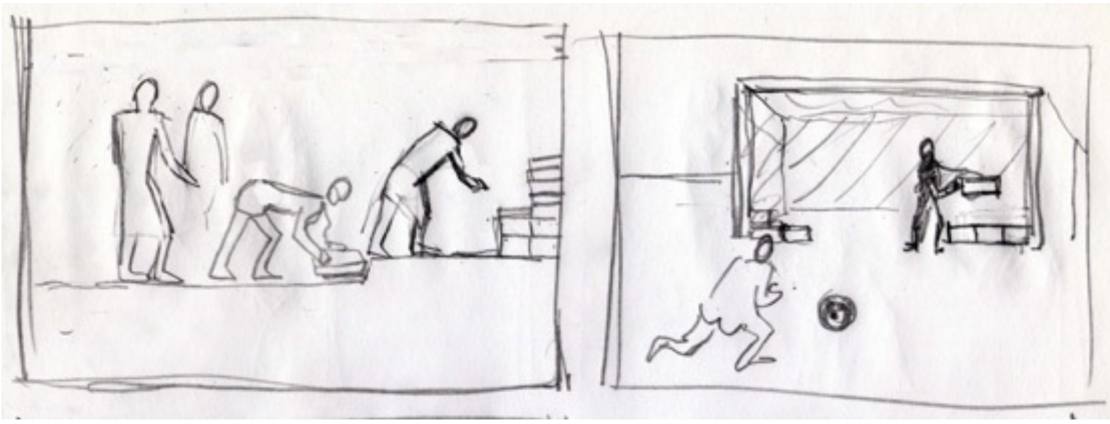


Figure 8.4 Egyptian construction site (left) & Footballers (right)

In Figure 8.5, I came up with a subject inspired by a real-life subject. The six-frame storyboard is intended to capture, in a multimedia format, the construction of a rustic style gate from large pieces of lumber. In the first frame, the pieces of lumber and a character form the whole composition, with the focus being on the human who is placed at the centre. The pieces of lumber may be associated with the coins and the human activity with the actions needed for the insights in the *8-coin* problem. The storyboard captures several elements and relations in a symbolic way, but all are linked to one aspect of the insights for the *8-coin* problem or another.

The subject, involving breaking a hole in the fence and creating an open gate from its pieces, is a process of problem solving itself. The top of the gate was added in the final two frames of this storyboard, which made sense in terms of solidifying the idea of the stacking hint; however, it might be a little confusing as the extra element is an addition to the mapped correspondences with the target problem, thus representing a *nonalignable* difference.

Hoping to come up with new concepts, I decided to shift from this representation to another representation, retaining the same kind of correspondence and mapping but in a different situation. The shift is usually based on transformations using some intuitive rules. One of the methods designers use is to decompose the wholes captured in the previous concepts into parts (e.g., a sketch of a landscape to be decomposed into its elements: houses, trees, mountains, fields, sky, etc.) and to replace some elements with new ones, evaluating the outcome and making a decision to go further with the design or to return to the generation phase. This shifting in representational method can be applied at symbolic or abstract levels as well as by combining two or more previous concepts. This process is considered essential in design practices and is mostly applied when generating ideas for new products or in solving creative problems.

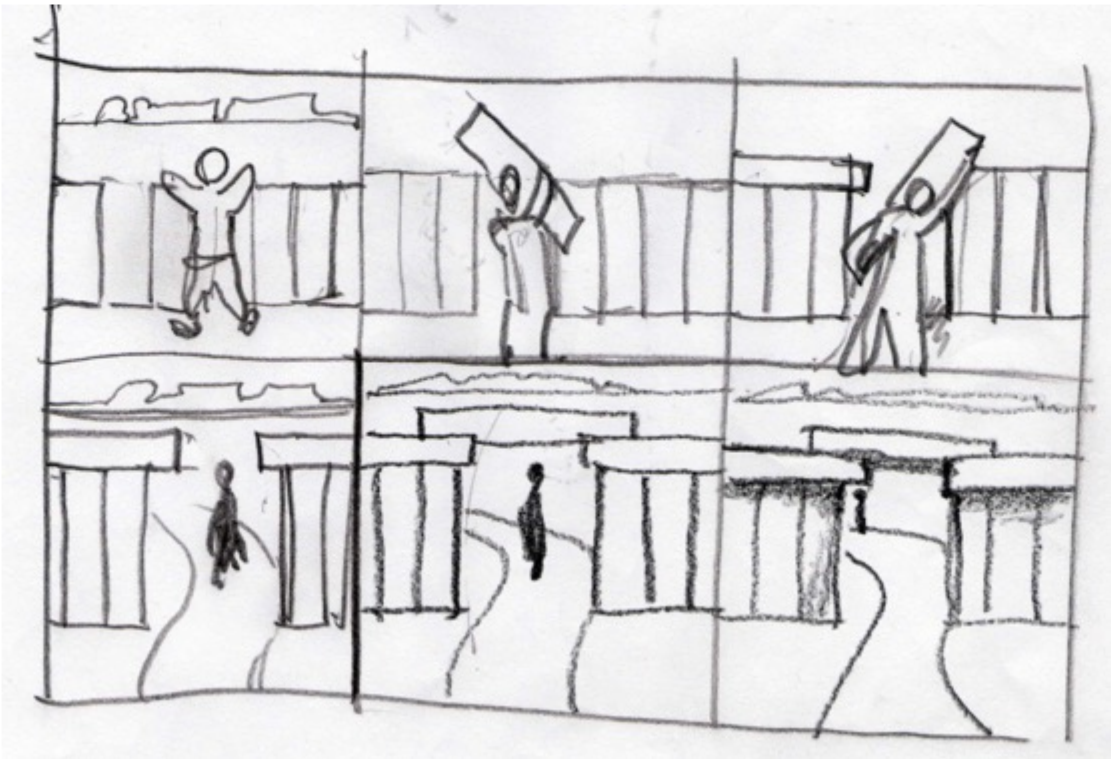


Figure 8.5 The gate

On the other hand, due to the nature of visual analogy for the insight problems, which are based on the similarity-recognition process and where the correspondences are consistently mapped with the ones in the target, the method of combining abstract concepts could become very complex and somewhat ambiguous. Also, past research provided evidence that the individual producing the analogy may influence the process of analogy selection and transfer (Spellman & Holyoak, 1996). Blanchette & Dunbar's (2001) study has shown that goals influence the choice of analogy, and the person making the analogy is more likely to have the tendency to focus on the domain-specific and task specific, being driven by these goals. To avoid being biased by our goals, I looked for inspiration from other domains like engineering, construction, or architecture to generate analogies.

In this search for new ideas, I am focusing on mapping similar properties of objects/instruments (functions or attributes) depicted in the previous sketches on this theme as part of the process of generating a new concept.

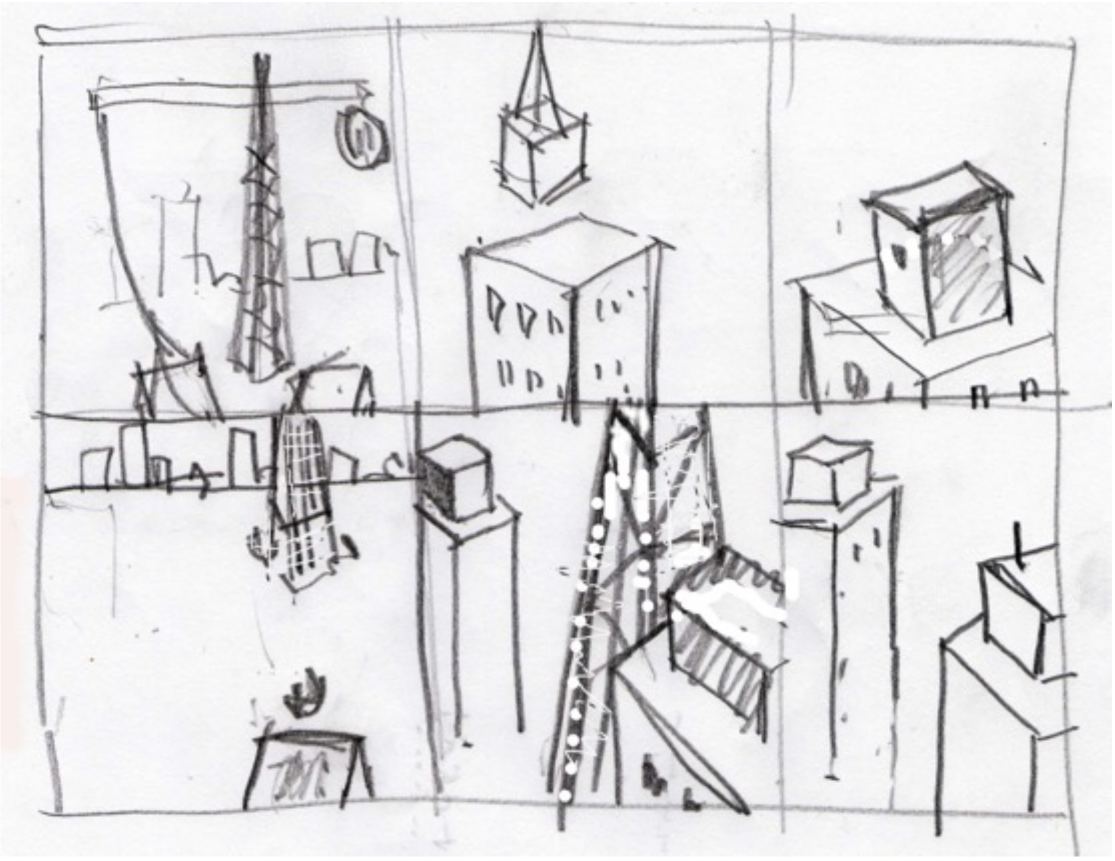


Figure 8.6 Construction site

Figure 8.6 captures a city construction site from a variety of angles. The sketches from the six frames depict the same landscape with a variation in the angles and scales including close shots of the object details. The forms and materials used in this sketch have a deliberate purpose. It was a deliberate choice, for example, that I am confronted with a bunch of construction materials that can be moved by operators to facilitate the changes needed for the insight. While analysing each frame, it occurred to me that moving buildings or even large parts of a building, with a crane as the operator, would not make the scenario believable and realistic, so I decided to decompose the building into even smaller elements. To get insights on forms and shapes that resemble the objects from the *8-coin* problem, I entered the keywords “construction materials” in the Google search bar to find some images for inspiration. After browsing the Internet for more than an hour, several items caught my attention. I thought that some rounded blocks and concrete pipes might be good candidates for future analogies, so I started to sketch some scenarios with these materials and the crane in my sketchbook.

The sketch from Figure 8.7 is the result of combining the construction theme from the previous sketches (Figure 8.2 and Figure 8.6) by replacing objects or transforming them. In comparison with the sketch from Figure 8.2, I changed the forms of construction pieces in the composition, in addition to increasing the number of items as a variation of the concept.

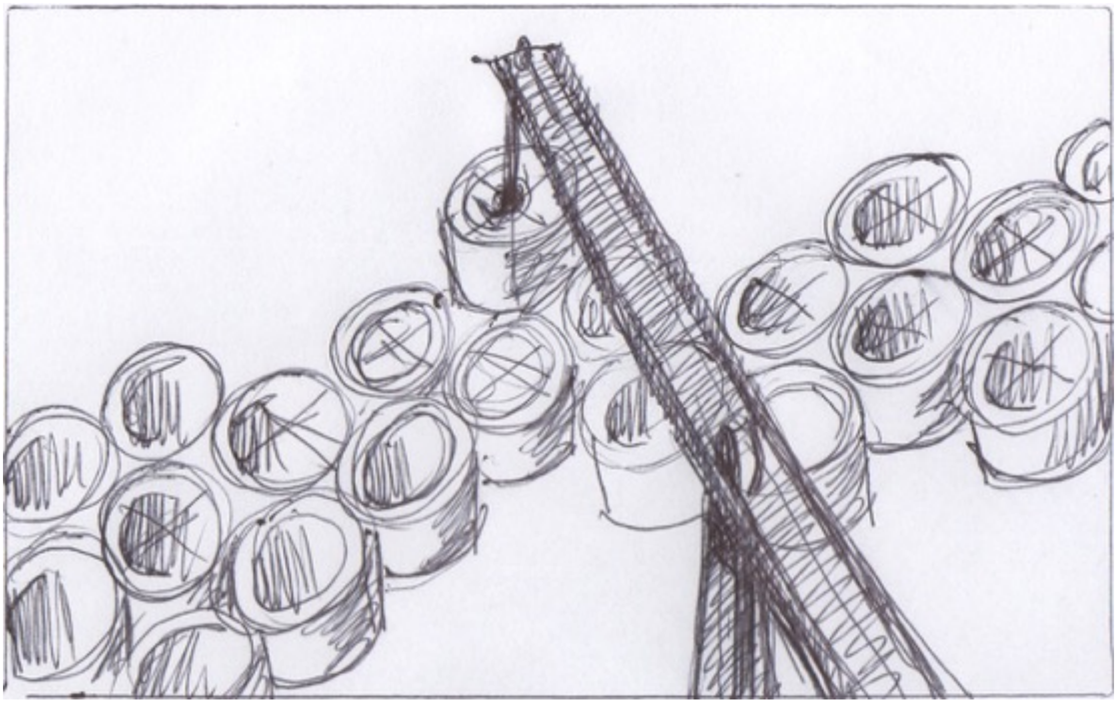


Figure 8.7 The caterpillar 2

In the next search to generate a new idea, I thought of taking a minimalistic approach in my composition. I played a little with some primitive pyramidal forms (the first row from the top of the sketch in Figure 8.8) to see if I could compose a simple type of housing complex with a structure so designed that each unit would be exposed to sunlight from at least three sides. In the middle row, the deco-style building on the left resembles the structure of the initial configuration of the coins, while the one on the right suggests grouping and stacking hints needed for the insight to find the solution. Noticing that the layout of the left building did not correspond structurally (i.e., it was flipped vertically) with the one provided in the initial configuration of coins, I decided to change the terrain from flat to a valley aligning these analogical correspondences. The building structure on the right-hand side of this sketch seems to capture the correspondences of the target for the *8-coin* problem accurately.

Figure 8.8 Future city

To create a new version of the same concept by retaining structural mapping similar to the previous sketch, I made an attempt to shift my search from *vista* to *figural psychological* space (Montello, 1993). In a discussion with my supervisor on generating new concepts, she suggested focusing on analogies that are based on small stackable pieces and that are close to the size of the coins from our problem, mentioning cupcakes, pies, or even certain Lego puzzles. The action of making cupcakes and stacking them on top of each other before putting them in the oven resembled the actions that were required for the insight for the problem. The cupcakes were easy to manipulate on the table, could be arranged in a variety of layouts, and could be represented from the same point of view as the coins in the problem; in addition, they shared surface similarities with the coins with the top rounded surface of the cup holders. A human hand manipulating the cupcakes might suggest the actions required to reach the insights in finding a solution for the *8-coin* problem.

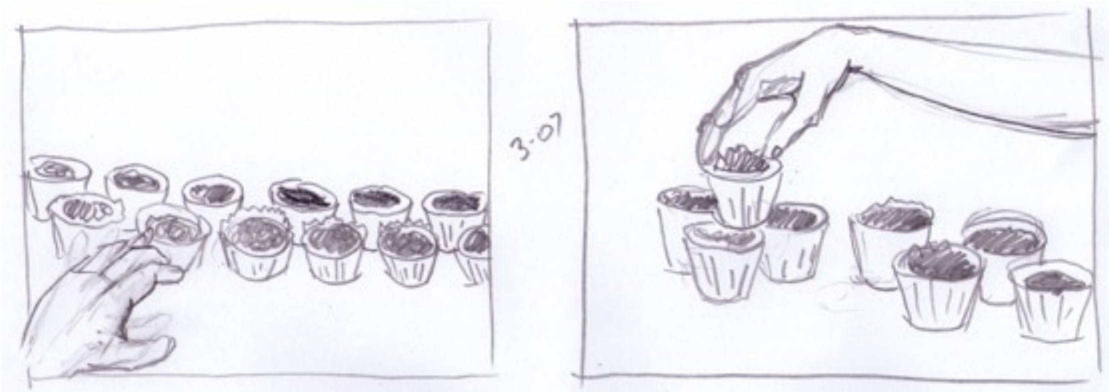


Figure 8.9 Cupcakes

Figure 8.10 is a sketch of a new concept using a tube map. The image from the left is an old map version, while the image on the right is a new version of the same map presenting the tube stations in a symmetrical arrangement.

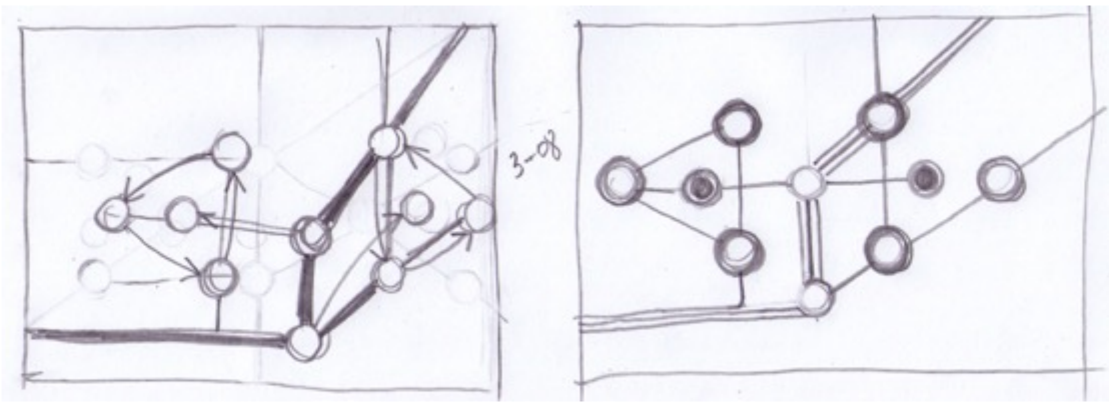


Figure 8.10 Old and new tube maps

The differences in these maps are in their representation. While the old version of the map represents tube stations geographically more accurately, the new version looks more like a diagram with the intention of making the tube connection and navigation for travellers easier to read. The new graphic image of the electronic map was intended to show the locations of the train tracks, their directions, and live movement of the tracks in a future animated clip. Inspired by the innovative design of Beck's London

Underground map (Gonzales-Aguilar & Vaisman, 2015), where he simplified geographical mapping into a system of three variants (horizontal, vertical and diagonal lines), the future visual analogy was intended to give participants hints for grouping the coins through rail line connections between stations and train movements in terms of necessary actions for the stacking insight. The first train moves on the central rail line (image from the right-hand side – horizontal line from the bottom), heading toward the station located at the centre of the left-hand side triangle by making a stop at the first station. The second train starts its journey from the same point, but makes its stop at the second station, then reaches its final destination in the station located at the centre of the right-hand side triangular configuration of the other three landmark stations. In the present static sketch, it is somewhat difficult to visualise the moving train tracks on the map; however, a well refined and finished animated diagram might be an effective analogy for the problem solving task as opposed to using arrows (Tversky, Morrison, & Betancourt, 2002) to show direction on the map.

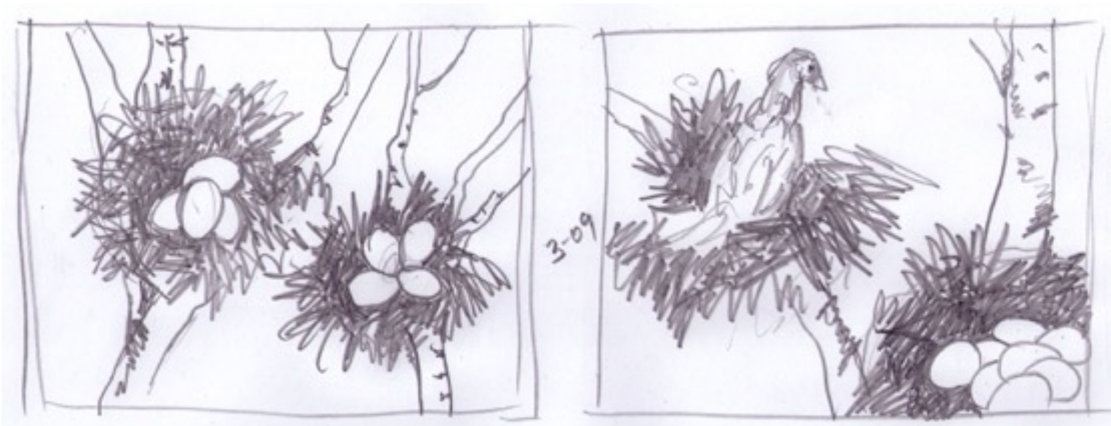


Figure 8.11 Bird's nest

The spring birds' "dawn chorus" gave inspiration for the next concept for a potential analogy for the problem. The purpose of these birds' sounds in the spring season is to attract potential mates for reproduction. A bird's nest with eggs in it (see Figure 8.11) might suggest growth and, consequently, while creating images or multimedia which includes this subject, its components can be manipulated in a variety of ways to meet the requirements for capturing the hints in the insight for the *8-coin* problem. A possible scenario suggesting the stacking insight might be: "On top of a tree is a bird's nest. In the nest, there are four eggs, one on top of three others." A second nest with four other eggs in it is placed near the first one which might suggest to problem solvers the grouping hint for the insight. The sketch on the right-hand side is intended to show the process of the insights.

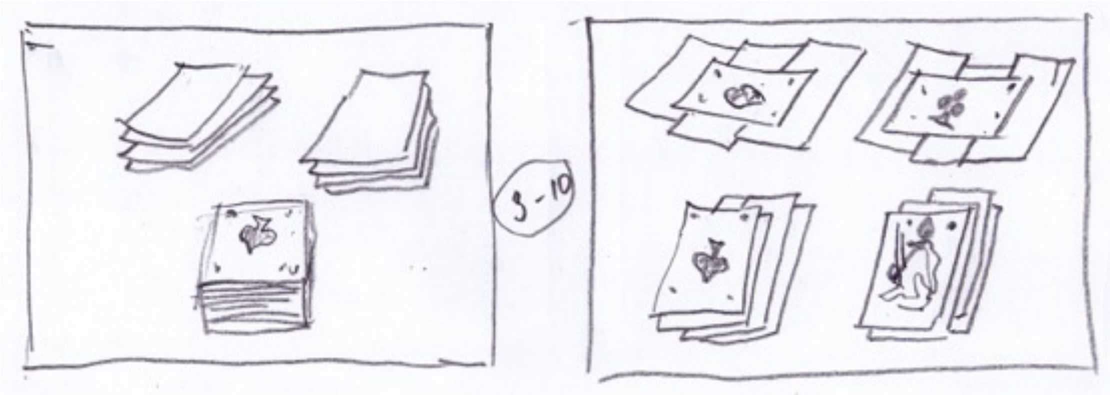


Figure 8.12 Playing cards

The *Playing cards* (Figure 8.12) concept sketch has employed the advantage of manipulating the pieces in a variety of configurations that could imply the insights for the problem. Captured in a *figural psychological* space, the subject of this theme allows problem solvers to touch, manipulate and move the pieces on the table to the same extent as those in the *8-coin* problem. The shape similarity with the objects from the *8-coin* problem in this sketch is ignored; the cards look flatter than the coins, and the colour is turned into grey shades as in previous studies. The layout in the first frame is intended to capture the process of the grouping hint showing the cards in one stack on the bottom and in the upper row as they are divided into two groups. Consequently, the second frame captures the process of the grouping hint followed by the stacking hint in the upper row.

Preselecting Analogical Concepts

As in previous studies, we evaluated and analysed the concept sketches for this experimental study using the same methodology. To determine the best candidates for visual analogies for this experiment we evaluated the generated concepts in three stages. The first stage was to determine their suitability for further development in a multimedia format and the applicability of analogical principles (i.e., *consistency and apprehension*) for experimental design fit.

After a few sessions of discussion and evaluation between the researcher and two experts (Appendix 14-2 – 2 & 3) in analogical reasoning, the following set of concepts was selected for the next evaluation stage: *The gate* (Figure 8.5), *The caterpillar 2* (Figure 8.7), *Cupcakes* (Figure 8.9), *Future city* (Figure 8.8), *Old and new tube maps* (Figure 8.10), and *Playing cards* (Figure 8.12).

In the second stage, the six selected concepts along with the experimental design were presented for evaluation to three experts (Appendix 14-2 – 1, 2 & 3) in analogical reasoning. Three (Figure 8.7, Figure 8.9, and Figure 8.12) out of the six concepts were selected for the further evaluation stage.

The third stage in the evaluation process included the researcher as a multimedia specialist along with the three experts in analogical reasoning to ensure that concepts could be adapted for a multimedia format to fit the experimental design variables.

At that point, the *Playing cards* (Figure 8.12) concept was abandoned for being too close to the structure and idea of a previous concept used in our first experiment (see images C & D and G & H from Table 3) where the role of process and depth had been explored in static visual analogies. Thus, two concepts (Figure 8.7 & Figure 8.9) remained for further development. These sketches allow both image schemas that had been explored in previous studies to be represented: forces and actions in the *The caterpillar 2* and gestures and actions in the making *Cupcakes* scenes. These sketches were tested on a small group of students to access their understanding of the insight cues. Four out of seven participants recognised both hints in both concepts.

Implementation

The preliminary sketches were isolated by frames to hierarchically organise the content of objects in compositional space for the future multimedia analogy. Also, the camera moves and shots were taken into consideration, so a preliminary storyboard was created, testing each analogue hint for timing. As had been done previously when developing new concepts for the *8-coin* problem, we ensured that the problem insights were adapted by implementing elements and mechanisms for constructing analogy from previous research findings and current theories in analogical reasoning.

A successful representation of objects in spatial composition that changes and unfolds over time could be valuable in showing how things look, especially from different angles of view. However, to explore what elements and principles work best in analogical transfer, in this study, the focus was on object representations from the most familiar angles of view to reduce the working memory load and extraneous information (Tversky, Morrison, & Betancourt, 2002) in animation that might confuse participants in the problem solving process. Thus, to manipulate the two in-between IVs proposed in our design, the hints were adapted to two perspective views: Normal Eye View and Bird's Eye View. The Bird's Eye View captures visual analogy objects from a panoramic aerial view, while the Normal Eye View captures these objects from a worm-like perspective. The second in-between conditions IV is to test whether the number of item correspondences is important in analogical transfer. Therefore, two animations clips were created, one containing eight items (i.e., eight coins in the problem) and one with an indefinite number referred to as *More coins* throughout this study.

Eight animation clips were created to test the hypotheses – four of them captured the force schema and four captured the gesture schema for the within subjects condition. Each category of the schema captured the problem insights through objects represented from two perspectives: the Bird's Eye View and the Normal Eye View (between). Also, two animations from the force schema category captured a matching number of items as the problem target, and another two clips did not match this correspondence with the target (between).

Refinement and Execution of Final Visual Analogy

Proceeding to the execution stage for the visual analogies, principles were implemented based on structure-mapping theory (Gentner, 1983), as well as *congruence* and *apprehension* principles for good graphics developed by Tversky et al. (2002) to ensure a proper interpretation of the conveyed correspondences between the source and target. There was a point of debate when constructing visual material for the two between variables that were matching the number of item correspondences for this experiment.

In the conditional groups for both perspectives for which the insights were due to be manipulated, the group of animations capturing the same number of correspondences as in the *8-coin* problem (eight coins – eight items) appeared more like instructions on how to solve the problem rather than an analogy. A test was conducted on a small group of students using a version of an animation with the caterpillar subject that was simultaneously capturing the sequential "*grab, pick up, move to the side, drop, return, repeat grab, move up, move to the side and repeat drop*" embodied schemas. As a result, the action of separating the whole into two groups of hints occurring as a result of these presented action schemas, showed that subjects easily followed each step and solved the problem without any difficulty. To avoid the floor effect (compare Image A with Image B from Figure 8.13), we decided to adapt the features of the visual analogies' structural elements in a slightly different way so that we could test their effectiveness in problem solving. Image C from Figure 8.13 captures the problem insights through partial representations of schemas (i.e., grab, pick up, move to the side, drop, and return) in the case of matching the eight-items group condition, while Image D captures the insights representing the full cycle of action schemas (i.e., grab, pick up, move to the side, drop, return, repeat grab, move up, move to the side and repeat drop) for the "*more coins*" conditional group.

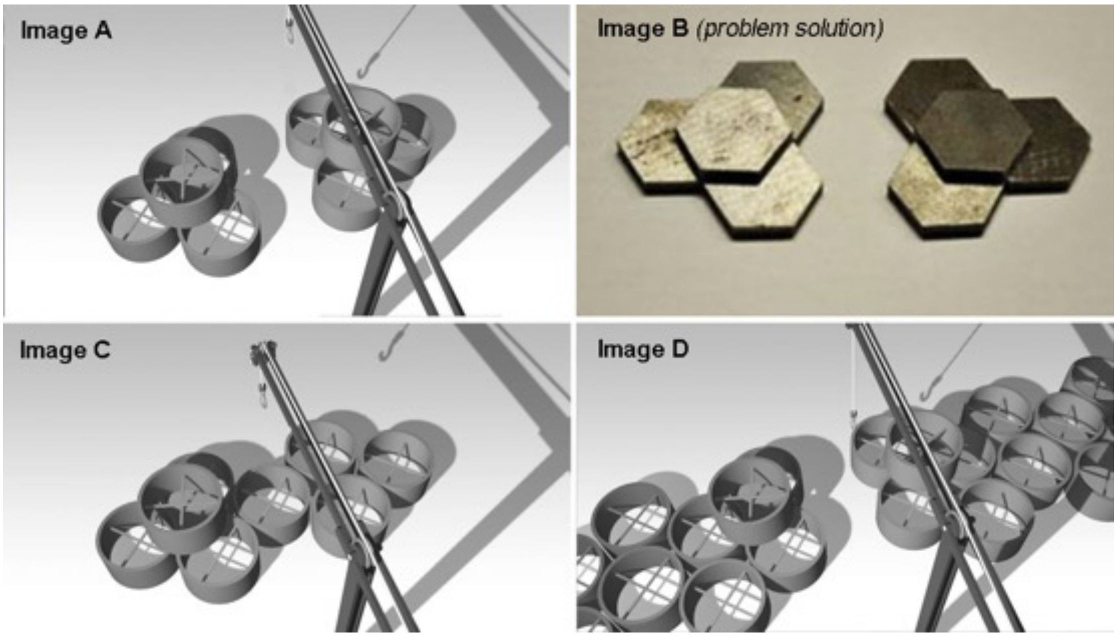


Figure 8.13 The end shots of animations capturing the action schemas

The differences between the Bird's Eye View and Normal Eye View conditional groups are in the angle of analogy representation. According to Montello's (1993) Psychological space classification, the cupcakes subject belongs to *figural space* as the objects are perceived from one position and can be touched or moved, while the caterpillar subject appears much larger than the human body and is perceived in *vista space*. Therefore, force/gesture schema and *vista/figural* spatial treatment factors may shed light on which of these elements is most effective in problem solving, especially when developing visual analogies for both insight and creative problems.

8.2.2.2 **Materials**

The following materials were used for this experiment:
2 sheets of paper with information for participants, Part I (Appendix 14-3) and Part II (Appendix 14-4), which included the consent form. A plain sheet of paper and a pencil were used for notes and the same 8 coins positioned in the initial configuration along with an image of the coins in the initial configuration as a reminder of its layout.
Also, in the experiment were used: a single sheet with the study instructions, 2 continuous animation clips for each conditional group as aid in the problem solving process and after the test a demographic questionnaire including questions if the participants were familiar with the problem. A Nikon D90 DSLR camera was used to record participants during the test, a MacBookPro notebook to play the animated clips and a 24" HD TV screen to display the visual analogies to participants.

8.2.2.3 **Apparatus**

A total of eight animated clips were created using Autodesk Maya 2011 software. Each one was 25 seconds in length and they are described in the implementation subsection of this chapter. The animations were exported in a MP4 movie format at 25 frames/second (standard ratio for PAL TV system) at HDTV 1920 x 1080 resolution, and shown on a 24" HD TV screen via a MacBookPro notebook, equipped with a 2.4 GHz Intel Core 2 Duo Processor, with a memory of 4 GB 1067 MHz DDR3 and a VRAM 256 MB NVIDIA GeForce 9400M graphics card.
Each animation started to play on the 24" HDTV screen at a set time for the conditional groups and regulated by the sound of a stopwatch, which announced the end of the test.

8.2.3 **Study Design**

The design is a 3x3x2 mixed factorial with two in-between and one within subjects design. To test the effectiveness of developed visual analogies for this experiment we had intervention and control groups.
The design includes two IVs, each at three levels, and a DV on two levels.

The first *IV – Perspective View* has three levels: the control group (no hint), the Normal Eye View, and the Bird's Eye View (see Table 13).

The second *IV – Items Number* has three levels: the control group (no hint provided), the eight coin group, and more coins group (see Table 14).

The DV was the success in finding the solution to the *8-coin* problem, whether the participant solved the problem (1) or not (0).

Conditions		**Visual Analogy**			
		Insight Aspect	**Total Participants:**		
Perspective View	**Items Number**	**Order of Insight**	**Per Subgroup**	**Per Group**	**Per View**
Control group	-	-	-	-	40
Normal Eye View	8 coins	Force / Gesture	10	20	40
		Gesture / Force	10		
	More coins	Force / Gesture	10	20	
		Gesture / Force	10		
Bird's Eye View	8 coins	Force / Gesture	10	20	40
		Gesture / Force	10		
	More coins	Force / Gesture	10	20	
		Gesture / Force	10		
(grey)	Control group				
(red / green)	IV – between: Normal Eye View / Bird's Eye View				
(blue / orange)	IV – between: 8 coins / More than 8 coins				
(yellow / purple)	IV – within: Time 1 / Time 2				

Table 13 Design / Experiment 4 (Perspective condition)

Conditions		**Visual Analogy**			
		Insight Aspect	**Total Participants:**		
Items Number	**View Point**	**Order of Insight**	**Per Subgroup**	**Per Group**	**Per Nr. of Coins**
Control Group	-	-	-	40	40
8 coins	Normal Eye View	Force / Gesture	10	20	40
		Gesture / Force	10		
	Bird's Eye View	Force / Gesture	10	20	
		Gesture / Force	10		
More coins	Normal Eye View	Force / Gesture	10	20	40
		Gesture / Force	10		
	Bird's Eye View	Force / Gesture	10	20	
		Gesture / Force	10		

Table 14 Design / Experiment 4 (Items number condition)

Hypotheses

H1 – Animated hint hypothesis: individuals presented with visual analogy hints will be more likely to solve the problem than those who are not.

Based on the lessons we learned from our previous experimental studies in the *8-coin* problem, practice-led research, documentation through diary, and our findings, we constructed a new set of visual analogies and expect to obtain a higher solution rate in the problem solving task.

H2 – Perspective hypothesis: animations capturing visual analogies from a Bird's Eye View lead to a higher success rate in problem solving than the animations capturing visual analogy from a Normal Eye View.

Our second hypothesis is based on the assumption that objects viewed from a more familiar point of view are more easily readable and comprehended (Rieser, 1989; Montello, 1993; Shelton & McNamara, 1997), and as a result, are more effective in terms of visual representations for problem solving. If the assumption is true, then calling attention to actions (Tversky & Hard, 2009) through the layout of represented objects captured from a Bird's Eye View point will better facilitate the incubation effect than that from a Normal Eye View.

H3 – Item match hypothesis: visual analogies that capture the same number of correspondences as the *8-coin* problem lead to a higher success rate than those that capture more or a different number of items than those in the problem.

Gentner (1983) claims that both analogy and similarity involve the same process of structural alignment and mapping. While analogy is a more sophisticated process used in creativity, similarity is based strictly on perceptual process. Due to the nature of the problem solving task in our experiment, we hypothesise that participants in the *8-coin* insight problem will rely mostly on perceptual *one-to-one* object mapping rather than on analogical similarities of higher order relations (e.g., causal, functional) of relations between relations (Clement J. J., 2008).

8.2.4 **Procedure**

This section describes the procedure used for this experimental study, emphasising the similarities and differences from the previous three experiments.

Recruitment

The recruitment for this experimental study was carried out in the same way as for the last experiment on the *8-coin* problem. We turned down the participants who were familiar with the problem or those who had participated in our previous studies on the same problem.

Experimental Setting

The experiment took place in the same room, and followed the same layout as previous experiments of our study (see 6.2.4 and 7.2.4).

Experimental Procedure

Each participant was tested individually. Upon entering the room, they were given a brief two-page information sheet which contained a description of the purpose of the study (Appendix 14-3) and details regarding the conduct of the study, as well as a consent form (Appendix 14-4). The participants were left to read the given information and were asked to sign the consent form if they agreed with the content. Then, the researcher accompanied each participant into the room where the test was to take place and randomly assigned the participant to the control group or to a treatment group. Participants were asked to make themselves comfortable at the table and were given instruction sheets for the assigned group (either the control group (Appendix 14-5) or a treatment group (Appendix 14-6)), while the steel coins positioned in their initial configuration were covered with a large piece of white paper (Figure 5.13). An image of the initial configuration of coins was displayed above the workplace as a reminder to participants to begin each attempt from that configuration. In addition to the instructions, each individual was provided with a blank sheet of paper and a pencil to take notes during the test if they wished to do so. Participants were asked if they understood the instructions and felt ready for the test. At that point, the researcher turned on the camera, uncovered the eight coins and the image with their configuration, and started the test. Each stage of the test was guided by computer sounds. The test was divided into three stages. In the first stage, participants were left to work on the problem for two minutes, and then, if they could not find the correct solution, they were stopped and were provided with the first animation hint for the condition to which they had been assigned. The animation was played on the TV screen for 25 seconds. The screen was set up in front of the participants at an approximate distance of four feet, and the stopwatch interval timer made a sound to prompt the participants to continue working on the problem. During the second stage of working on the problem for two additional minutes, the animations were left looping for participants on the screen. At the end of this stage, another sound prompted them to stop and watch the second provided hint for 25 seconds, and then, to move on to the last stage of working on the problem for two more minutes.

Participants were randomly assigned either to the control group or to one of the four treatment groups. Those assigned to the control group were not given any visual hints during the test. The first and second groups were each provided with two animation clips after two and four minutes of working on the problem. Half of the participants from each group received the animation clips that captured the force schema (crane) as their first hint, while the other half received the one capturing gesture schema (cupcakes). All sets of animated clips were represented from a Normal Eye View; however, for the first group, the number of items matched the number of items in the *8-coin* problem, while the second group was provided with sets of animated clips containing more items than there were coins in the problem.

Participants from the third and fourth conditional groups were treated in the same manner as the first two groups, except that here, the insights were presented from a bird's eye point of view.

Individuals in the control group were not provided with any hints during the test, so, they worked on the problem for a total of six minutes without interruptions. Individuals who solved the problem at any time during the solving period were marked as successful and proceeded to the next stage of the experiment. After a total of six minutes of working on the problem, both the participant and researcher were alerted by the stopwatch's last clapping sound that the test had ended, and the result was recorded as successful or unsuccessful. At the end of the test, the camera was stopped. During the test, the researcher observed and monitored the participant's moves and reminded them to set the coins back in the initial configuration after each unsuccessful attempt. Also, after each two-move attempt, the participant was asked to rate on a scale of "0" to "10" how close he/she felt he/she was to finding the solution.

After the test stage, participants were given time to fill out the forms and surveys that are described in the following generic data collection section.

Generic Data Gathering

A template (Appendix 14-7) was used to collect information about participants' performance during the test; then, they filled out a form containing demographic questions (Appendix 14-9), a form with questions regarding the helpfulness of the hints in problem solving (Appendix 14-10) and the Santa Barbara Learning Style Questionnaire (Appendix 14-8), a survey to measure participants' learning styles. Recorded video material during the test was used in further analyses.

Out of a total of 125 participants in this experiment, two of them were familiar with the solution to the problem due to having taken a psychology course at Lancaster University; one refused to engage in the solving process just a few seconds after the test had started, and two participants did not properly follow the instructions and the guidelines for the study, so all five were excluded from further analyses.

This left us with a total of 120 participants: 40 subjects for the control group and 40 subjects for each of the two experimental groups.

8.3 Results

A 3x3x2 mixed factorial ANOVA was conducted to compare the main effects of perspective and number of items and the interaction effect perspective x number of items on the performance of participants in the *8-coin* problem solving task. Perspective type included three levels (control, Normal Eye View, and Bird's Eye View groups) and item number consisted of three levels (control, 8 items, more items).

All in-between factors were measured at two points of time (within factor): after working with the first hint for two minutes (time 1) and after another two minutes working with the second hint, if participants had not found the solution.

The main effect for perspective yielded an F ratio of $F(1, 115) = .80$, $p > .05$, Partial Eta Squared = .007, indicating that the effect for perspective was not significant. Although, there is no statistical difference between the levels in the perspective factor, the Tukey HSD post hoc comparisons revealed that the mean score for the Normal Eye View group ($M = .72$, $SD = .45$) and Bird's Eye View group conditions ($M = .80$, $SD = .40$) were significantly different to the control group ($M = .05$, $SD = .22$).

Experiment 4 – Visual Analogy / Animations

	Groups	Subgroups - Number of Items	Subjects	Time 1 [2>4 min]	Time 2 [4>6 min]		
	Control group **[A]**	N/A	40	0	2	2 (5%)	
	Conditions:			**Within subjects** First schema **[D]**	Second schema **[E]**	Total solved:	
Between subjects	Normal Eye View **[B]**	8 Items **[b1]**	40	9	5	29	61 (76.25%)
		More Items **[b2]**		12	3		
	Bird's Eye View **[C]**	8 Items **[c1]**	40	13	2	32	
		More Items **[c2]**		9	8		
	Total solved:			43	20	63	

Notes on independent variables:
***Type of Perspective** - 3 levels: Control* **[A]**, *Normal Eye View* **[B]** *and Bird's Eye View* **[C]** *(between subjects)*
***Number of Items** - 3 levels: Control* **[A]**, *Force 1st* **[b1+c1]** *and Gesture 1st* **[b2+c2]** *(between subjects)*
***Image Schema** - 2 levels: First schema* **[D]** *and Second schema* **[E]** *(within subjects)*

Table 15 Participants' successful solution rate in the 8-coin problem in Exp. 4

Therefore, an UNIANOVA procedure was conducted to compare the effects of provided visual analogies as hints in the *8-coin* problem in control and intervention conditions. Analyses show that there is a significant difference between the two groups F (1, 118) = 97.478, $p < .001$, Partial Eta Squared = .452, a strong effect.

For all that, the Normal Eye View and Bird's Eye View conditions did not statistically differ from each other.

The main effect for number of items captured in the hint showed the F ratio of F (1, 115) = .80, $p > .05$, Partial Eta Squared = .007, indicating that the effect for this factor was not statistically significant either. The Tukey HSD post hoc test indicates that the mean score for the *8 items* group condition (M = .72, SD = .45) and *More items* group condition (M = .80, SD = .40) were significantly different to the *Control* group (M = .05, SD = .22). However, the *8 items* and *More items* conditions did not statistically differ from each other. The results suggest that hints capturing the same amount of items as the problem yields the same effect on participants' performance as if that number is increased in the hints.

The interaction effect perspective x number of items was not significant, $F (1, 115) = .09$, $p > .05$, Partial Eta Squared = .001.

Mixed factorial ANOVA tests of within-subjects effects were conducted to compare the main effects of time and the interaction effects: time x perspective, time x item number, and time x perspective x item number. The main effect for time factor (hints provided to participants after two and four minutes during the hint period) condition was statistically significant, $F (1, 115) = 11.98$, $p < .05$, Partial Eta Squared = .089, a moderate to large effect. Examination of the cell means indicated that overall solution rate after working with the first hint ($M = .36$, $SD = .48$) was moderately higher than at the end of the second hint period ($M = .17$, $SD = .37$). Excluding participants from the control group because they were not provided with any hints during the experimental study, and looking at the results, it seems that the first provided hint did indeed lead to a success rate with more than 53% of participants finding the correct solution to the *8-coin* problem. These results suggest that the constructed visual analogies helped participants observe, connect and apply the insights captured in animations in their problem solving process.

Type of hints (Between subjects)	Number of participants solving the problem		
	[2>4 min]	[4>6 min]	
Control group **[A]**	0	2	2
Conditions	First schema	Second schema	Total:
Normal Eye View **[B]**	21	8	29
Bird's Eye View **[C]**	22	10	32
	43 + 0	18 + 2	61 + 2

Number of participants per condition: Control ***[A] = 40****, Normal Eye View* ***[B] = 32****, and Bird's Eye View* ***[C] = 40.***

Table 16 The results for Time (within-subjects) factor

In addition to the main effect of time, the test revealed that the interaction effect of time x perspective $F (1, 115) = .03$, $p > .05$, Partial Eta Squared = .000 and interaction effect of time x item number $F (1, 115) = .70$, $p > .05$, Partial Eta Squared = .006 were both statistically insignificant. However, the interaction effect of perspective, item number, and time appears to be statistically significant, $F (1, 115) = 6.23$, $p < .05$, Partial Eta Squared = .05, –very close to a moderate effect.

8.4 Discussion

In this study, we based our hypotheses on the premise that the *8-coin* problem is confronted mostly using spatial relations and depth perception; thus, it is mostly a visual insight problem. This kind of problem requires the capacity to negotiate environments by using the visual systems. Memories of past experiences or inspiration from the environment were used in the development of visual analogy processes.

The UNIANOVA test to compare the effects of provided visual analogies, as hints in the problem solving task in control and intervention conditions, shows that there was a significant difference between the two groups $F(1, 118) = 97.478$, $p < .001$, Partial Eta Squared = .452, a very strong effect. It also shows that the intervention group generated a solution rate of 76.25% compared to the control group of just 5%. This is impressive compared to the solution rate of 20% obtained in the first, 60% in the second, and 33% in the third experiments with a total average of ~38% of participants solving the problem when providing them with visual analogies as hints in problem solving tasks. It is worthwhile to mention that while the average success rate in our previous three experiments is close to the result obtained by Ormerod et al. (2002) in their experiment 1 (42%) and experiment 2 (33%) using both verbal and visual hints (see Table 6), the solution rate increased drastically in this experiment, with more than 76% of participants solving the *8-coin* problem. Thus, with each consecutive experiment we learned more about how to visualise analogies, and gained more confidence in the methods and approaches used for this study.

The **H1 – Animated hint hypothesis:** individuals presented with visual analogy hints will be more likely to solve the problem than those who are not. This was supported by our findings encouraging further investigation of other spatial and relational aspects in visual analogy constriction able to ensure analogical transfer.

The result for the **H2 – Perspective hypothesis:** animations capturing visual analogies from a Bird's Eye View lead to a higher success rate in problem solving than the animations capturing visual analogies from a Normal Eye View. This was refuted.

Our assumption that representing the analogy from a bird's-eye view would make its visibility clearer for problem insight recognition in participants was rejected. Even though the result shows a statistically insignificant difference between the two manipulated viewpoints in our experiment, the outcome encourages further investigations on this issue. Firstly, the solution rate among participants in the Bird's Eye View group (80%) was slightly higher than for those in the Normal Eye View condition (72.5%), and secondly, the only difference between the two was the raised visual boundary on the Y-axis in the Bird's Eye View condition, which makes us question what result could be obtained if more conditions (e.g., front, side, above) were added to the design and tested for dependability from these viewpoints. We speculate that the Bird's Eye View gives a new and different view on the problem compared to how participants were looking at it from the more familiar typical perspective. Research on spatial navigation (Tversky & Kahneman, 1983; Shelton & McNamara, 1997; Tversky B. , 2011; Montello, 1993) shows that people are able to make better decisions about what route is the shortest from a point where they stand to a destination when following maps, diagrams (Perkins, 1990; Tversky & Hard, 2009) or 3D digital architectural models (Pelosi, 2014) than when they are given directions (e.g., "at the tall building make a right, then, upon reaching the equestrian monument, turn to the street that the horse is facing….etc."). Compressing the necessary information into a smaller space (Montello, 1993) made up of symbols could be more effective in terms of reading and conveying the intended message.

Even though the findings from this study do not support the views on the dependability of the viewpoint representation of objects in space, there is a need for further investigation into these issues. We manipulated only two perspective points of view for which the objects' spatial coordinates are very close to each other.

H3 – Item match hypothesis: Visual analogies capturing the same number of items with the *8-coin* problem lead to a higher success rate than those capturing a different number to the problem. This was not supported by the results of this experiment.
This is interesting, as both animations from these conditions generated a high solution rate for the problem solving task compared to the control group where visual analogy was not provided. In fact, participants from the Bird's Eye View / 8 Items group generated 13 correct solutions, while those from the Normal Eye View / More Items group generated 12 during the first schema (Table 15); however, a comparison of the total number of found solutions per group shows that there is no significant difference

between them. We can speculate that in the visual analogy construction process, the prioritisation of a specific type of similarity used in its making is not important (Dundar, 1995). The use of the *one-to-one* mapping (Gentner, 1983) similarity of objects (i.e., number of items, form) and the mapping similarity of relations between objects (i.e., first from the left, the one on the top) may be beneficial in visual analogy construction as long as there is a balance between the two and the outcome conveys the message of the analogy in the simplest way possible. It seems that students can draw, evaluate, and transfer to the target analogical inferences (Forbus K. D., Gentner, Everett, & Wu, 1997; Clement J. J., 2008) from both encodings (*one-to-one* object mapping and mapping the relations between objects).

Moreover, it was observed from video recorded sessions that when using families of image schemas in the construction of visual analogies, participants engaged more actively in the problem solving process by moving their hands/heads depicting objects in the air, locations, transformations, or movements of items just before making decisions on next moves.

8.5 Conclusion

The goal of this study was to explore the impact of animated visual analogies and their level of spatial representations from two different perspective viewpoints – Normal Eye View and Bird's Eye View – as well as their level of mapping the similarity on two levels: object *one-to-one* and higher order relational mapping in cueing the solving process for the *8-coin* problem.

Findings suggest that both levels of spatial representations in perspective were effective in the problem solving task. Additionally, the results show that the efficiency of mapping the similarities between the source analogue and the target can be achieved in visual analogy through a structural method of mapping the objects *one-to-one*, of mapping the objects relations, or through an integration of both these methods.

In addition, the lack of clear evidence in the literature and our experiment on the use of *one-to-one* mapping which matches the number of items from the source with that of the target, as well on the use of multiple perspective points of view from which an analogy can be represented, provides grounds for investigating more these issues in greater depth.

9 Solving the Cheap Necklace Problem with Animated Visual Analogies

This study reports on an experiment designed to test the effectiveness of constructed visual analogies as an aid to the *cheap necklace* problem. Studies investigating the use of time-based visual analogy, especially animation to facilitate problem solving have shown that people often fail to convey the concepts in presented information and may only discriminate such information under particular conditions (Höffler & Leutner, 2007). The ultimate goal of this experiment is to understand how to construct an integrated model that will accurately capture the objects/actors and their causal and functional relations/actions in an external representation (Hegarty, 1992; Hummel & Nadolski, 2002). Thus, the subject will be able to extract and draw conclusions about the mentioned underlying relations from the depicted system (Mayer & Moreno, 2002). In a laboratory study, we examined if providing visual analogies that are developed based on the literature and lessons learned from previous experiments (e.g., *8-coin* problem) will work for another insight problem – the *cheap necklace* problem. Developing animations within a richer variety of abstractions in depicting these analogical concepts (Bonnardel, 1999) so that the solver will gain a better understanding of both causal and functional relations/actions illustrated in animations will increase participants' performance on the *cheap necklace* problem test (e.g., analogical transfer).

9.1 Chapter Overview

This chapter contains a description of our fifth experiment on problem solving using the *cheap necklace* problem, which is another archetypical insight problem focusing on the effectiveness of constructed visual analogies captured in animation. Cognitive psychologists often used the *cheap necklace* problem to investigate insight, fixation or incubation in the problem solving process. Some studies focused their investigations on how to overcome functional fixedness (Ohlsson S. , 1992; MacGregor, Ormerod, & Chronicle, 2001), some, on inducing fixation in naive participants to observe the used strategies to escape from it (Fioratou, 2005), and others engaged in investigating the incubation effect in problem solving (Silveira, 1972; Chu, Dewald, & Chronicle, 2007; Norlander, Bergman, & Archer, 1998) and the mechanisms that facilitate change in a problem's representation (Ohlsson's representational change theory). Although these contributions are more than plausible, far fewer studies have been designed to investigate the effect of visual imagery in problem solving, in particular, visual analogies (Bonnardel, 1999) including their development and use in visual insight and creative problems (Sas, Luchian, & Ball, 2010; Luchian & Sas, 2011). The benefits of previous studies on the *cheap necklace* problem (2.3.4), the evidence from investigations in insight problem solving and contributions from theoretical accounts, as well as the limitations and their concluding notes helped to shape the design of this experiment. Here, we replicate one of Fioratou's (2005) laboratory experiments from a series of a total of eight on the insight for *cheap necklace* problem. The reason for replication is threefold: firstly, the problem carries a visual insight; secondly, it involves physical objects that need to be manipulated in a small 3D space; and thirdly, the collected data can be compared with the obtained data from the original experiment on the effects of verbal and static imagery cueing. Another benefit of replicating the *cheap necklace* problem in our study relates to information on the method of extracting accurate data on the progress made during our study in terms of visual analogy development. The chapter starts by describing the goals of the study and its general intent, followed by a description of the method, design and the procedure for this experiment, a report on the results, and finally, a discussion and concluding notes on the research.

9.1.1 **Experiment 5: Rationale and Research Questions**

The primary goal of this study was to construct a new set of visual analogies in a time-based media format (i.e., animation) for another insight problem, the *cheap necklace* problem, and test its effectiveness in a laboratory setting. Besides implementing the standard techniques and methods in our analogy development process, we supplemented it with new elements and principles for constructing visual analogy emerged from the lessons learnt from previous experimental studies. We explored spatial data and the variation in object quantity correspondences between the source and the problem target in last experiment. In this study, our investigation is focused on the type of abstract concepts used in the analogy, and their embodied schemas in the initial state of the problem. As described by Johnson (1987), an image schema derives from the sensory and perceptual experience of interacting with the world and moving through it. The term "schema" or "image schema" is an abstract concept consisting of schematic patterns which emerge from repetitive actions of embodied experience (2.2.1.2). However, these image schemas can occur in clusters and become internally complex. While the effect of force and gesture schemas embodied in visual analogies for problem solving as standalone schemas were explored in previous experiments, in this study, the effect of a network of related schemas capturing the problem insights is investigated. By the same token, being inspired by the work of Ball and Litchfield (2013) and Christensen and Schunn (2009) who investigated the impact of embodied hints in problem solving, we decided to test the effect of multiple analogy cueing in the present experiment. Thus, the present experimental study addresses the following questions:

- Which clusters of image schemas captured in visual analogy are more effective in the *cheap necklace* problem solving process: Gesture, Force, or a combination of both?
- What is an adequate quantity and quality of hints to be provided to participants to maximise the solution rate in the *cheap necklace* problem?

To answer these questions, we created three short animated clips, each capturing both insights of the *cheap necklace* problem, and each one embodying a different family of image schema. The similarities and differences between the animated analogies and the schemas used to capture the insights are described in more detail in the following subchapters.

9.2 Method

Concept sketches for visual analogies were generated using design methods. They were evaluated, constructed, refined, and tested for their effectiveness in another insight problem solving task. The developed set of analogies focused on the implementation of new families of image schemas. These visual analogies were tested in laboratory settings for their effectiveness. They were analysed along with data collected on participants' preferences, demographics, my notes during the test, and the outcome of each experiment, for the formulation of guidelines for constructing effective visual analogy for insight and creative problem solving.

9.2.1 Participants

One hundred and twenty students acted as participants in this experimental study. Ninety participants were undergraduate and postgraduate students from Lancaster

University, UK and thirty were undergraduate students from Arizona State University, USA.

The sample consisted of 62 (52%) males and 58 (48%) females with a median age of 25.45; 28% of the participants were younger than 21, 63% were between 21 and 30, and 9% were over 30 years of age.

9.2.2 Materials

This section describes the materials used in the study. The first part includes the visual analogy ideation, evaluation, refining and implementation phases, while the second part describes the materials used in the laboratory experiment to test the developed visual analogies.

9.2.2.1 Stimuli – Development of Visual Analogies

In this subsection the processes of analogy development, diary marks during the development, selection methods for the best candidates for our visual analogy, implementation of the proposed elements and principles, and the execution of the animations embodying the problem insights and its refinement are described.

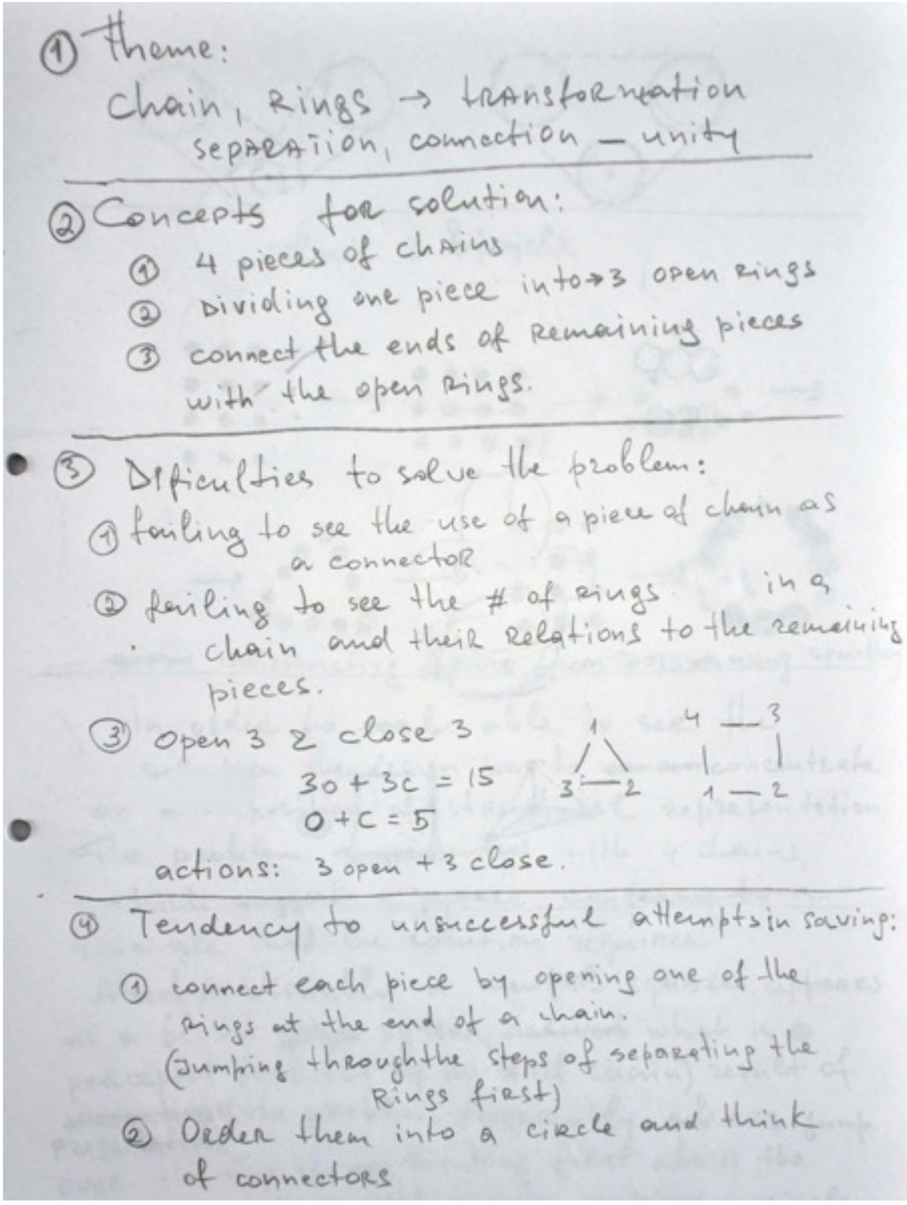
Initial Ideation

The challenge in this initial stage to generate new analogies for this experimental study represented a problem in itself. The *cheap necklace* problem had to be well-understood visually even before any thoughts could be put on paper. A few sketches of this type focused on problem finding and problem understanding, and are shown below in this subsection.

As per Figure 9.1, the researcher clearly deconstructs the problem into four main components, each one of them capturing keywords to serve as an aid to memory and a description of the constraints in the generation stage for analogy. The first part describes the objects in the problem and a few of these objects' attributes. Fioratou et al. (2005) used this problem in their experimental studies and concluded that the most difficult task for participants while solving it was fixation and how to overcome it; additionally, hints that help participants to attempt to perform actions in the solving process are more effective than the conceptual hints that are focused on giving directions.

In the second row, the number of items involved in the problem and the required actions to reach the solution to the problem are mentioned. The third row describes the common difficulties that participants have had in previous experimental studies in solving the same problem when provided with verbal and schematic diagram hints, while in the fourth component, there is a list of observations on participants' first moves during the test. Upon focusing on such a description and, at the same time, scribbling, one can hope to evolve an idea from the shapes and forms drawn on paper.

The second sketch shown in Figure 9.2 is a playful idea that was inspired during a typography workshop, while the instructor was showing students how to create and remain consistent in the development of a new typographic font.



<u>Figure 9.1 Understanding the problem / Sketch 1</u>

The visual material from this workshop was about consistency in the development of a new font, and in particular, stressing the idea of using a minimum of outlines of primary shapes (i.e., circle, rectangle, square, and a straight line) to begin. Taking these basic shapes, breaking them up in small pieces and then reconstructing all or some of those pieces into new shapes, often, scaling them to resemble the letters from the alphabet represented the main manipulative and transformative actions to get the desired results. The workshop started with a demonstration of how the letter “a” might be created in both upper case and lower case. During the workshop, I had a pencil and a sketchbook, and from time to time, I would doodle different letter shapes in it, coming up with my own designs for my initials, and attempting to apply the instructor’s strategies to my designs while also trying to finish ahead of the instructor to see if his designs would match mine. The idea of creating an analogy that maps with the *cheap necklace* problem came up at the moment when the instructor took a new circle, and the foundation of the letter “O” as a model to create the letter “C”. He erased a portion of it, creating an open shape, so that the “O” became a “C”. The eraser resembled the first action-insight to be performed in the problem. Displaying the top chain as being made of links that each resemble the letter “C”, might give solvers the idea of breaking one chain by unlinking each link. There are a lot of possibilities in developing this idea into a visual analogy for our experimental study, but how we might construct it and apply the principles so that they are effective is definitely not yet well-defined. It is definitely worthwhile considering this as each additional sketch gives the artist new insights into the problem s/he faces; moreover, sketching is a means of finding new approaches.

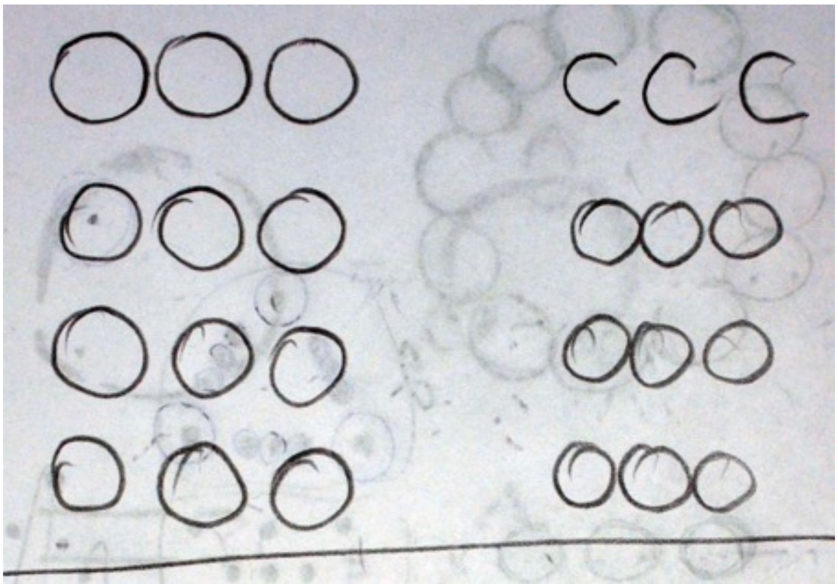


Figure 9.2 Understanding the problem / Sketch 2

The sketch from the upper side of Figure 9.3 is an exploration of understanding the problem visually in a variety of versions: the cheap necklace problem version containing a total of four pieces of chain in the initial description, a second one containing only three chains, and the third one, with only two chains. In a pilot test on these versions of the problem with nine (three per version) voluntary participants who received no hints, the result showed that the participants had the same difficulties when solving the problem regardless of the given version. Most participants tended to open one link from the side of a chain, and then tried to connect it with the next chain by closing the link. Some arranged the chains in a circle before taking any action, explaining that doing so might help them understand the problem better visually.

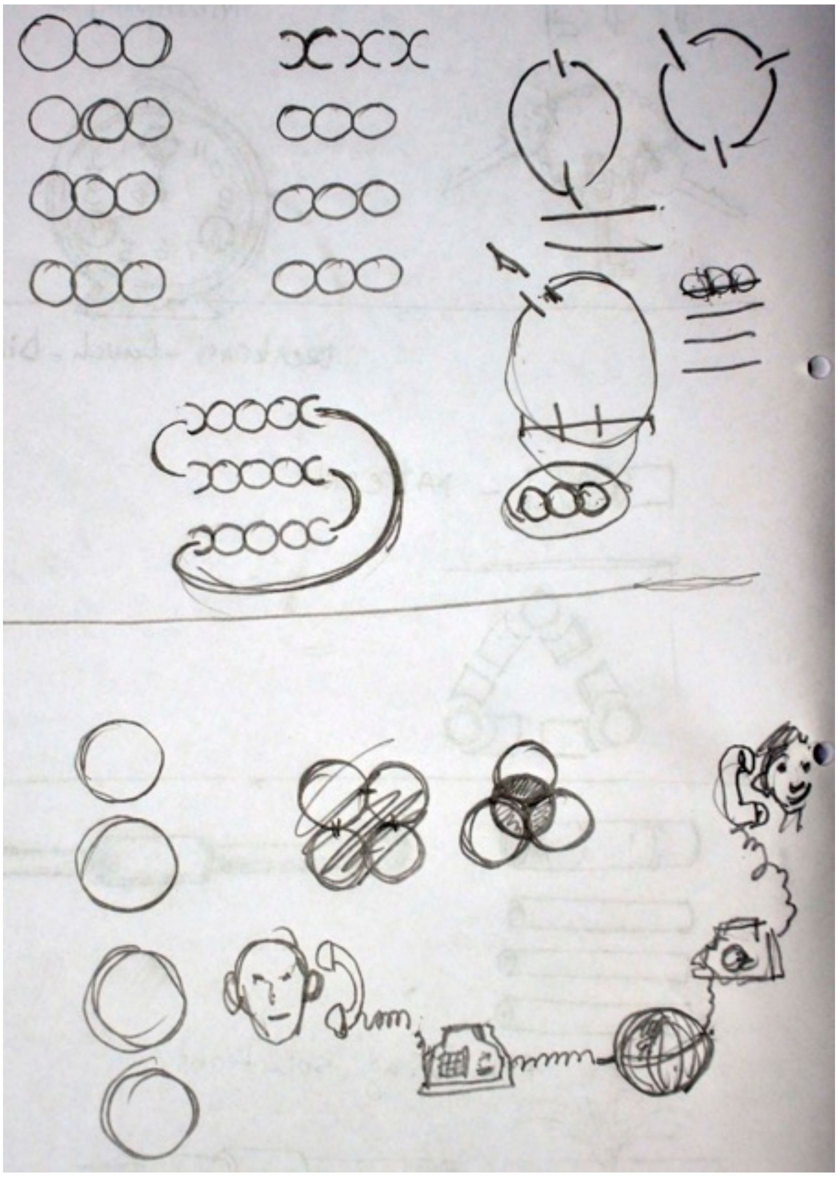


Figure 9.3 Understanding the problem / Sketch 3

The sketch from the upper left-hand side of Figure 9.3 is another version of the typographic idea, but this time, using the “X” letter to suggest the opening of the links. Graphic designers often use the technique of flipping or mirroring elements in their designs, either to express a message, enhance the composition, accentuate the focus in it, or to balance the design.

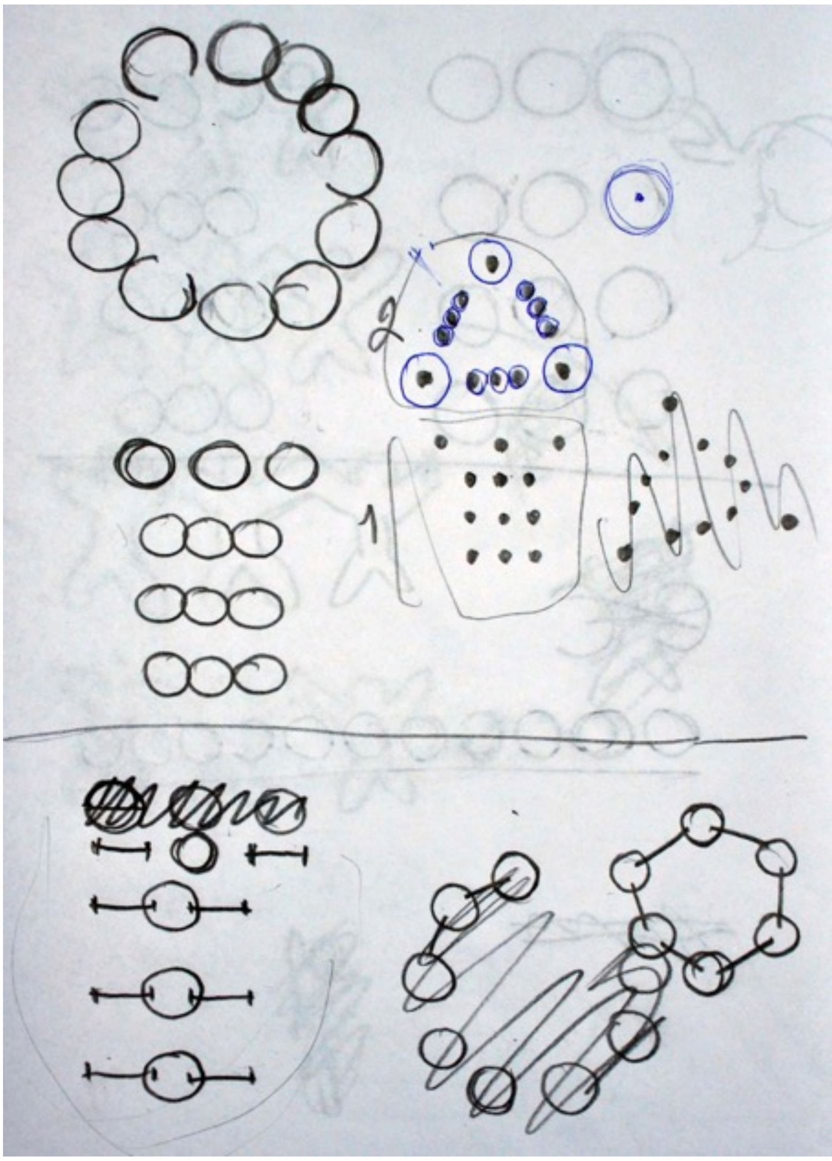


Figure 9.4 Understanding the problem / Sketch 4

Sketches from the lower part of the Figure 9.4 capture a new idea for the experimental study, or are at least a new attempt at developing one. In the case of commissioned works, it is customary for the artist to hear or read about the subject matter as fully as possible before even starting the project. Then, s/he applies his/her intellectual abilities and craftsmanship to execute the work in accordance with his/her understanding of the subject. When there is no explanation of the subject or how the work should be, artists usually doodle and sketch, often, choosing random subjects in search of new compositions, shapes, forms or relationships.

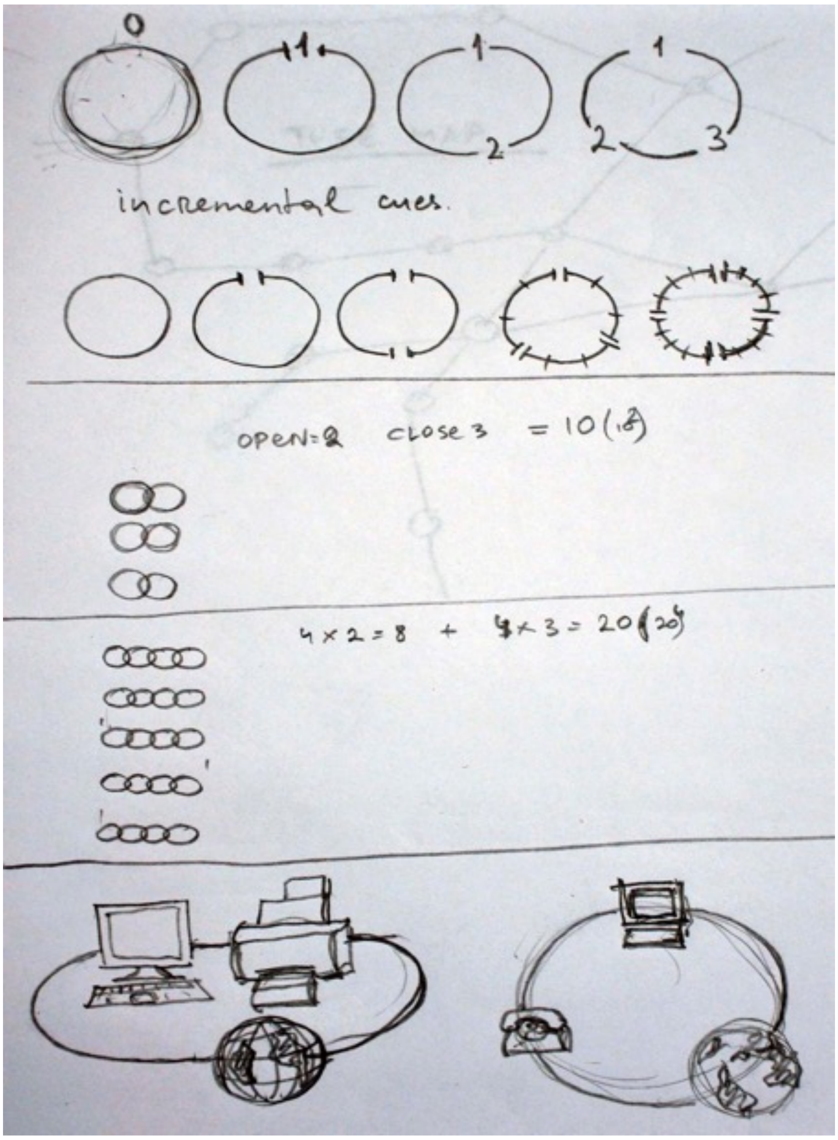


Figure 9.5 Understanding the problem / Sketch 5

These preparatory sketches are called into play (Patherbridge, 2010) and used as a search for new ideas for future works. This method has been well-known since the late sixteenth century and is endorsed by academics. In his work *On the True Percepts of the Art of Painting*, Armenini (1977) made an observation about a similar methodology by referencing Leonardo da Vinci's approach: "he investigated first all the appropriate and natural effects of every figure and other thing in conformity with his idea supplementing it by studies from life in sketchbooks".

The strategy in developing spontaneous analogy for this problem is to attempt to include subjects that are similar to the structure but different from the original problem state. The goal is to capture the problem insights without difficulty, ruling out the ones that involve only surface similarities. For insight problems, the generation of subjects of spontaneous analogy is expected to relate to a variety of themes, not linked to a particular domain, and also express structural or functional relationships corresponding to the target problem. Such efforts to transit between understanding the problem to ideation and generation phases in this process can be seen in the sketches from the lower side of Figure 9.3 and Figure 9.5. In both sketches, the analogy captures the abstract concept of connectedness through modern technology. Of course, in the problem instructions, this relationship is already known, and the question arises if it should be included or not in the potential analogy as an aid to solving the *cheap necklace* problem. Considering that this relationship is part of the problem solving process, in addition to being a requirement in finding the problem solution, the visual analogy has to not only emphasise it but also make it the paramount driver of associated correspondences between the source and target. In all the sketches in Figure 9.4 and the three from the upper part of Figure 9.5, I am still at the stage of understanding the problem in this development process. While I sketched five devices in the first image related to the World Wide Web theme, in the second and third versions (Figure 9.5) I only captured three, thus, exposing a variation in the subject at the structural level and a transition from understanding the problem to the ideation stage. It seems that new concepts of analogy can be generated from lessons learned from previous experiences with other problems. Sketch 2 from Figure 9.4 is an excellent example of employing this method, where I studied the nine dots problem meanwhile searching for equivalent analogies and features for the current problem.

Sketching Analogies

A similar activity that might offer the answer for the *cheap necklace* problem is a traditional Romanian folk dance (Hora). The *Hora* dance means “round dance”. Accompanied by the sounds of musical instruments, the dancers hold each other’s hands and perform a few steps back and a few steps forward. In this version, the humans are captured in a simplified form of stick figure drawings, and, at the beginning of the dance, they are arranged in an identical layout with the target problem, which is very similar to the structure of the initial configuration of the *cheap necklace* problem. As the dance continues, the groups of dancers move to the left or the right, and then spread out and move toward the centre to form a circle. The way they move suggests that this analogy might help participants to see the links between the hints and the solution to the problem they face.

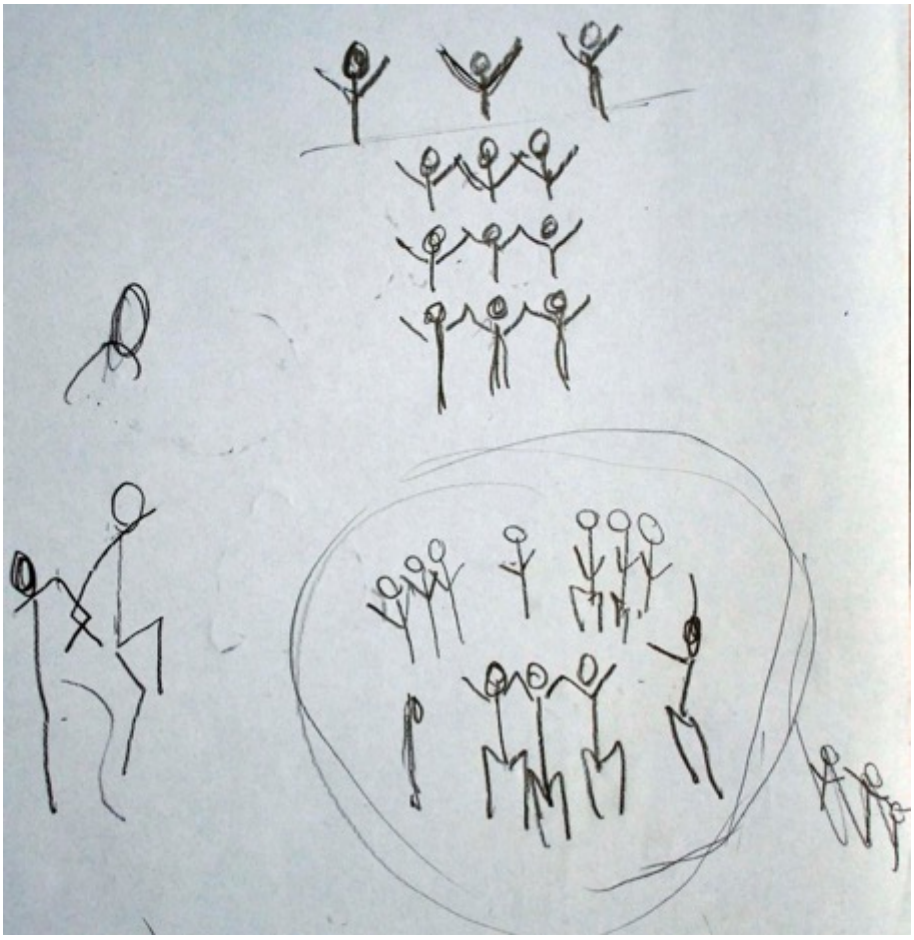


Figure 9.6 Generating ideas / Hora – round dance

The sketch for this analogy seems to instil confidence in a successful transfer of all the analogical correspondences to the original problem. During this stage, this idea might be changed, transformed, or manipulated to fit the scenario of actions and schema occurring in the *cheap necklace* problem. There are variations in the dancers' moves in the *Hora* dance. It is a strong candidate for a successful analogue to be embedded into a multimedia format.

Figure 9.7 shows a new idea for a potential analogue. This time, the attention is directed at the three units as wholes with their heads as possible links. The sketch is suggesting that the three chains be left intact, and that the bolts be allowed to act as links between them. The action of tightening bolts, although only implied, might suggest consolidating, unifying, linking, joining these three tools together to form a closure. It looks like this idea might be missing some correspondences, perhaps a mismatch of the steps in the problem solving process.

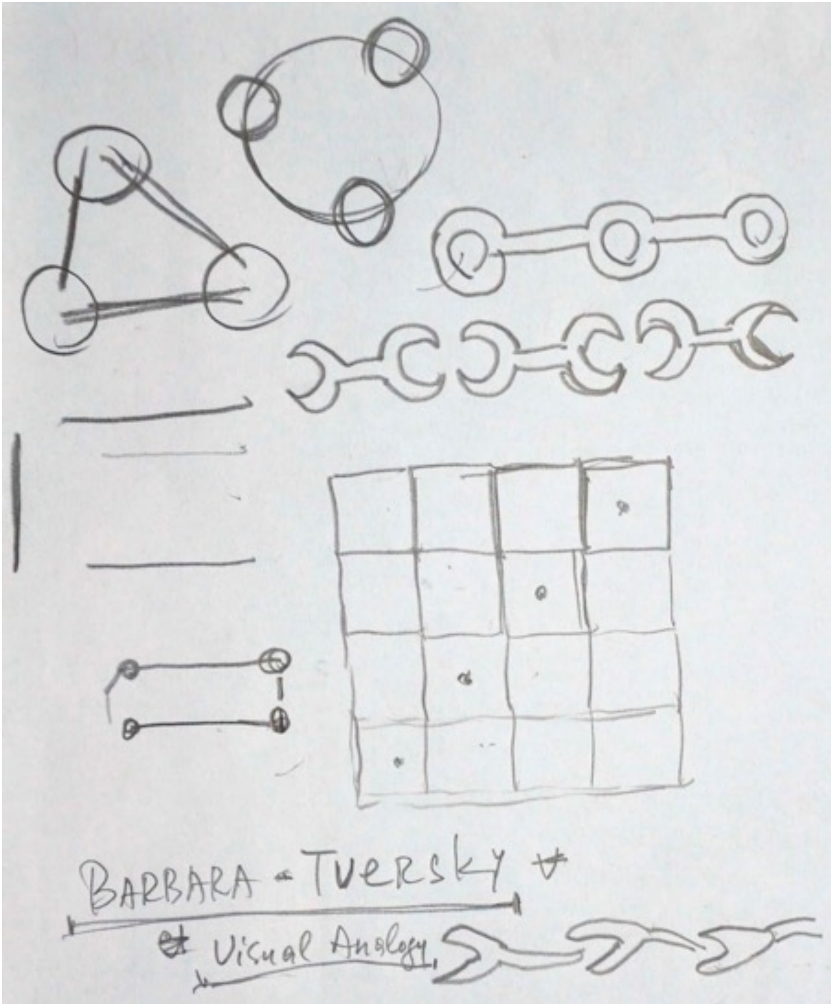


Figure 9.7 Generating ideas / Wrench tool set

The next attempt at an analogy would be a scenario relating to making a bracelet from beads (Figure 9.8). One has a string, three large beads and nine beads of a smaller size. The three larger beads might be of different material, but similar in shape. Visualising the process of making a bracelet from the listed materials by following the design from this sketch might encourage subjects to pay attention to the function of the three large pieces of design and take action. Thus, the group of larger beads may be separated to be woven onto the string after each pattern of three smaller ones. The relationships between the bead patterns resemble the chains from the target problem, and if the visual analogy is properly aligned with the problem's initial configuration, its layout, and its processes, then one might connect the dots and get an insight into how to solve the *cheap necklace* problem too. This can only happen if the visual items from the animated clip are properly aligned and congruent with the abstracted structure and order of subsequent actions of the target.

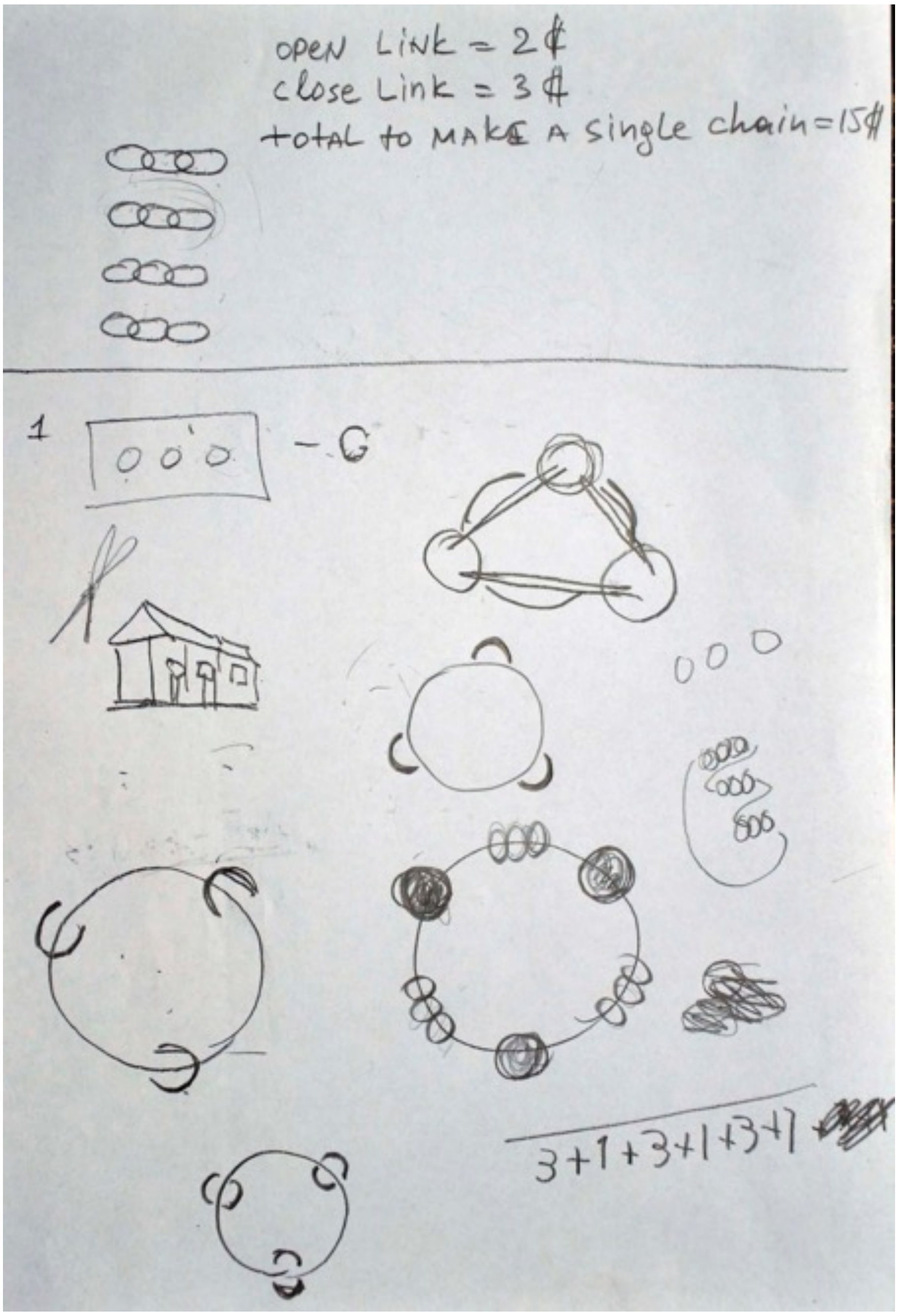
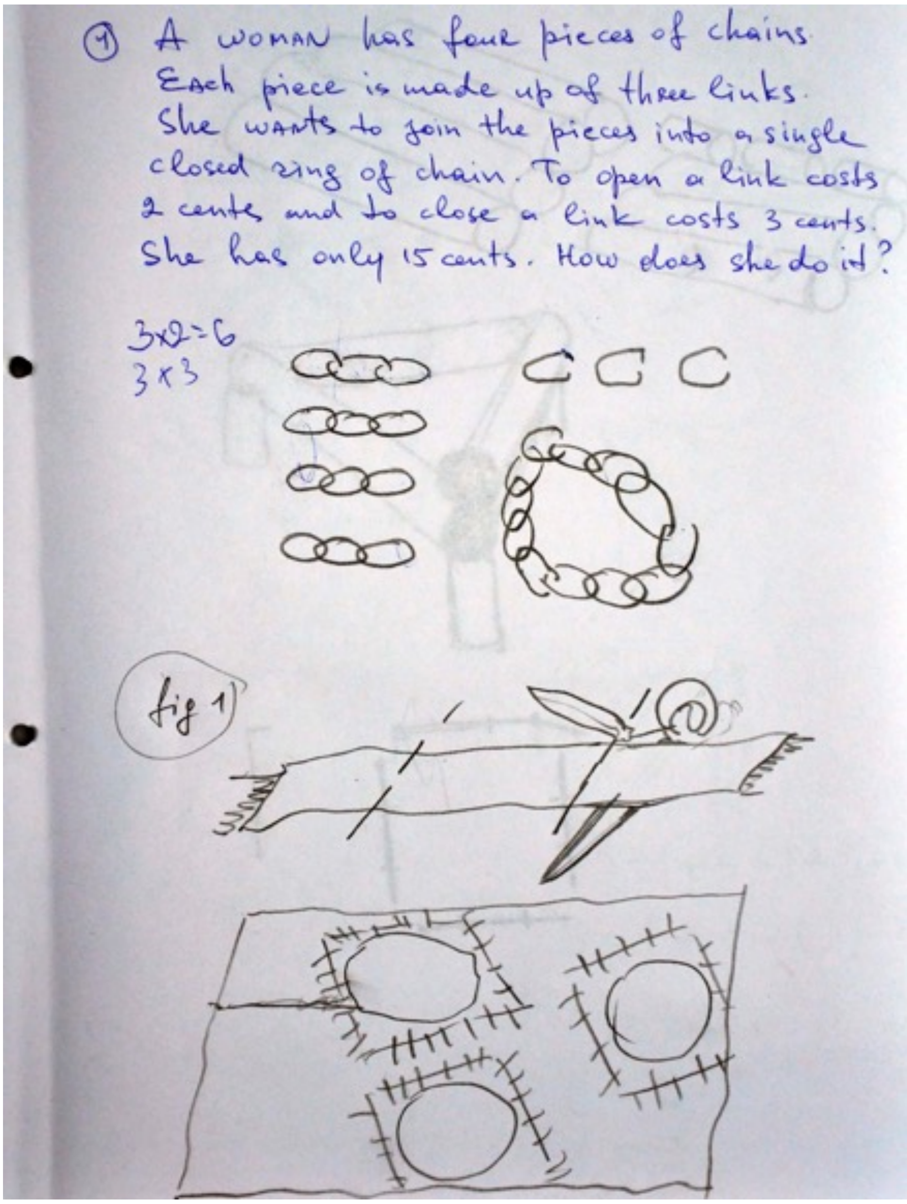


Figure 9.8 Generating ideas / Hand bracelet making

The analogy depicts beads of different sizes, and this might indicate its weakness, a *nonalignable* correspondence, which eventually confuses some problem solvers in the process. This leads to an uncertainty that is similar to the previous analogous case with the round dance (Figure 9.6). For that, it seemed that all main correspondences could be aligned properly in the clip using staging and secondary actions (2 of the 12 principles of animation) as transitions between the main actions (e.g., open a link, closing a link, move) of the intended analogy.



<u>Figure 9.9 Generating ideas / Quilt making</u>

Using the transitive material in the proposed animated clip enhances the imagery and is appealing (another principle of animation) to the viewer, and by eliminating these basic principles of animation just because they play the role of “extraneous information” in the analogy could muddle subjects even more.

The next idea for an attempted analogical candidate for our problem is captured in Figure 9.9. A quilt-making process could offer a natural explanation for the hidden actions to produce a result. Usually, before starting to execute a project, quilt makers, mosaic makers and other professionals buy an extra 10-25% of materials to make sure that they will not run out of materials for the project. The extra piece of the quilt, about a quarter of it, is cut from the whole piece to be used for the details in its patterns. The three marked design patterns suggest that the sets of chains should be left untouched, and the extra piece is divided and cut subsequently into three smaller pieces, for the designer to use to enhance each of the patterns.

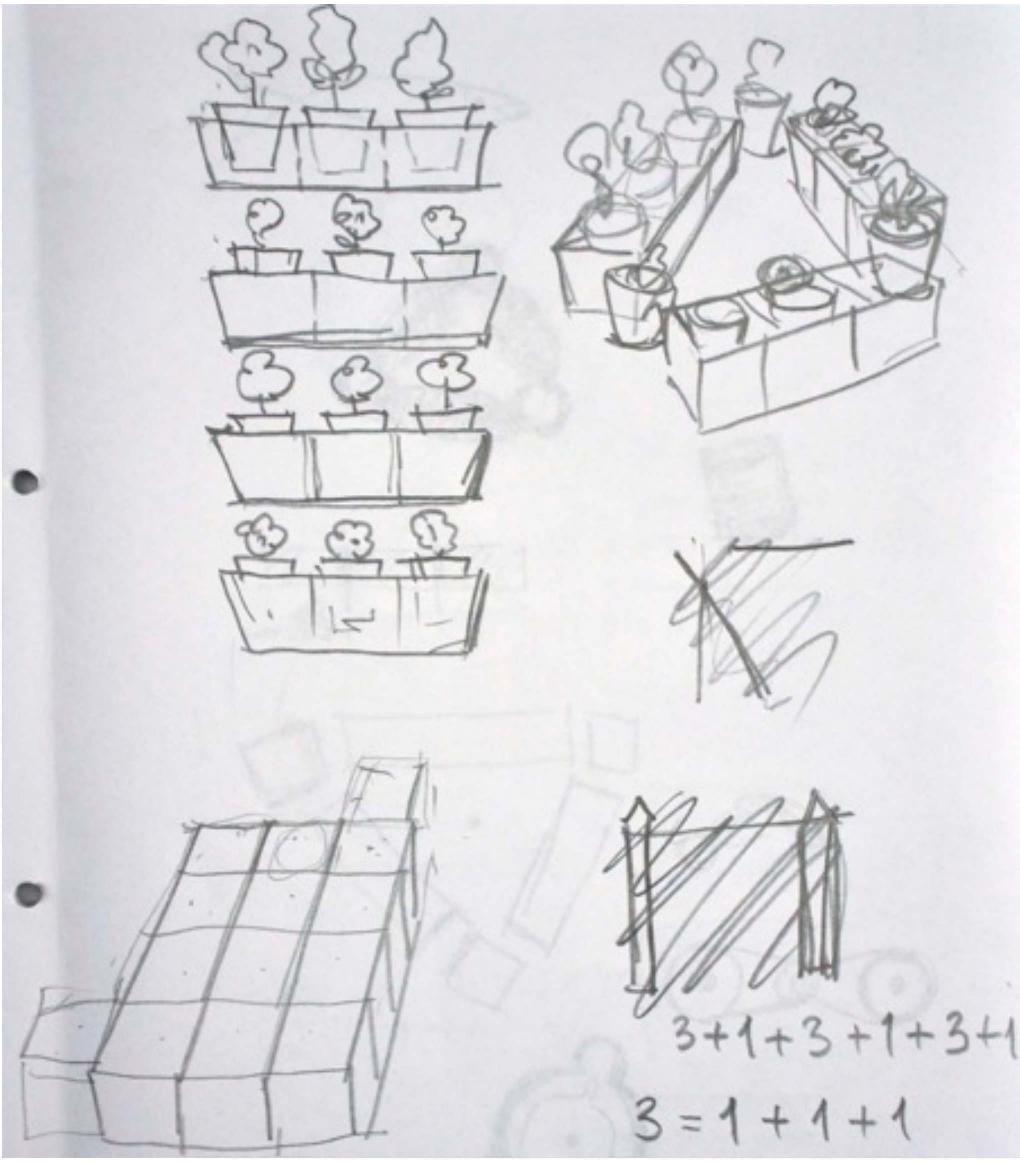


Figure 9.10 Generating ideas / Flower buckets arrangement

It seems a bit sophisticated and at first sight, it appears unrelated to the target problem, but focusing on showing the craftsman's processes for solving his design problems could provoke the viewer into thinking about possible similarities and sources in finding a solution for the necklace problem.

The sketch from Figure 9.10 is an old idea, inspired by the previous problem (Figure 5.4 and Figure 5.5). The difference in this one relates to its structural arrangement. The principle of generating a new analogous case via transformation was applied. It is very common for an artist to initiate an exploratory process by playing with marks or shapes on a 2D surface. The deployment of meandering lines and shapes leads the artist to discover new techniques or ideas. Often, artists do not have a set goal for their future work, but by bringing the objects, tools and materials into play, they discover new ideas.

In the case of analogy construction for an insight problem, the goal is defined, so this free-spirited process shifts the analogy maker to search for new ideas from observed natural structures or imagistic simulations of comparable schemas that are stored in the memory. Discovering new ideas through meandering lines or shapes is no longer the goal of the analogy maker. Instead, he is looking at what relationships play the most important role in the given problem and how they can be visually presented to suggest a correct path for the solution, hoping the first sketched idea will generate new ones.

The bench subject from Figure 9.11 was also used in the generation process for analogies for the *8-coin* problem. In this drawing, the layout has been changed and some transformations have been followed to fit the kind of relationships relevant for this problem. The new triangular shape of the bench violates the surface similarity but becomes stronger at the conceptual level, where the closure is implied by taking one of the four given pieces of wood and breaking it into three for the bench legs, and consequently the closure.

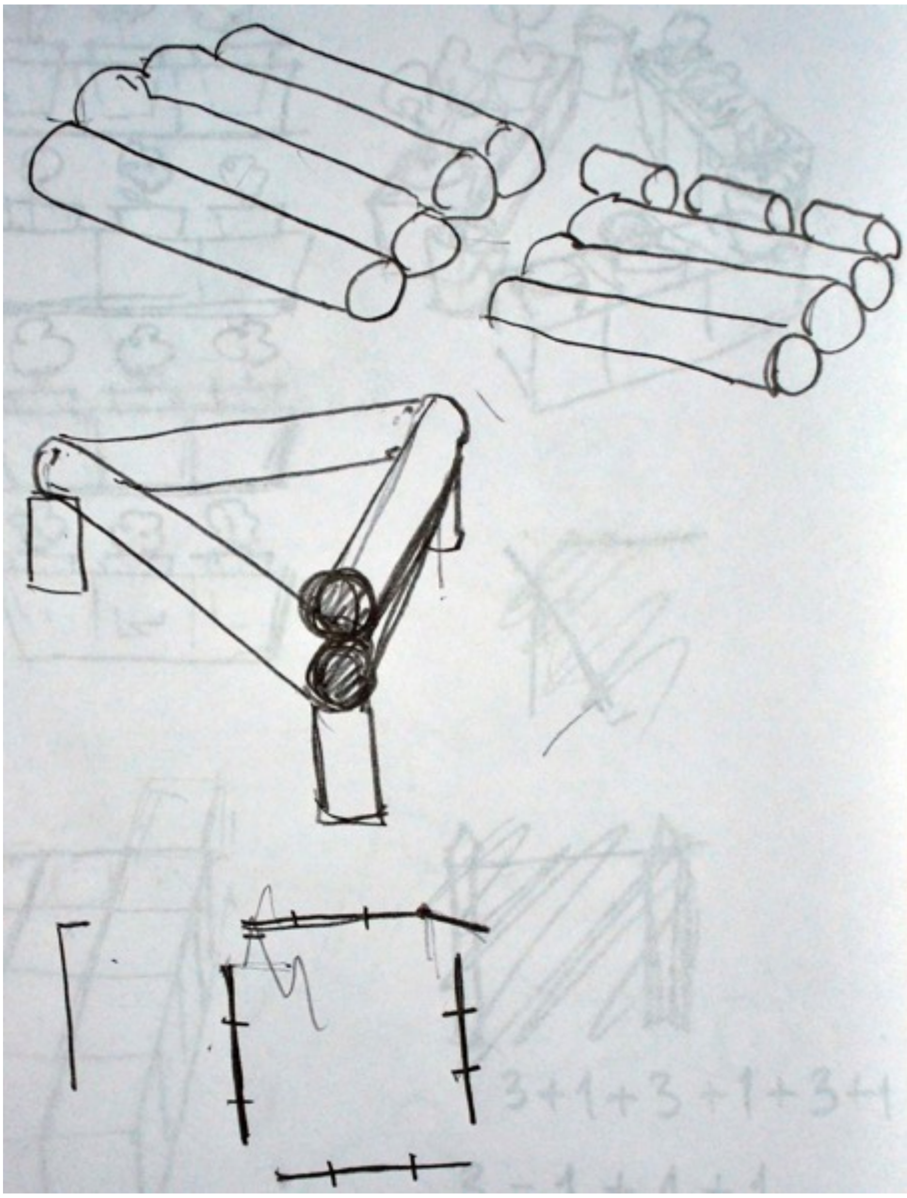


Figure 9.11 Generating ideas / Log bench

The next idea (Figure 9.12) emerged from the *Log bench* drawing. The arrangement of the main pieces is the same; it is only scaled down in terms of the figural psychological space. The similarity of the number of pieces and layout is used here to resemble the structural aspect in the target problem, ignoring the form. Four rectangular strips will be used as main parts in the animated clip of the future analogy. Also, the closure of the final pattern in the finished design will be in the form of a triangular shape instead of the expected circular one of the necklace. A widespread approach to depicting binary relationships, to show actions or to point out an outcome is to use glyphs or arrows (Tversky, Morrison, & Betancourt, 2002; Forbus & Usher, 2002) in the analogy. Most of the studies to date have used arrows to show directions or to point out the target outcome as a result of source modification. It is not intended to use arrows, glyphs or other symbolic signs in these animated clips. One of the reasons that signs and glyphs are avoided in the process of visual analogy development for this study is that these analogies are being designed to be as realistic and as close to the natural scenes and events as possible. The definition states that a glyph is a single graphical unit designed to convey multiple data (Ware, 2000), representing things with its visual attributes and values converted into codes. It is unlikely one would find drawn arrow signs that point north and south in the middle of a forest. In such a situation one would have to look for other kinds of information, perhaps from the environment, which might lead to a solution.

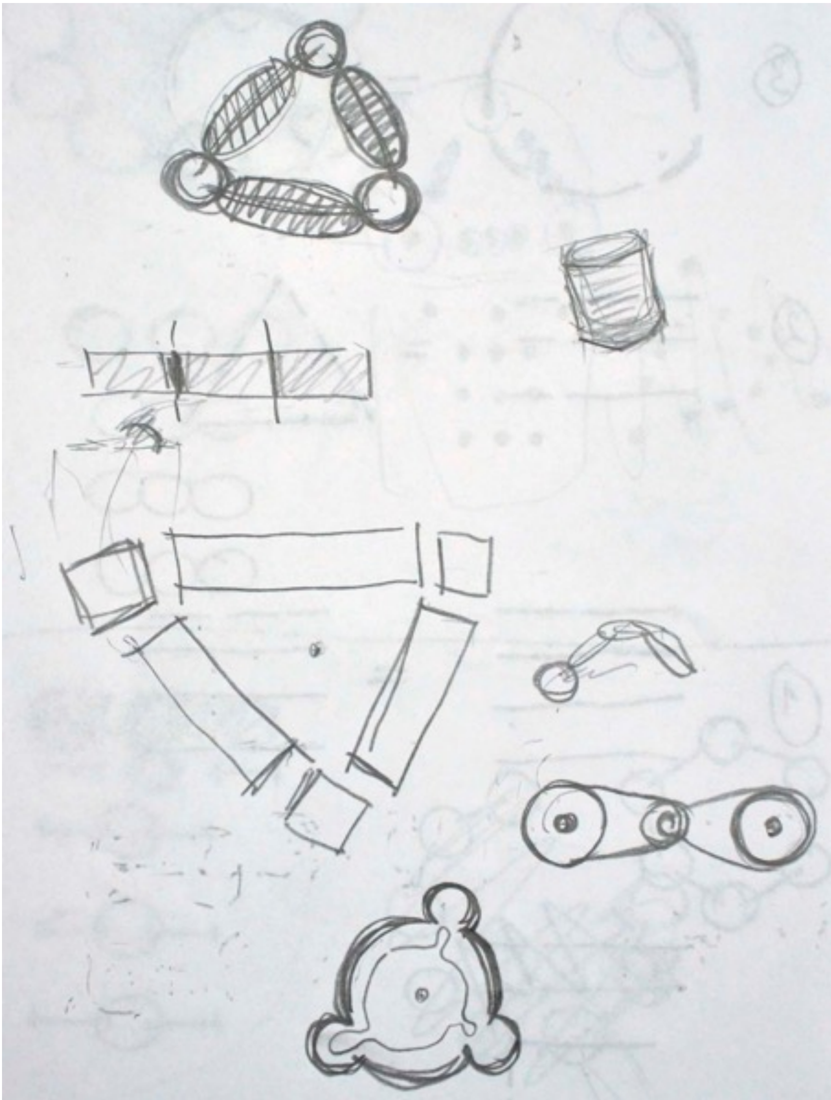


Figure 9.12 Generating ideas / Pattern design

From of the perspective of the processing properties of the human visual system, people can abstract images (Witkin & Tenenbaum, 1983). Based on what we see in front of us, we impose organisation on data regardless of whether we understand the meaning of it or not. What is more interesting is that these structures seem to be perceived at the primitive perceptual level by both a naïve and informed person. The difference is in the interpretation, the selected choices relating to the relationships between important things and non-important things and causality depending on whether they are perceived by an informed or naïve individual. Professional artists use the appropriate techniques and select the forms by employing the properties of a visual system acquired through observational practice, and succeed because they reflect these properties of the visual system in their work. The next sketches are good examples of generating new ideas exploiting a variety of different objects and forms.

The sketch from Figure 9.12 captures an idea of a simple creative exercise. It allows one to discover new design patterns. The task is to manipulate the four groups of squared shapes into a triangular pattern design. This idea was inspired by the layout of the initial configuration of the necklace problem. Often, in design courses, students are given exercises like this so that they can boost their problem solving skills, imagination, and to improve their compositional proficiency. Besides a brief description, such tasks impose constraints and rules in terms of finding authentic solutions. In this case, the intended multimedia clip will capture a scene of a student solving the triangular pattern design problem from the given fixed number of squares positioned in a layout like that for the initial configuration for the *cheap necklace* problem. The order of actions during the proposed clip will follow the order that is necessary for solving the problem target, except that the forms of the rings will be replaced, making them rectangular instead of oval. According to our findings from the previous experiment on the *8-coin* problem, the surface similarity of objects in a 3-dimensional space does not affect the ability of problem solvers to find a solution.

Figure 9.13 presents a new idea of a possible visual analogy for the *cheap necklace* problem. In the lower part of the image, there is a car safety highway emergency sign – a warning triangle. The "do it yourself" packages that are sold for driving emergencies contain a possible solution for the necklace problem. Upon opening the package, one gets four bagged items which are identical in length. The first bag contains three plastic nuts and bolts, and the other three each contain a red plastic strip with holes at both ends. An instructional flyer with a photograph of the item completely assembled is also included. The number of items from the package and their equal length is reminiscent of the initial configuration of the *cheap necklace* problem. The four bags form the main elements of the package. Upon opening each bag, one finds three links that are needed to join the stripes to assemble the sign, and the result of these actions can be seen in the closure of that sign.

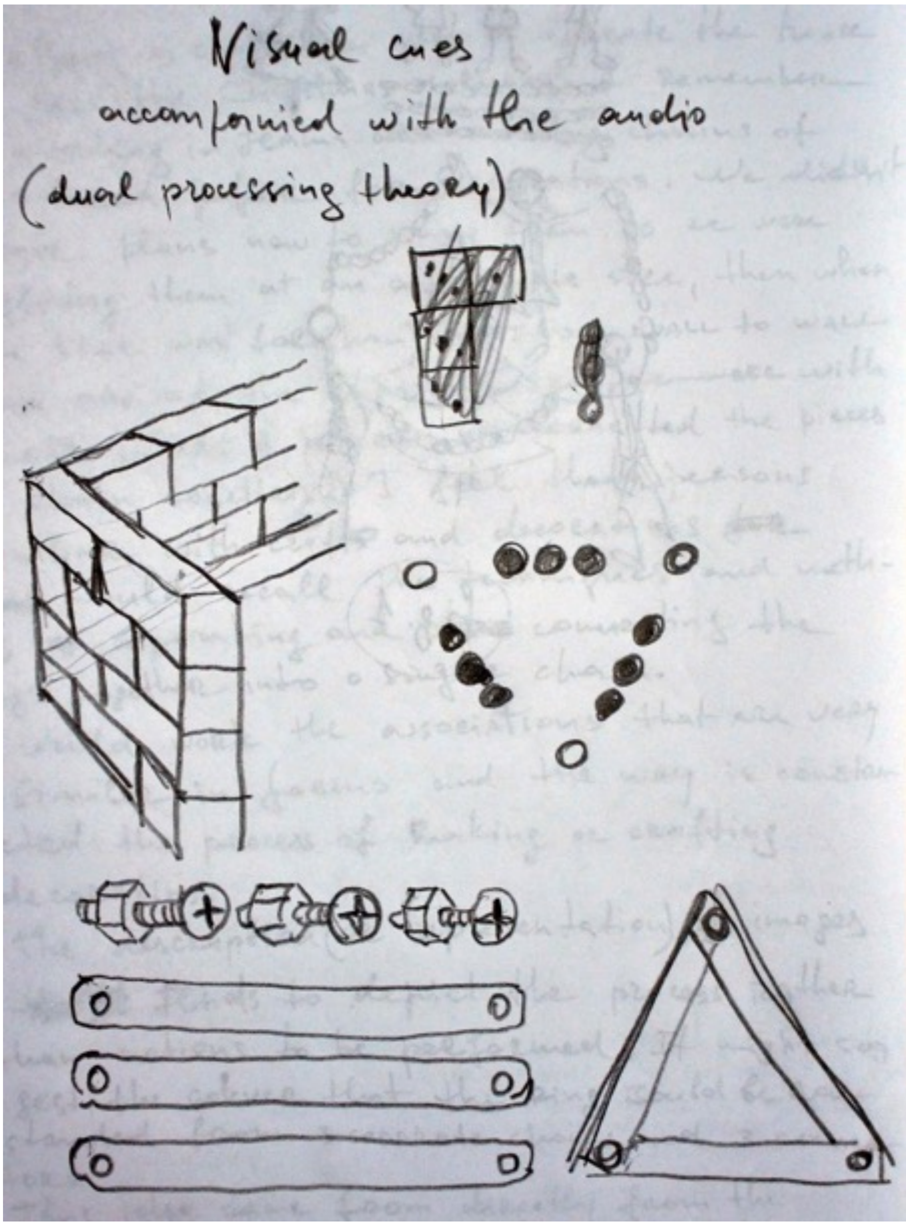


Figure 9.13 Generating ideas / Car safety highway emergency sign

A reasonably similar idea is achieved in the sketch in Figure 9.14, presenting a class practice exercise for middle school pupils. The main task is to produce three classic extendable table tops from four given wooden sheets. The sketch depicts the process of making these three table tops, and a written scenario for the analogy in a time-based media format.

The objects depicted in this scenario are aligned only as components of the whole to resemble the layout of the initial configuration of the chains in the *cheap necklace* problem. Also, the actions will suggest the insights for the problem solution.

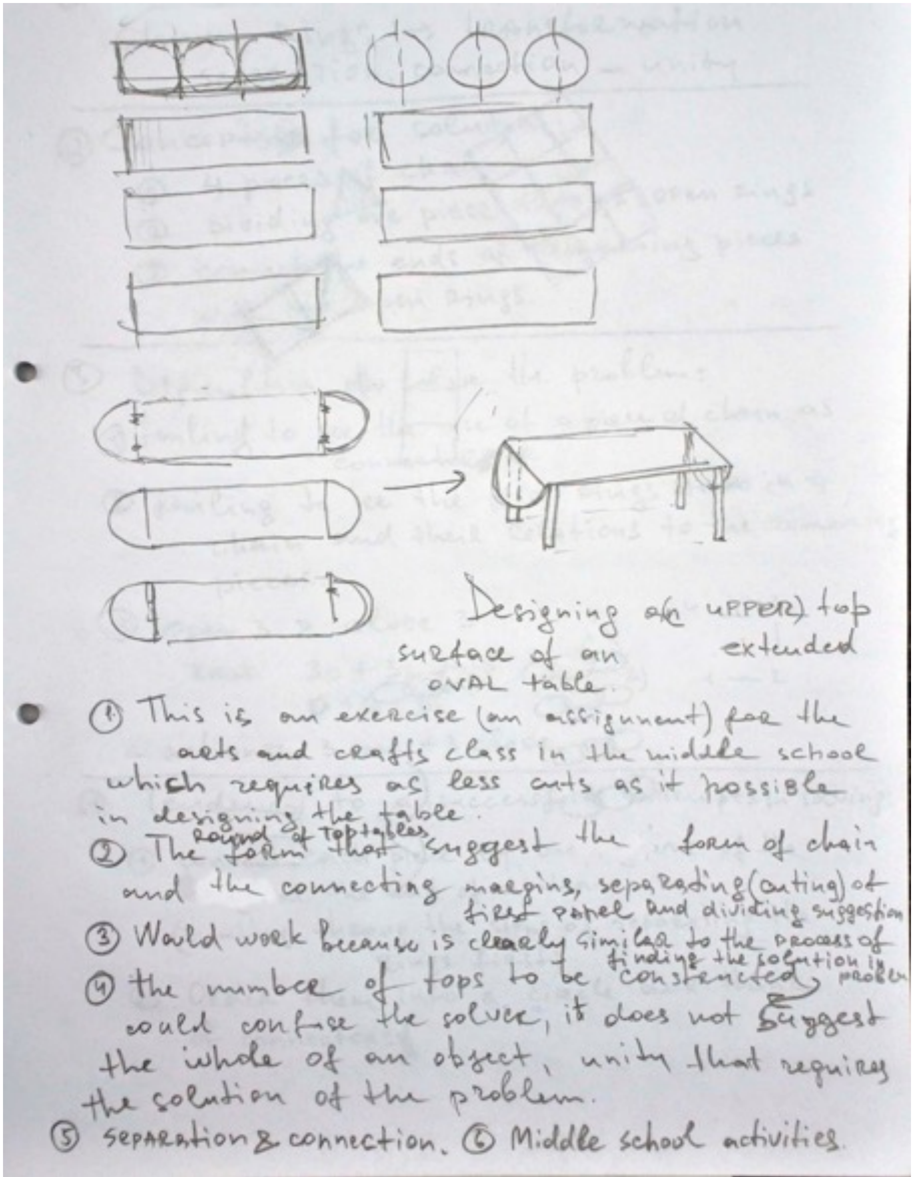


Figure 9.14   Generating ideas / Three extended tables

As opposed to the sketch of the pattern design exercise, here, we propose to keep the three wooden sheets as inseparable wholes, hoping that solvers will decide to leave them intact and think first about how to create the extended parts of the table tops. The scenario may or may not include humans (i.e., hands) manipulating these objects, but a proper capture of their transformations in the scene at any stage of the process would be helpful for participants to see a path to the solution to the *cheap necklace* problem they face.

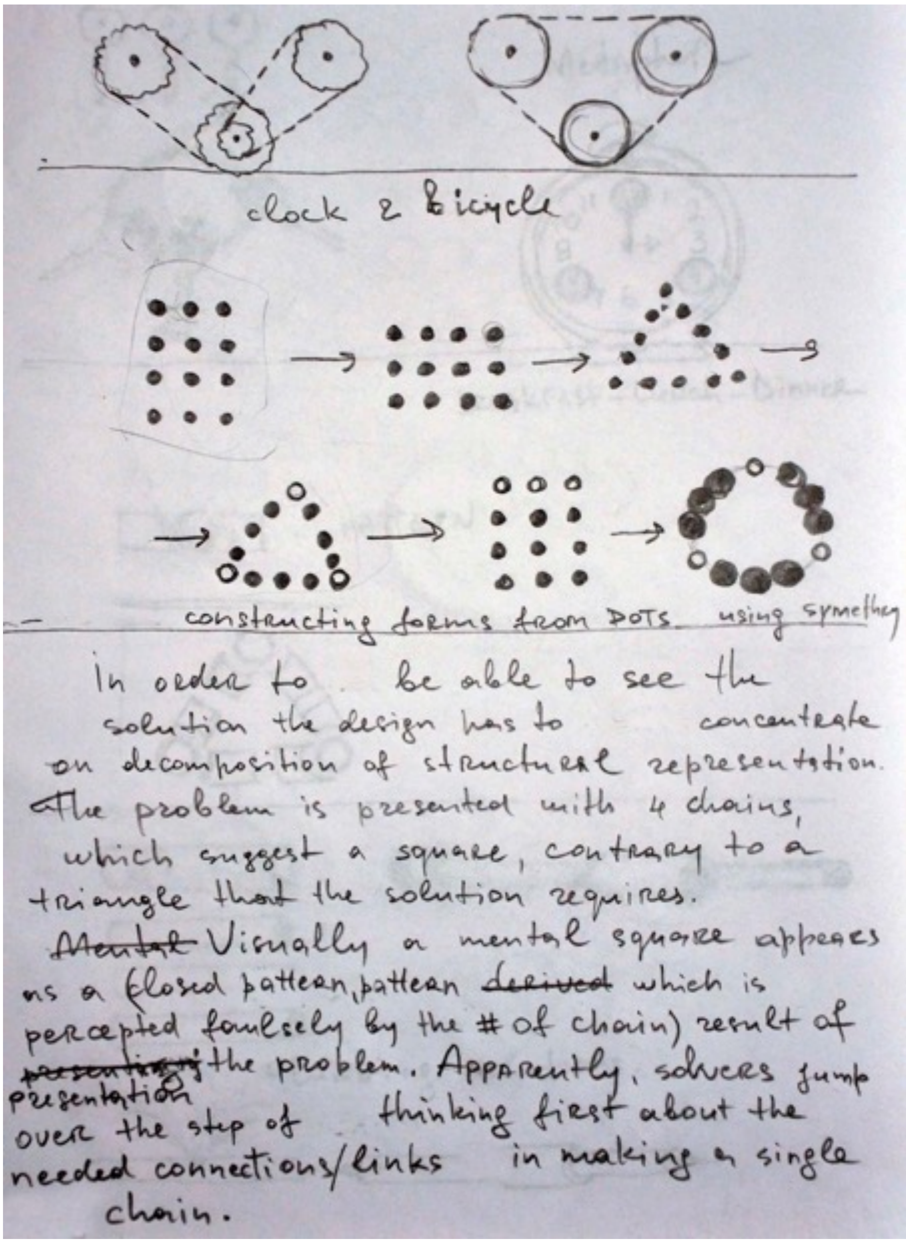


Figure 9.15 Generating ideas / Clock and bicycle chain rings

The suggestion in the next sketch (Figure 9.15) involves searching for opportunities to look at different ways of connecting things. This is an abstract idea for a visual analogy that is not based on objects that can be aligned or structural aspects of the source and the target. It is a conceptual idea intended to capture two facets of the problem.

The upper left-hand side drawing in Figure 9.15 shows how two chains could be attached to four rings, and in the drawing next to it, how a chain can connect three rings.

Figure 9.16 captures the generation of various ideas for possible analogies for the *cheap necklace* problem.

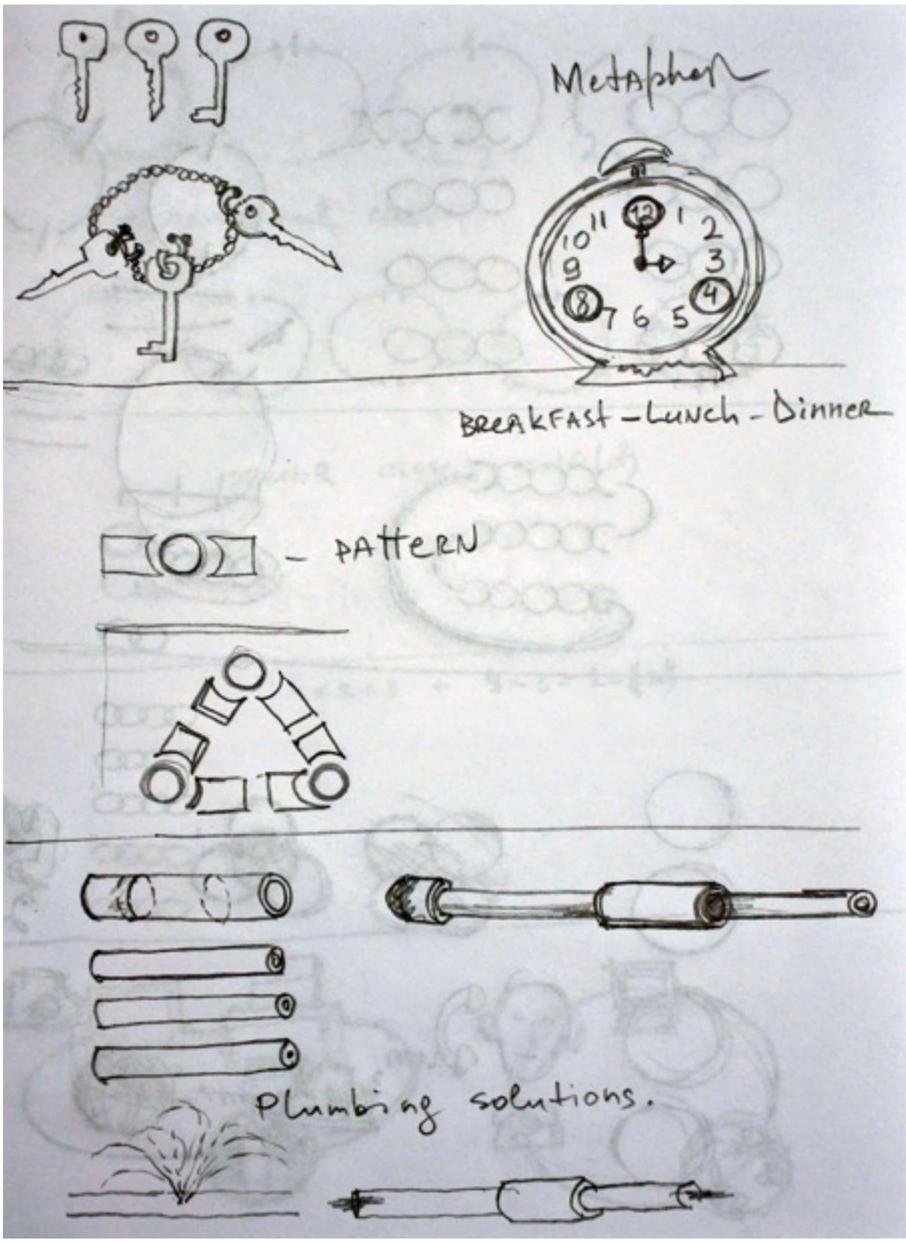


Figure 9.16 Generating ideas / More concepts

The one from the upper left-hand corner suggests a focus on the main driven components or actions (key elements of separation and unification) that can be manipulated to solve the problem. The clock image with the circled times marked for breakfast, lunch and dinner (although imprecise) from the upper right-hand side of the picture is a direct invitation to take three breaks from the total of twelve hours, but leave the three parts untouched.

Visually, this analogy reiterates that the hours between the breaks are kept in the same format (unlinked) as presented in the initial configuration of the problem, except that they are moved in-between the “meal” hours to form the whole “day”. The pattern design sketch from the middle part of the image was explored in various versions, so this is just one of several that have to do with some aspect of the design aesthetics, in the hope that doing more such drawings would bring additional insight and new ideas.

I paid particular attention to the activity of a friend while I visited him. He was trying to build a sprinkler system for his garden. He grabbed a few flexible pipes of the same length from his store, and made a rough plan on paper for the system. After cutting the larger pipe into three equal parts, he used them to connect the three thinner pipes, one by one, between them, into a perfect circle. He made several little holes along the sides of the system and a larger one to attach the hose. When I asked why he opted to use only three, he replied: “for the system’s legs, and three, only for its stability on the ground”. At that moment I thought: “This scene could serve as a good analogy leading to the solution for the cheap necklace problem”, so the idea was sketched at the bottom of Figure 9.16.

The last idea for a possible analogy for our problem that is worth mentioning is the one shown in Figure 9.17 titled *The Christmas dance*. The concept intends to capture a scene of dancing children who are holding decorations for the tree. The script for the animated analogy is still in its inception, and not fully formed, but it seems to have the potential to be developed into a good visual hint. The sketch presents the three little girls on the top row of the sketch as the subjects making the changes (connectors) in the animated clip by engaging in the dance process. Three long decorative items serve as elements that have to be connected, subsequently capturing the necessary insight relating to completing the circle.

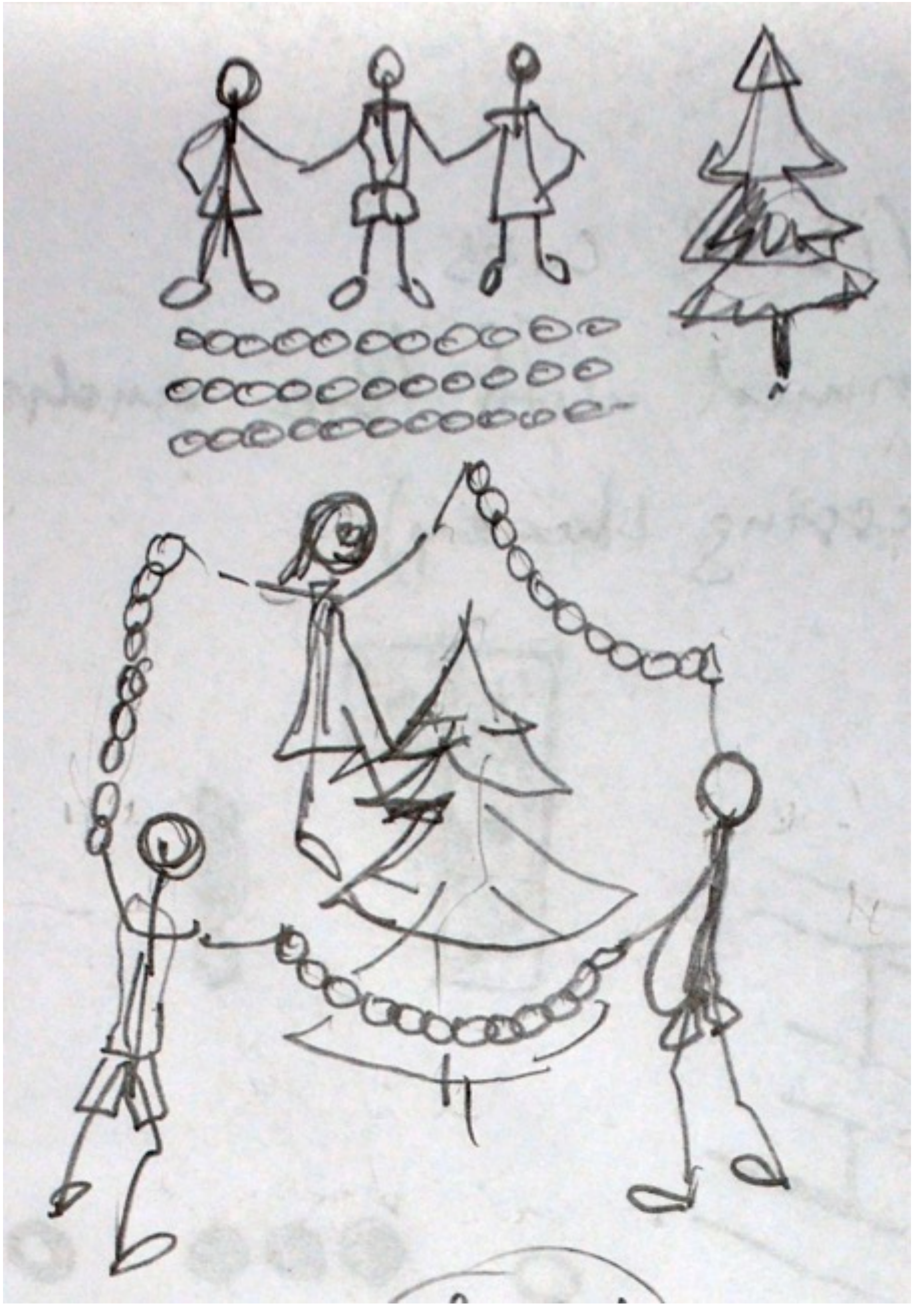


Figure 9.17 Generating ideas / Christmas dance

Preselecting Analogical Concepts

We evaluated and analysed the concepts for this experimental study using the same methodology as we used for previous experiments in the *8-coin* problem. To select the best candidates for visual analogies the generated sketches were evaluated along with the notes in three stages. The first step was to determine their suitability for further development. In particular is the consistency of each idea in terms of the applicability of analogical principles (i.e., consistency and *apprehension*) in a multimedia format for our design conditions was considered. Two expert researchers (Appendix 14-2, 1 & 3) who work in the field of analogical reasoning and who are familiar with the study, participated in the selection process with the researcher. After the first round of discussions and suggestions from the experts, the researcher went back through all the sketches to evaluate and describe them based on what type of schemas they might carry when converted into time-based media.

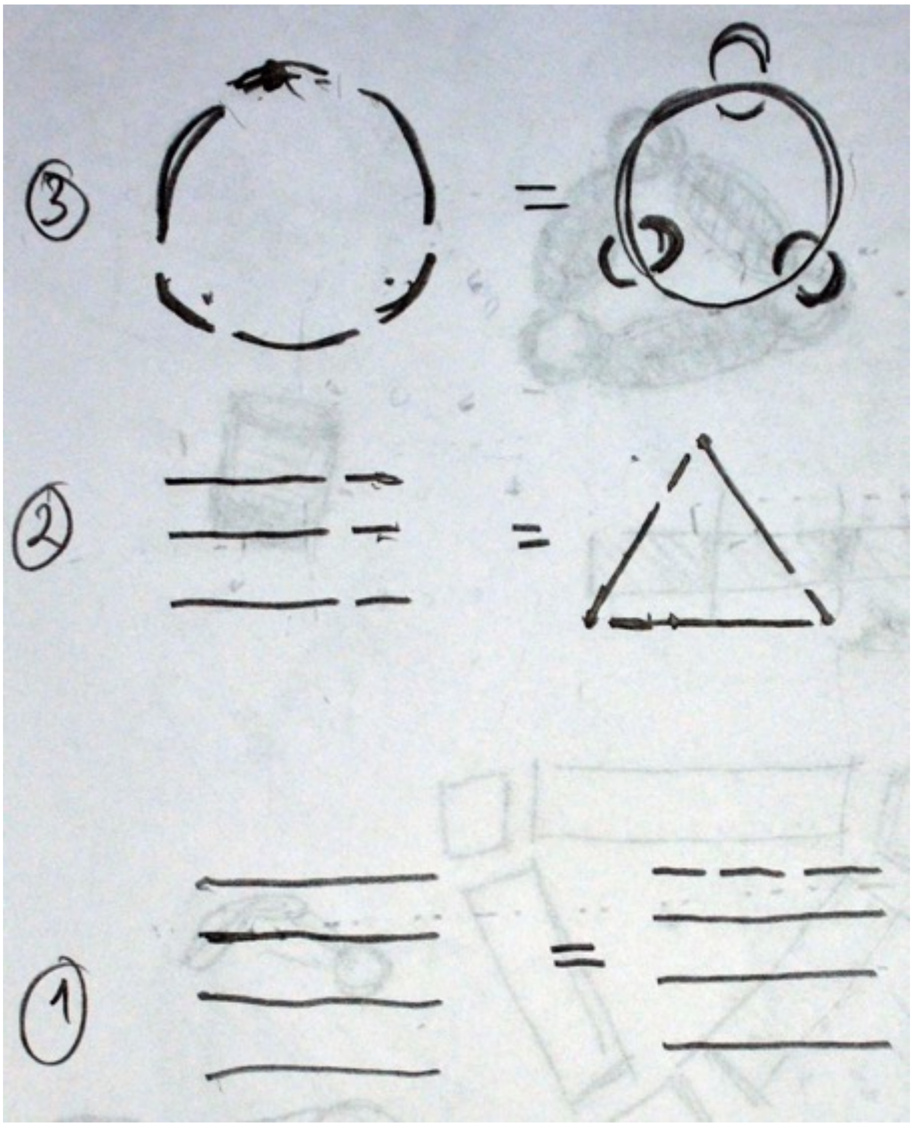


Figure 9.18   Schemas of selected analogies

For all the sketches, brief descriptions of possible scenarios and simulated visual action schemas (e.g., up, down, horizontal, vertical, push, pull, etc.) were made. On the second meeting attended by the same experts in the field, these descriptions and visual representations of schemas were presented and further discussed and analysed for their fitness and suitability for the intended design. The visual schemas of the three concepts in Figure 9.18 were selected for further development into animated clips.

The schemas from the images (Figure 9.18) are captured in the following set of concepts for the subsequent development and execution stages: 1) in *Pipes' circle* (bottom of Figure 9.16), 2) in *Pattern design* (Figure 9.12), and 3) in *Hora – round dance* (Figure 9.6). In the third stage, the selected concepts along with rough storyboards for each future visual analogy and a refined experimental design were presented for evaluation to the two experts (Appendix 14-2, - 1 & 2) the supervisor of this thesis, and an independent researcher. This stage included a thorough evaluation to ensure that concepts could be adapted into the intended animated format, and the action schemas would fit the experimental design variables.

These storyboards were tested on a small group of students to access their understanding of the insight cues. More than half of the participants recognised both hints in all three selected concepts. During the preselection process, feedback from the piloted participants, the experts in the field, the supervisor and fellow researchers and artists constantly guided the researcher.

Implementation

The selected sketches for this experiment were further developed in storyboards, to ensure that future animation would capture the *cheap necklace* problem insights. Here, the image schemas were identified and implemented for each scenario of the selected concept, ensuring the appropriate matching of structural and superficial analogical correspondences between the source and target.

The *Round dance* animation (http://luchian.info/html/05_01.html) captures the two insights through a set of interlinked schemas. To elaborate, we describe how these cluster schemas were captured in the animation. An image schema is thought to be structured and can be both static and dynamic (Lakoff & Johnson, 1999). As described by Mandler and Pagán Cánovas (2014), each schema is composed of three different levels: spatial primitives, image schema, and conceptual integration. While spatial primitives are the conceptual building blocks shaped from spatial information and image schemas are their conceptual spatial storytellers, the conceptual integration adds a non-spatial element such as force, gesture or emotion to both levels. This partitioning into levels gives the advantage of adding, replacing or removing extraneous elements, consequently enabling more meaningful connections between image schemas in framing the story.

From the start of the *Round dance* animated clip to the point where the dancers are fully aligned with the arrangement of the initial configuration of the *cheap necklace* problem, the following generalised families of schemas were sequentially implemented: START_PATH – BODY_MOVEMENT – MOVEMENT_ALONG_PATH – OUT_PATH – SOURCE_PATH_END. START_PATH capture the humans (i.e., spatial primitives – OBJECTS) moving (i.e., START_PATH) rhythmically in a pattern of steps (i.e., BODY_MOVEMENT) toward the centre (i. e., MOVEMENT_ALONG_PATH). The camera zooms out slowly, (OUT_PATH) while dancers reach their destination forming the schematic layout (SOURCE_PATH_END) of the initial configuration of the *cheap necklace* problem. Even though END and GOAL schemas might both suggest a location, the end location of a cluster of schemas may not correspond with the location of the ultimate target goal. Thus, throughout this experiment, we will refer to the base GOAL family of image schemas as the final representation of all insights needed to solve the problem and the END family of image schemas as the end location of an animated sequence.

The first moves in the *Round dance* animation serve as an entrance in terms of presenting the *cheap necklace* problem, a starting point that captures only a portion of the problem solving processes. This animated sequence is structured and presented in time, thus, each of the embodied families of schemas describing the story of the sequence are subordinated to the base image schema SOURCE_PATH_GOAL (i. e., the participant is going to use the visual analogy to reach its final goal of solving the problem) from the top of the hierarchical organisation. The first image schema SOURCE_PATH_END (dancers move to form the initial configuration of the problem), is followed by the second one that leads to the idea of rearranging the chains into a circle BODY MOVEMENT IN LOOPS_PATH_OUT, and interchangeably with the third UNLINK_MOVEMENT IN LOOPS_LINK capturing the insights for the problem of opening all the links in a chain and connecting the ends of remaining chains by closing the earlier opened single links. The implemented families of image schemas in this visual analogy are integrated and stem concurrently in time, as the insights require some of the tasks to be repeated in order to advance in the problem solving process. For example, in this animation "breaking one chain into separate links" occurs in parallel with other tasks of "rearranging the three chains in the form of a necklace". The *Pipes' circle* animation (see http://luchian.info/html/05_02.html) involves objects manipulated by humans. Here, we applied the families of gesture (i.e., hand manipulation), force (i. e., divide, pick, push), path (i.e., from, to) and movement (i.e., up, down, right, left) schemas. The chains are represented in this animation as four whole entities. To delineate the differences between gesture and force schemas, we refer to the actions that are manipulated by human hands as gestures and those containing support elements that change the events in a scene as force. The animation clip starts with the GESTURE_DIVIDE with a series of MOVEMENT_FORCE (front, back, left) schemas in between, followed by PICK UP_LINK_MOVEMENT and other repeated families of schemas that suggest the insights for the problem.The third clip we created as an analogy for this experimental study is the *Making a design* animation. The resemblance with the *cheap necklace* problem initial configuration of chains in this clip is shown in a 90-degree clockwise rotation. The reason we did this was to remind the participants that each chain constitutes a whole of three parts that can be rearranged, separated and linked back in different ways. In this clip the following families of schemas were implemented: camera rotates and zooms out ROTATE_OUT, GESTURE_MOVEMENT, and DIVISION_MOVEMENT_UNITY with several intermediate and shareable image schemas and their elements in between (see http://luchian.info/html/05_03.html).

Besides the careful selection of implementations of these families of schemas in these animated analogies, the consistency of *one-to-one* structure-mapping (Gentner, 1983) similarity, as well as Tversky's et al. (2002) *congruency* and *apprehension* principles of dynamic visualisation were scrutinised.

Refinement and Execution

The *Round dance* concept (Figure 9.6) clip started with the first dancers' moves capturing its introduction to the audience. As the dancers move toward the centre, the camera zooms out until all the dancers are composed and clearly seen in the frame. We felt that adding this camera move would enhance the animation artistically. Today, a 3D animator has the ability to manipulate the camera and render the characters and animated scenes from any point of view with just a few clicks of a button. We rendered the *Round dance* clip in two versions: the first involved capturing all the dancers in the frame with no camera move and the second involved adding the camera zoom in/out trick described above (presented version). The two versions of the *Round dance* animation were shown to a group of students to select the most interesting and visually appealing one. Five out of six students chose the second version in which the camera moves and follows the actions conveyed in the scenario. Most of them detected the actions performed in the scene in their sequential order.

The rotational aspect of the original arrangement of the elements at the beginning of the animated clip with the *Pipes' circle* (Figure 9.16) motif was added to match the arrangement in the original problem's initial state, and represents a modest change relating to a structural aspect of the insights compared to the other two clips. In the third animation capturing the *Making a design* (Figure 9.12) concept, the introduction in the animation involved delivering the insights sequentially, without any extraneous actions from the beginning to the end.

In the execution of these animated clips it was decided not play tricks with exact spaces and distances between objects or characters, but rather to simulate their real-life relative aspect ratios. Also, an equal time for each sequential action for the insights in all three clips was not allocated, as timing in animation can be a challenge. Tversky et al. (2002) suggest that animations are linear, and one should be careful with timing in animation, "as events in time are critical steps that are not uniformly distributed in time". The allocated time for each performed action in each clip was determined by simulating a close to real-life scenario for the subjects/objects involved in the analogy's construction.

9.2.2.2 **Materials**

A Participant Information Sheet containing two parts was handed out to the students. The first part informed the participants briefly about the experiment and its purpose and the second part included a consent form to be signed by both the participant and investigator. Students' permission to be video recorded during the problem solving session was included in the consent form. A sample of the Participant Information Sheet can be seen in Appendix 14-3 and Appendix 14-4; the sheets were updated to reflect the current problem. Study instruction sheets for control (Appendix 14-14) and for treatment groups (Appendix 14-15, Appendix 14-16, and Appendix 14-17) were given to students individually. Instruction sheets described the *cheap necklace* problem and the rules each group had to follow. A pen and a sheet of paper for making notes during the test were given to each participant. The four chains of stainless pins, each of three links of about one and a half inches in length were placed on the work surface.

9.2.2.3 **Apparatus**

The three animations capturing the analogy were created with Autodesk Maya 2011 software by the researcher practitioner. Each animated clip was 30 seconds in length, and they are described in greater detail in the implementation subsection of this chapter. The final versions of the animations were rendered and exported in an MP4 movie format at 25 frames/second (standard ratio for PAL TV system) at HDTV 1920 x 1080 resolution, and shown on a 24" HD TV screen via a MacBookPro notebook, equipped with a 2.4 GHz Intel Core 2 Duo Processor, with a memory of 4 GB 1067 MHz DDR3 and a VRAM 256 MB NVIDIA GeForce 9400M graphics card.

The animated clips started to play on the 24" HDTV screen at a scheduled time that was designed for each of the conditional groups, and both the participant and the investigator were guided by the stopwatch, which made a sound to indicate that the test had ended. Also, during the test, a Nikon D90 DSLR camera was used to record the participants' attempts at solving the problem and their hand movements.

9.2.3 **Study Design**

Table 17 shows the layout of the design for this experiment.

There were two IVs.

The first IV relates to the number of hints between groups at four levels: control group, one hint, two hints, and three hints.

The second IV relates to the time point (working time with the hints) and has three levels: after the first two minutes of working with the hint, after four minutes and after six minutes (end of test).

Thus, the experiment involves a mixed factorial design with one between-subjects factor and one within-subjects factor. The between-subjects factor is the number of hints on four levels, and the within-subjects factor is the time point on three levels, i.e. 4 x 3. Each visual hint was presented as an animated movie. The DVs were whether the problem was solved or not.

Experimental conditions			**No hint period**		**Visual hints – Visual hints and their displayed time (see colour chart below)**					
			T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**
#	Participants		0>1	1>2	2>3	3>4	4>5	5>6	6>7	7>8
0	0-h	Control group	no hint							
1	1-h / 1	1-hint group	no hint		dance					
2	1-h / 2		no hint		pipes					
3	1-h / 3		no hint		design					
4	2-h / 1-2	2-hint group	no hint		dance			pipes		
5	2-h / 1-3		no hint		dance			design		
6	2-h / 2-1		no hint		pipes			dance		
7	2-h / 2-3		no hint		pipes			design		
8	2-h / 3-1		no hint		design			dance		
9	2-h / 3-2		no hint		design			pipes		
10	3-h / 1-2-3	3-hint group	no hint		dance		pipes		design	
11	3-h / 1-3-2		no hint		dance		design		pipes	
12	3-h / 2-3-1		no hint		pipes		design		dance	
13	3-h / 2-1-3		no hint		pipes		dance		design	
14	3-h / 3-1-2		no hint		design		dance		pipes	
15	3-h / 3-2-1		no hint		design		pipes		dance	

Notes:

T1 to T8 – working on the problem time slots in minutes (e.g., 0>1 = 1st minute, 1>2 = 2nd minute, etc.) and colours chart representing:

Between groups		***Provided hints and left them to loop on the screen***	
(grey)	*- Control group*	(light grey)	*- no hint provided*
(yellow)	*- 1-hint group*	(orange)	*- round dance animation*
(amber)	*- 2-hints group*	(green)	*- pipes' circle animation*
(dark amber)	*- 3-hints group*	(cyan)	*- making a design animation*

Table 17 Chart of provided hints to groups and subgroups / Experiment 5

Hypotheses

H1 – Animated hint hypothesis: participants will be more likely to solve the problem if they receive visual analogies than if they do not.

For this experiment, we developed a new set of visual analogies to be tested for the *cheap necklace* problem. After analysing the provided hints used in previous experiments, reflecting on their strengths and weaknesses based on the results and written notes that were taken during their construction and participants' feedback, a new set of visual analogies for another insight problem were developed. The new set of developed animated clips is based on the experience and practice of analogy-making gained from all previous visual analogy development processes for the *8-coin* problem. It is expected that these new visual analogies will generate an even higher solution rate than the last developed animated clips for the *8-coin* problem.

H2 – Number of hints hypothesis: participants provided with two visual analogies will be more likely to generate correct solutions than participants who receive one or three visual analogies in that same time frame.

There is an interesting question relating to how many visual analogies one should see to solve a problem. Are one, two, three, even ten analogies enough to find the solution to a problem? From our observation on how participants work on a problem, behave, act, and make decisions when provided with a visual analogy during a problem solving task, we assume that there is a certain number of provided analogies that impacts on the solution rate among participants.

H3 – Family of image schema hypothesis: participants who saw the dance hint first will be more likely to solve the problem than participants who did not.

In examining the visual analogies capturing the insights of the *cheap necklace* problem, the dance becomes circular almost immediately, whereas the other hints take longer to demonstrate an approximation of the problem shape.

Furthermore, dance most easily demonstrates the visual elements of arrangement and movement (which were among the preferred elements associated with increased likelihood of solving the problem). Thus, we expect that the visual analogy embodying gesture and movement schema families, in particular, will generate a higher solution rate than for those receiving animated clips with *Making a design* and the *Pipes' circle* analogy.

9.2.4 Procedure

The procedure section explains the recruitment of participants, experimental setting and the procedure for this experiment.

Recruitment

Flyers similar to the one in the Appendix 14-1 were posted throughout the Lancaster University campus, inviting students to sign up for the study. The information and details about the problem or test involved in this experiment were not communicated prior to the study. Those who were interested in the study were invited to go to a web page and read about its general intent. The web page displayed the address of the location for the experiment, informed them that participants would need to be able to spare 20-25 minutes of their time, and that they would be compensated £7 for their participation. The web page included an automatic system showing the availability of time slots for the study, which those who are interested could choose and sign up for. Each time a participant signed up or cancelled a scheduled participation, the researcher was notified of the change by the system.

Experimental Setting

The study took place in the same room as the previous experiments on problem solving. The layout of the room can be seen in Figure 6.16 with the following difference: on the participant's table were the four metallic chains, each of the three elongated oval links in the initial state configuration (Figure 2.3) and above the workspace there was an image of both the initial state and the goal state as a reminder for them to reposition the links after each unsuccessful attempt to solve the problem.

Experimental Procedure

The experiment was conducted with each participant individually in a quiet room (Figure 5.15) in the InfoLab21 building at Lancaster University over a period of two weeks. Before the test, participants were provided with a two-page (Appendix 14-3 and Appendix 14-4) package of general information about the study which included a consent form to be signed by both the participant and the investigator as an agreement to the study conditions. Participants were randomly assigned either to the control group, or to one of the three conditional groups, and each participant was tested individually. The participants in the control group were given the instructions for their group (Appendix 14-14), and those chosen for the conditional 1-hint group (Appendix 14-15), 2-hint group (Appendix 14-16), and 3-hint group (Appendix 14-17) were given instructions for their respective condition.

During the test, the researcher was sitting facing participants, ensuring that they understood the instructions, kept track of the number of attempts, made notes, and provided the hints at the designated time. The four chains, and each of the three links, were placed on the desk in front of the participant. A sheet of paper was taped onto the desk to denote the workspace for the chains. The experimenter showed the participants how to open and close the links.

After participants' acknowledgement that they understood the problem and the test requirements, they were asked to rate their feelings during the test, and particularly, after each attempt to solve the problem. They were shown a scale that ranged from "0 – completely stuck" to "10 – extremely close" and were asked to report a number from the scale to represent their rating in terms of how close they felt they were to the solution. Participants were given pens and paper to make notes during the test if they wished.

From the start of the test to the end, the participants were guided by a web stopwatch timer which was customised for each condition, to ensure that each of them spent a total of eight minutes working on the problem. After each unsuccessful attempt at solving the problem, participants had to return the four chains to their initial state configuration (Figure 2.3) before making their next attempt. During this task, the participants were also asked to rate their feelings of warmth (Appendix 14-7). Participants were allowed to make notes, graphs and try as many solution attempts as they wished.

After two minutes of working on the problem, subjects were stopped and prompted to watch a 30-second animated clip that was presented on a computer monitor screen in front of them (Figure 6.16). Those from the control group were not given any hints during the test, so they continued to work on the problem for a total of eight minutes without interruption. To ensure equivalent exposure, after 30 seconds of watching the hint, participants from the 1-hint conditional group were instructed to restart work on the problem, and they did so for the rest of the hint period of six minutes. The participants in the 2-hint conditional group followed the same procedure but stopped again after a total of five minutes of working on the problem, and were provided with the second hint. The participants in the 3-hint conditional group were given the hints successively after two, four and six minutes of actively working on the problem. During the hint time working period, the animation was looped on the screen until it was replaced with the next hint or until the test ended, so that participants could watch it again if they wished to do so.

Each experimental group was divided into subgroups. The 1-hint group had three subgroups: those in the first subgroup were provided with the *Round dance* animation as a hint, those in the second were provided with the *Pipes' circle*, and in the third with the *Making a design* animated clip. The 2-hint conditional group was divided into six subgroups, covering each combination of the three animations provided as first and second hints. For example, if *Round dance* = 1, *Pipes' circle* = 2, and *Making a design* = 3, then the first subgroup was provided with 1 (*Round dance*) as the first hint and 2

(*Pipes' circle*) as a second hint; the second subgroup was provided with 1 and 3; the third subgroup, with 2 and 1; the fourth subgroup, with 2 and 3; the fifth subgroup, with 3 and 1; and the sixth, with 3 and 2. The 3-hint conditional group was subdivided as follows: the first subgroup was provided with 1-2-3; the second, with 1-3-2; the third, with 2-3-1; the fourth, with 2-1-3; the fifth, with 3-1-2; and the sixth, with 3-2-1. A detailed chart of the hints provided to each subgroup can be seen in Table 17.

During the test, the investigator recorded the number of attempts that were made to solve the problem along with participants' ratings of feelings of warmth after each attempt.

Participants who solved the problem in the first two minutes (no hint period) without receiving the hints were scored as successful and were excluded from analyses along with the ones that did not correctly follow the study instructions or were familiar with the *cheap necklace* problem (Appendix 14-9). Those who solved the problem during the experiment were scored as successful along with the amount of time it took them to solve the problem, and those who did not solve it in the period of eight minutes were stopped and scored as unsuccessful.

At the end of the test, all participants were given a set of questionnaires pertaining to the helpfulness of the provided visual analogy in finding the solution, a survey to measure participants' learning styles, the participants' demographics, and their preferences for visual elements and relationships in analogical transfer.

Generic Data Gathering

The same techniques and templates were used to gather information about participants' performance and their feelings of warmth self-ratings (Appendix 14-7) during the *cheap necklace* problem experiment as for the previous experiments, as well as the same survey used for previous studies to gather demographic data (Appendix 14-9), the same survey on helpfulness of the visual analogy as a hint to the problem (Appendix 14-10), and the SBCSQ Version 1.0 survey – (Appendix 14-8) to measure each participant's learning style. Participants were video recorded during the test for further analyses.

There were no exclusions, so all 120 participants (30 participants for the control group and 30 participants for each of the three experimental groups) were included in the analyses.

9.3 Results

Table 18 shows the design including experimental conditions for the between and within factors and the solution rate for each condition. For statistical tests, a significance level of .05 was applied. For post-hoc analyses, analysis of variance was used. Effect sizes are expressed in terms of partial eta squared (partial η^2).

A 4 (number of hints) x 3 (time points) mixed factorial ANOVA was conducted to compare the main effects of the number of hints provided to participants on the solution rate in solving the *8-coin* problem across three points of time, as well the number of hints x time points interaction effect. The main effect for the number of hints was statistically significant $F (1, 116) = 25.33$, $p < .05$, Partial Eta Squared = .396. Thus, there was a significant difference in the solution rate between control, the 1-hint, 2-hint, and 3-hint group conditions.

Experimental conditions				**Visual hints** – **Found solutions to the problem per time slot** – **No Hints**		**Provided Hints (see colour meaning below)**						**Total:**		
				T0	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**			
Groups	Code	Subjects		0>1	1>2	2>3	3>4	4>5	5>6	6>7	7>8			
0 no hint	Ctrl. Gr.	30	30	0	0	0	0	0	0	1	1	**2**		
1 dance	a.1	10	30	0	0	0	2	2	2	1	0	7	**23**	**70**
2 pipes	a.2	10		0	0	1	1	2	0	3	1	8		
3 design	a.3	10		0	0	2	3	1	1	0	1	8		
4	b.1.2	5	30	0	0	0	1	0	0	2	0	3	**23**	
5	b.1.3	5		0	0	0	2	0	0	0	1	3		
6	b.2.1	5		0	0	0	2	2	1	0	0	5		
7	b.2.3	5		0	0	0	1	0	0	3	0	4		
8	b.3.1	5		0	0	0	2	0	0	0	1	3		
9	b.3.2	5		0	0	1	2	2	0	0	0	5		
10	c.1.2.3	5	30	0	0	0	2	0	0	0	2	4	**24**	
11	c.1.3.2	5		0	0	0	1	0	2	0	1	4		
12	c.2.3.1	5		0	0	0	2	1	1	0	1	5		
13	c.2.1.3	5		0	0	2	0	1	1	0	1	5		
14	c.3.1.2	5		0	0	1	0	1	0	0	1	3		
15	c.3.2.1	5		0	0	0	2	0	1	0	0	3		
	Total:	120		**0**	**0**	**7**	**23**	**12**	**9**	**10**	**11**	**72**		

Between groups:	**Type of hint provided:**
Control group	**dance**
One hint	**pipes**
Two hints	**design**
Three hints	

Note: *Numbers in the cells are the numbers of found correct solutions per 1-minute time slot (e.g., T2 = from 2nd to 3rd minute).*

Table 18 Results / Experiment 5

An examination of the cell means indicated that although there was a large increase in the solution rate relating to the number of hint scores measured across the three points of time, only the total score for the control group (M = .07, SD = .254) is significantly different from the total scores for the other three experimental groups: one hint (M = .77, SD = .430), two hints (M = .77, SD = .430), and three hints (M = .80, SD = .407). There are no statistically significant differences between these three treatment groups. However, these results suggest that providing participants with visual analogies for the *cheap necklace* problem solving task significantly increases the solution rate in participants regardless of how many hints are provided to them over the same period of time working on the problem.

The main effect for time points (time 1, time 2, and time 3) revealed that F (1, 116) = 1.582, p > .05, Partial Eta Squared = .013 and there was no overall difference between the time points: time point 1 (M = .25, SD = .435), time point 2 (M = .17, SD = .382) and time point 3 (M = 18, SD = .382).

A non-significant number of hints x time points was also obtained, F (1, 116) = .644, p > .05, Partial Eta Squared = .016. Thus, there was no significant interaction effect between number of hints and time point factors.

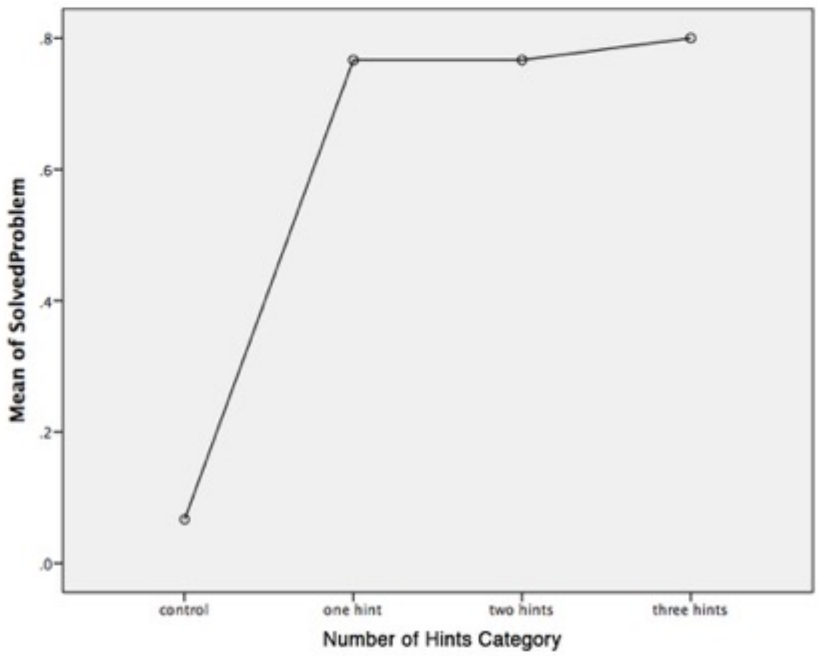


Table 19 Marginal means for 'Number of Hints' category for Experiment 5

To test our **H3 – Family of image schema hypothesis** a 3x3 mixed-model ANOVA was conducted to compare the main effects of the provided number of visual analogies and the type of design capturing family schemas on participants' performance in the *cheap necklace* problem solving task.

The provided number of visual analogy types was the between factor on three levels (1-hint, 2-hint, and 3-hint groups) and the design capturing the family image schemas as a within factor consisted of three levels (*Round dance*, *Pipes*, and *Making a design*).

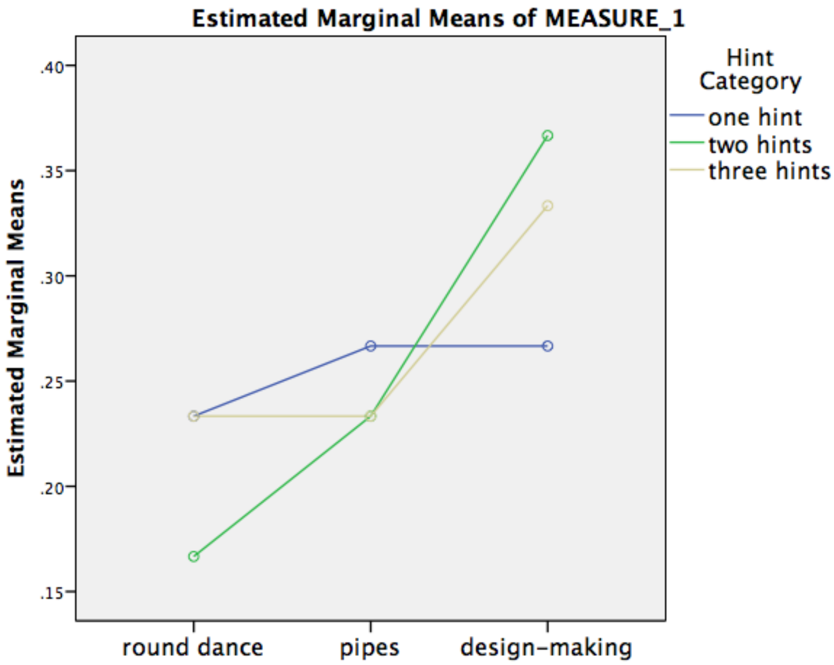


Table 20   Plot for Number of provided hints and solution rate per image schema

The analyses revealed that the main effect for the provided number of visual analogies was not significant F (2,87) = .062, p > .05, Partial Eta Squared = .001. Thus, there was no overall difference in the task scores between the 1-hint (M = .21), 2-hint (M = .24), and 3-hint (M = .32) groups.

A non-statistically-significant main effect for the type of family of image schema was obtained, F (2, 87) = 1.11, p < .05, Partial Eta Squared = .013. The Hint Category x Type of Image Schema was also obtained, F (2,87) = .395, p > .05, Partial Eta Squared = .009 yielding a non-statistically significant interaction effect between these factors.

9.4 Discussion

The present study examined whether constructed visual analogies embodying three families of schemas were useful in solving the *cheap necklace* problem or not, and whether the time and interaction of embodied schemas support cueing with animation in problem solving or not, and which ones are more effective. The result demonstrated that participants who received visual analogies were more likely to solve the *cheap necklace* problem than those who did not receive any hints during the problem solving task. This finding is in line with our hypothesised main effect of the visual analogies captured in an animated format on participants' performance in insight problem solving.

Our **H1** – **Animated hint hypothesis:** participants will be more likely to solve the problem if they receive visual analogies than if they do not – is supported by the results of this study, as well as by the results of previous studies (Sas, Luchian, & Ball, 2010; Luchian & Sas, 2011; Luchian, 2011).
In fact, it was expected that the gained experience in the visual analogy construction processes from the previous exploration would lead to a better understanding of how to develop and construct more efficient visual analogies that would generate a higher solution rate for the *cheap necklace* problem.

Insight Problem	Condition	Participants	Solved the problem
8-coin (Experiment 4 - Table 15)	Normal Eye View	40	29 (72.50%)
	Bird's Eye View	40	32 (80.00%)
	Total:	**80**	**61 (76.25%)**
Cheap necklace (Experiment 1 - Table 18)	One Hint	30	23 (76.67%)
	Two Hints	30	23 (76.67%)
	Three Hints	30	24 (80.00%)
	Total:	**90**	**70 (77.78%)**

Table 21 The results / Experiments 4 and 5

Table 21 shows the solution rates for the last two experiments. As per these results, even though there were no statistically-significant differences between the conditions in the *8-coin* problem, 80% of participants solved the problem in the Bird's Eye View compared to 72.5% in the Normal Eye View. Learning from this lesson, all three animations for the *cheap necklace* problem captured its objects from a Bird's Eye Viewpoint, or at least projected from such a spatial point. The application of the Bird's

Eye View point in the layout of constructed visual analogies for the current problem generated the same 80% solution rate for the three-hint condition, and an average of 77.78% compared with the average of 76.25% for the final *8-coin* problem.

Findings in Catrambone & Fleming's (2002) study also suggest that the animation group performed slightly better than the static group in complex transfer problems, in addition to a result from an earlier study by Thompson and Riding (1990) that led to the conclusion that animations facilitate learning when they present the micro-steps of processes that static graphics do not present. Another study by De Koning et al. (2010) suggests that animation can be effective in learning.

However, an implied merely attention to a prominent location on a surface level (e.g., coloured or exaggerated parts) in animation does not necessarily help people to process the functional relations at the conceptual level. In the same study, the authors provide evidence that self-explaining with a cued animation can improve understanding of the cardiovascular system not only for secondary school students but also for those at university level.

Also, it should be mentioned that although the *cheap necklace* problem is considered an insight problem, it was never associated with a problem space (Schnotz, Baadte, Müller, & Rasch, 2010). The insight for this problem is assimilated with the problem restructuring (Ohlsson S. , 1992) and operators to perform it. The results of this experiment demonstrated that the provided visual analogies capturing the insights through the developed concepts in a 3D spatial arrangement, in addition to the attempts to embody Kristensen's (2004) *scaffolding* (e.g., dancing and design-making spaces – places for creativity) structures in them, produced a success rate of 77.78% among participants, thus rejecting the assumption that *cheap necklace* problem is not associated with a problem space. The *cheap necklace* problem can be solved less painfully through analogising, by creating visual analogies that enable simple sequential steps for operations (i.e., *Round dance*, *Making a design*) that transform the initial configuration state into the goal state.

Our second hypothesis **H2 – Number of hints hypothesis:** participants provided with two visual analogies will be more likely to generate correct solutions than participants who receive one or three visual analogies in that same time frame – was not supported by the results of this study.

We speculate that failure to see differences in performance between the groups that were provided with a different quantity of visual analogies capturing the insights to the problem might be dependent on each participant's visual style and ability to connect and make analogical inferences between a received analogy and problem solution. For example, Gentner (1986) states that there are not only internal factors (e.g., *systematicity* principle) pertaining to analogical mapping, but external ones as well, including a person's characteristics such as age or expertise or time pressure, context, and processing load that might hinder them from identifying and interpreting inferences. If one cannot identify an analogical inference between the first given source and a target, it is less likely that one will identify other inferences between another given analogy, similar to the first source and that target. Gentner (1986) suggests that *literal inferences* are easier to identify than *relational* ones; however, this experiment only investigated visual analogies of the same type, thus, it did not allow for a conclusion to be drawn about the average number of analogies needed to solve a problem.

The **H3 – Family of image schema hypothesis:** participants who saw the dance hint will be more likely to solve the problem than participants who did not – was refuted by the result of a mixed-model ANOVA analysis showing no significant differences between the three conditions.

It is worth noting that contrary to our predictions, the *design* condition generated 29 correct solutions, higher than *pipes* which generated 22 and *dance* which generated 19. When constructing analogies for this experiment, we assumed that the inferences in the analogies capturing the gesture and movement families of image schema would be more easily recognised by participants. To elaborate: the dance scene shows all the pieces moving in unison, rather than single elements at a time (like the pipes or design hints). The hint demonstrates the circular nature of the problem first, then splits apart and adds the missing "dancers" (links) in a consistent, non-stop movement. This may be an example of parallel processing, which encourages more efficient cognitive performance from participants. In contrast, the pipes and design hints show elements separately and involve one element moving at a time to join together into the final shape, taking longer to approximate the shape of the puzzle.

Conditions	**Treatment groups (# of hints provided)**			
Visual analogy	One VA	Two VAs	Three VAs	Total
Dance	7	5	7	19
Pipes	8	7	7	22
Design	8	11	10	29

Table 22 Solution rate in the CNP by the type of families of schemas

This may be an example of linear processing, which, in the case of the visual analogy, may make it harder for participants to keep track of what is going on (and therefore, harder to see a connection). These assumptions were refuted by the results as well. More surprisingly, the design-making animation was the most effective in the *cheap necklace* problem, whose theme reminds the viewer of a creative activity (Csíkszentmihályi, 1988) simulating visual, haptic and tactile experiences (Ackerman, Nocera, & Bargh, 2010; Gallace, 2012) in lookalike puzzle task (Newell, Shaw J, & Simon, 1958; Simon H. A., 1978) and captured in a relational space for creativity (Gibson C. , 2005).

9.5 Conclusion

The embodied approach, described in Section 2.2.1.2 of Chapter 2, has been useful for this experiment as it resonates well with the creative processes in visual analogy-making, in which the manipulation of image schemas initiates and transforms views on representations facilitating problem solving and creativity.

One implication derived from the results of this experiment is that using embodied schemas in visual analogies to support the offload memory may be a useful instrument for creators of visual materials for instruction and learning. The first benefit is that the use of image schemas or families of schemas in such materials activates the mirror neurons, which prompt sensory motor systems to automatically retrieve similar experiences and act, thus reducing memory load and making it easier for the problem solver to focus on inferences between the source and target, understand them and follow a correct path in finding solutions to the problem. The second implication is that using image schemas in visual analogies makes it easier to understand the conceptual relationships not only between the presented analogy, the problem we face and the desired solution, but also the relationships between how we perceive that analogy, how the body acts and the mind interprets it. Image schemas embodied into analogy provoke and motivate us (Duit, 1991).

The results of this experiment also showed that the solution rate was higher than for the previous one, confirming that we improved the quality of the developed analogies from experiment to experiment.

This result was impressive as it demonstrated that a correct path in the visual analogy development processes had been followed. The new set of analogies that were created from scratch and were based on previous findings facilitated the improvement in the participants' solution rate in another notorious insight problem, the *cheap necklace* problem.

10 Sketching as a Generative Tool for Visual Analogy

This study explores the much less investigated research question of how visual analogies as hints for insight problem solving are generated using freehand sketching. More specifically, we focused on the creative process of the first author who is a professional artist, for generating two sets of visual analogies to support solving a classic insight problem of *8-coin*. First set of sketches was generated for analogies capturing the problem insights through static images, while the second set capturing the problem insights through a dynamic, time-based media format. We employed an experiential research method consisting of artist's documentation through the diary method, and reflections on his freehand sketching practice in his creative process. Inaccuracy of freehand sketches presents opportunities to generate new concepts of analogy. This study contributes to a deeper understanding of how visual hints can be generated, and what principles, tools, in particularly, through freehand sketching, and what methods of practices can be used in research.

10.1 Overview

The chapter starts by describing the methods and procedure, whose outcomes are subsequently described. The following section offers a discussion of these findings, while some final remarks conclude the chapter.

10.2 Methods and Data Sources

We are exploring methods and tools of the creative process for analogy-making from the point of view of the researcher's reflective notes. This work aims to investigate effective techniques for visual analogy-making to support insight and creative problem solving. Considered in this study were the diary notes on sketching analogy for the first two (see generated sketches for static analogy in Chapter 5 Section 5.2.2.1 and for dynamic analogy in Chapter 6 Section 6.2.2.1) of a total of four experiments on the *8-coin* problem, as their concepts were generated from scratch. In the following experiments, were mostly used ideas and sketches that were from the same portfolio; however, some were refined and adapted to fit their intended experimental conditions in other formats and media. We excluded the diary notes taken on analogy-making process for Experiment 3 (Chapter 7) and 4 (Capter 8) from analyses as most of their analogical concepts were modified or transformed without being generated.

The development of hints for these two experiments was captured through a rigorous on-action reflection process. A set of reflection prompting questions was iteratively revised, and the final set consists of 16 questions (Appendix 14-12) divided into four main stages, namely (i) understanding the challenges of the problem, (ii) generating hints, (iii) analysing and evaluating the hints, and (iv) learning from the experience and appraising the tasks. During analogy conception, the researcher is focused on some constraints related to the construction tasks of the problem, as visual analogies must satisfy a set of specifications that will fit and be tested in the insight problem. Both types of constraints – the problem-oriented constraints such as programmatic, economic or environmental that are pre-established problem requirements and the independent constraints pertinent to the practitioner's background and expertise – are considered in this study.

The researcher used the template (Appendix 14-12) as guidance for recording his notes during the analogy generating process. After each attempt at generating a new idea and sketching the potential candidate for analogy on a piece of paper (see an example in Appendix 14-13), the researcher wrote out his thoughts, where he was looking for inspiration, the possible implementation of the new concepts, and his thoughts on changes for better support, evaluation of and satisfaction with the product. Use of the reflection questionnaire (Appendix 14-12) for writing notes and dividing it into four stages, systematically guided the artist through his reflective practices, and supported the researcher to separate, synthesise and sort the gathered data through qualitative coding and categorisation. The reason for employing the reflection-on-action approach rather than reflection-in-action (Schön, 1983) was to avoid the observed overshadowing effect during the think-aloud (Schooler, Ohlsson, & Brooks, 1993) process when talking about perceptual information can interfere with the retrieval of that information from memory (Schooler, Fiore, & Brandimonte, 1997).

Traditional video recording footage used in studying the creative process has its benefits for exploring human behaviour; however, it is limited to only what is observable. The unspoken feelings and thoughts of a subject can only be guessed at or inferred (DuFon, 2002), hence the need to recruit a more introspective method. Some limitations of the chosen reflection-on-action approach include forgetting some thoughts and details, or sources for hint generation. In order to minimize this limitation, the notes were taken right after each sketch was produced. We used "HyperRESEARCH" (ResearchWare, Inc., 1997-2012) software for coding the text for the notes and preparing data for qualitative analysis.

10.2.1 **Procedure**

Twenty-two notes were taken by the researcher during the development phase of analogies, and were designed as hints for experimental studies to investigate the support of insight in the *8-coin* problem. We used the reflection questionnaire (Appendix 14-12) to answer each question, and for each sketched concept. The notes were gathered during the developmental period of visual analogy generation for the first two experimental studies, for the first experiment using static and for the second using discrete and continuous animated analogies. The gathered data from the notes were codified, categorised, and subcategorised for further qualitative analysis.

10.2.2 **Coding Scheme**

The primary data consisted of 22 notes (~10,000 words) and were completed with an overall number of 16 quotes related to hints. During the coding process, we identified 34 emerged concepts (see Figure 10.1) that led to the development of categories grounded in the text and based on grounded theory approaches (Kelle, 2007). We employed Glaser & Strauss's approach of analyses, where the researcher does not have to force preconceived categories on the data, but allows the categories to emerge from data (1967) through a constant comparison of codes, subcategories, categories, and their properties. The following sentence is an example (an answer to the question 15 from Appendix 14-13 on sketches from Figure 6.3):

> "So, let me have a go: in the first frame will be shown (or not shown) a person with several buckets (probably 8 in total), aligned in 3 rows and seen from a frontal view, then the individual enters the scene and picks up a bucket from the centre and stacks it on the other 3 ones on the side".

This sentence was encoded into four codes. The first part of the sentence "So, let me have a go: in the first frame will be shown (or not shown) a person with several buckets" was encoded "Media" as the subject is pointing out the entrance frame for the animated hint. The second code was assigned to the part of the sentence where the artist mentioned the quantity of objects or order – "/(probably 8 in total)/ and /in 3 rows/" and was encoded "Number". The following segment: "/aligned and seen from a frontal view/" was coded as "Perspective", and the rest of the sentence "/then the individual enters the scene and picks up a bucket from the centre and stacks it on other three ones on the side/" was described as a "Transformational" indicator.

Codes including "Adding new things", "Break in", "Discarding things" and "Transform" trigger changes or transformations to be made in the sketch. "Character", "Composition", Emphasis and focus" codes are describing aesthetic design principles, " Form", "Shape", "Line", "Perspective", "Media", "Number" and "Other sources" are related to the design elements and design tool groups. The ideation category included segments of the text describing thoughts, feelings and sources of inspiration in the generative process of visual analogies and was coded as "Imagination", "Impression giving", "Thinking and inspiration", "Logic" and "Inspiration from real life". The last set of codes is composed of instances of evaluating and supporting hint development: "Promising ideas", "Satisfied", "Usable", "No good idea", "Too much" and "Unexpectedness" segments.

10.2.3 **Categorization**

Categories and subcategories emerged from a constant comparison of data and codes.

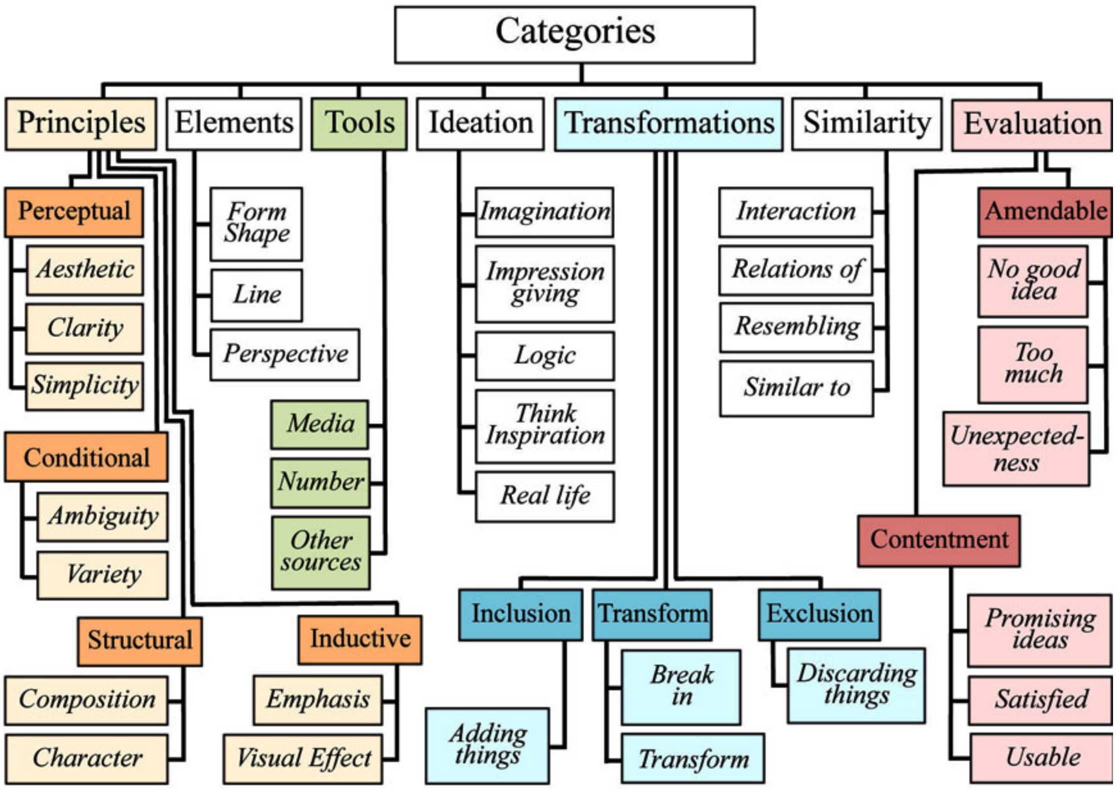


Figure 10.1 Categories, subcategories and codes

To gain a better understanding of how categories (1st level) and subcategories (2nd level) emerged, we assigned each code (3rd level) to a central category taking into account the structural aspect of objects and their properties mentioned by the artist, the relationship between them, instances, tools, inspiration sources and the evaluation of the sketch (see Figure 10.1).

The category of "Principles" for the design was divided into the following subcategories:

1. "Perceptual" – including "Aesthetic" quality, "Clarity" and "Simplicity" codes describing the qualitative properties of perceived objects;
2. "Conditional" – such as "Ambiguity" (misleading insights in the sketch) and "Variety" (diversity of ideas in the concept) codes;
3. "Structural" – including "Composition" (harmony), and "Character" (object's quality) codes;
4. "Inductive" purpose – containing the "Emphasis" and "Visual Effect" codes.

The category of "Elements" of visual design includes subcategories:

1. "Form and Shape" emerged from descriptions of surface(s) properties
2. "Line" emerged from descriptions of lines characteristics (straight, curved, implying direction, etc.)
3. "Perspective" describing spatial structures of objects and their relationships.

The category of "Tools" consists of the instruments and mechanisms of communication to carry the *8-coin* problem insights and was divided into the following subcategories:

1. "Media" – codifying the text that describe discrete or continuous format of the future visual analogy in the sketch,
2. "Number" – describing the number of objects to be presented in the sketch, and
3. "Other sources" – describing other used tools in generating visual analogy (see example of a sketch for Experiment 2, Figure 6.4).

The category of "Ideation" includes a set of codes that divides it in subcategories:

1. "Imagination" - describing mental images, imagined things or situations,

2. “Impression giving” – describing the perceptual qualities of structures in the sketched concept,
3. “Logic” – containing text of analyses of objects and relations between them,
4. “Think and inspiration” – brainstorming for new analogy concepts
5. “Real life” – descriptions of sources of inspiration (real life situation, art, etc.)

For example, the researcher writes in one of his notes: “Just sharpened my pencil to get ready, and there is a loaf of bread that left from my breakfast”, which points to the source of inspiration, and in this case, the segment was assigned to the inspiration from “Real life” subcategory and placed in the ideation category. In the sentence “The bread could be of a perfect cylindrical form and sliced into eight equal parts to match exactly the number and the forms of the units in the problem”, the researcher uses his imagination and thoughts on how to connect that real-life situation (as inspiration) to come up with an analogy for a new hint (see Figure 6.11) for the *8-coin* problem. In this note, he talks about forms, associations, number of units and common structural components with the target problem, and fractured data were assigned to appropriate codes, subcategories, and categorised, respectively.

The category of “Transformations” emerged from the segments of text that describe changes to be made in sketches and was divided into three subcategories of instances:

1. “Inclusion” - describing adding things to the sketch (“Adding things” code),
2. “Transform” – describing changes such as break in or divide (“Break in” code) and transforming the imaginary object or visual sketch (“Transform” code)
3. “Exclusion” - discarding or abandoning things (“Discarding things” code)

The category of “Similarity” is composed of four subcategories codified as:

1. “Interaction” - describing the interactivity of objects and their relationships;
2. “Relations of” – describing the connectivity of objects and relationships between objects;
3. “Resembling” – describing associations with other objects and;
4. “Similar to” – describing correspondences between objects, attributes, and their properties.

The last category of product "Evaluation" is divided into two subcategories:

1. "Contentment", which combines codes such as "Promising ideas", "Satisfied", and "Usable" as positive values, and
2. "Amendable", which includes "No good idea", "Too much" and "Unexpectedness" codes as a negative appraisal of the sketched analogy.

10.3 Summary on observed data

Emerged categories are based on image making and theoretical frameworks for visual analogy. The four subcategories indicating the use of principles of design (Lidwell, Holden, & Butler, 2010) in the analogy-making process (Clement J. J., 2008), describe the perceptual, conditional, structural and inductive spatial arrangement aspect of objects in a scene (Do & Gross, 1996). Analysing the frequencies of the artist's statements between categories for the two studies (static and dynamic), we noticed a significant increase in dynamic analogy in the principles group (Figure 10.2). "Conditional" and "Inductive" subcategories (Figure 10.3) for this group show significant differences between two studies.

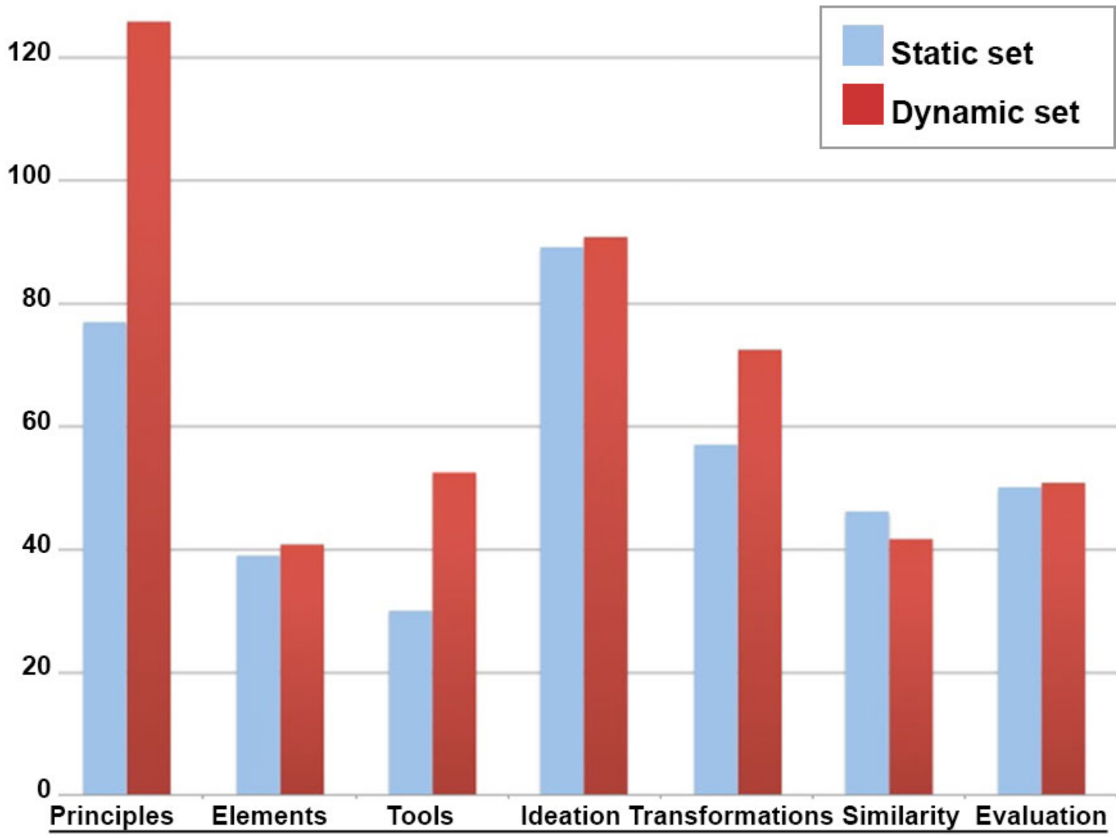


Figure 10.2 Between overall categories of static and dynamic studies

The "Conditional" subcategory consists of two codes: "Ambiguity" and "Variety" (Figure 10.4), which will be discussed in more detail in the next section. Another two codes: "Emphasis" and "Visual Effect" from the "Inductive" subcategory of the "Principles" category will be detailed here, as well. The statements about "Elements" of design in the researcher's reflective notes are aligned with the theoretical framework of elements identity (Rosenberg, 2008) to represent forms and space (Samara, 2007). In this category, no differences were observed between the two studies.

The "Tools" category involves the intended media (static or dynamic) to fit the requirements (De Koning B. B., Tabbers, Rikers, & Pass, 2007) for the type of experimental study and how the insight will be presented in the image (Goldschmidt G. , 1991). Slight differences in statements between the two studies in this category were observed. The differences appear to be as a result of adding the dynamic feature to the visual analogy for the experiment using animation.

The "Similarity" category included segments of statements related to similarities, resemblances, relationships (Goldstone, Gentner, & Medin, 1989), and interaction between objects in context (Chun & Jiang, 1998) and was based on Gentner's (1983) structure-mapping theory. There are no differences in this category between the two studies.

The "Ideation" category includes segments of statements about mental images, inspiration, impressions, and logic that help the artist to come up with the concept for analogy and are based on Clement's (2008) methods to generate analogy and sources of inspiration for analogy (Benyus, 1997; Eryildiz & Mezini, 2012; Christensen & Schunn, 2009). The statements from this category were balanced in both studies.

The "Evaluation" category consists of two subcategories: "Amendable", where statements are negative, and "Contentment", where the artist is satisfied with the outcome of the sketched analogy. Overall, there are no differences between the two studies in this category. However, we noticed the opposite effect when compared to their subcategories, the "Amendable" and "Contentment" subcategories counteract each other. The more amendable the statements are addressed during the process of development for an analogy concept, the less contentment is expressed and vice versa.

10.4 Discussions

The artist's understanding of the goals varies depending on the questions raised by the type of experimental study. He states that the information about the problem involves patterns, lines, shapes, forms, mental manipulations and transformations of imagined objects that can be selected, combined and refined in a continuous dynamic way. As an analogy maker, he points out differences between the information he is attempting to convey while working on analogy making for the *8-coin* problem in a physical space by using physical objects and information about the created artefacts, which will be presented, on a fixed 2D surface, either on a computer screen or a sheet of paper.

One of the major concerns in the challenges is the additional requirement to construct analogies specifically for each intended feature of the experimental study, such as adding sequential and simultaneous delivery of insights, form and order of presentation and kinds of relationships between insights.

So, the generation of hints is a constrained creativity process. Once a mental image has been formed and the first line has been drawn on paper, sketching becomes structured thinking; this links back to sketching as a method for organising thinking (Rosenberg, 2008; Tversky B. , 1999). Transformations to the content are applied continuously and one idea leads to a different one (Patherbridge, 2010). These ideas are usually generated while thinking about the set problem and reaching its goals (Dominowski & Dallob, 1995; Smith & Blankenship, 1991).

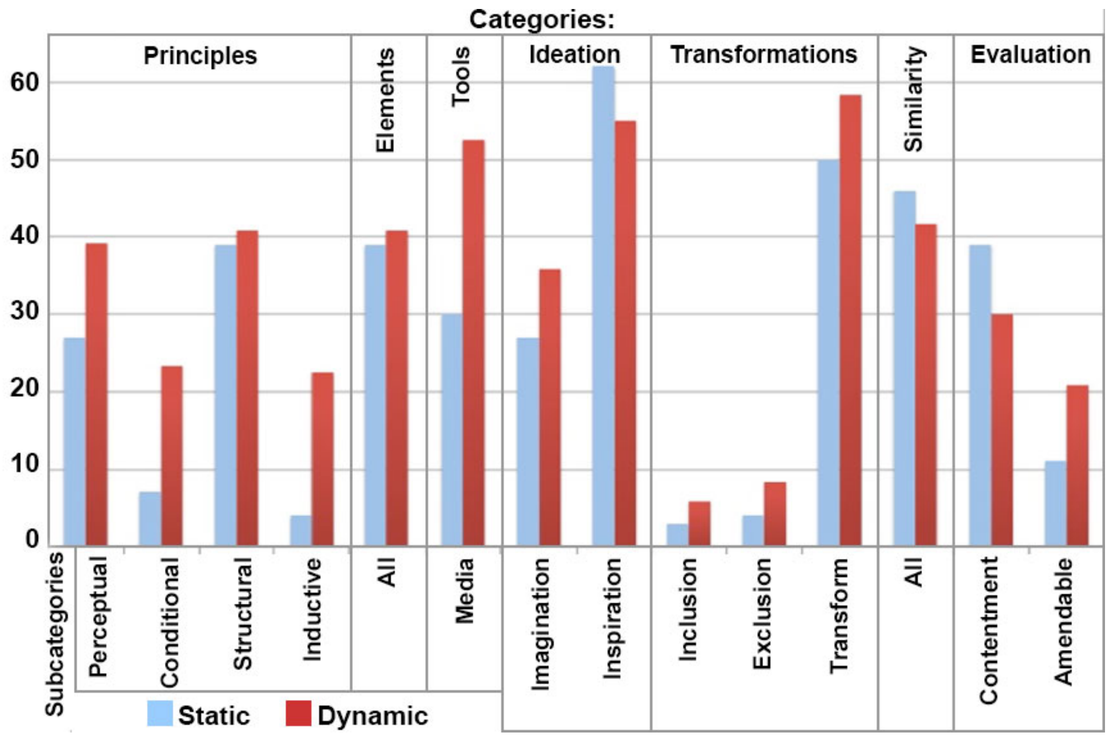


Figure 10.3 Between subcategories of static and dynamic studies

Ambiguity is very important as it is not mentioned in analogy theory, and this is specific to hints. The WordTree design-by-analogy method (Linsey, Wood, & Markman, 2008) suggests using rich sources of adaptive mechanisms such as life form collections to overcome the fixation.

We speculate that designers are sensitive to visual inconsistencies; they create ambiguities and these can lead to new opportunities for more ideas in the generative phase of the creative process. The role of sketching in the creative process has proved to be beneficial not only in collaborative practices (Mamykina, Candy, & Edmonds, 2002), but also in individual practices serving as a method of "looking beyond" and reflecting on the visual qualities (Schön, 1983) of the artefact. In the design "Principles" category, from the graph (Figure 10.3), we observed some differences between the statements on analogy sketches for two experimental studies in two subcategories: "Conditional" and "Inductive". The "Conditional" subcategory combines two codes: "Ambiguity" – a condition of misleading, and "Variety" – a condition of unified diversity used in works of art. "Variety" is discussed more often in the notes for sketches for study involving animated visual analogy, but the frequency decreases toward the evaluation stage as opposed to "Ambiguity", which sees an increase in the supporting stage (Figure 10.4).

To generate new ideas, one needs ambiguity in sketches, as this ensures that sources of design symbols are unlimited. During the visual analogy development processes, the artist had to take into consideration the similarities and differences of the goals between these studies in order to fulfil the specifics for each experiment. Four main categories: "Elements", "Similarity", "Ideation" and "Evaluation" are discussed in the reflective notes for both studies. A slight increase in using such terms as media is observed in the "Tools" category in the artist's notes for study using animation.

A careful examination and comparison between each code statement in both categorical and in-between studies revealed that the increase of the use of these means in the artist's notes is due to the specific goals and tasks that each experiment required. In the first study, the term "Media" was used to clarify, appraise or evaluate a sketch (e.g., "…it will look good in 2D format"), while in the second study, the term"Media" becomes dominant as the researcher takes into account the inclusion of time-based media and image schema constraints needed for the dynamic capture of problem insights. The code

"Number" from this category is equally used in both studies (e.g., "the second drawing to show them into two groups"), and the "Other sources" codes show the same ratio, as well. In the "Transformations" category, the increased need to use the terms for incorporated codes is due to the additional tasks requiring capture of the insights "in time" and using "gesture schema" required by experimental study involving animation. Statements on "Adding things" and "Discarding things" in sketches that were coded and integrated into the same category are used significantly more in discussion for the same reason – for adapting a generated idea to the specifics of the experimental conditions of study using animation.

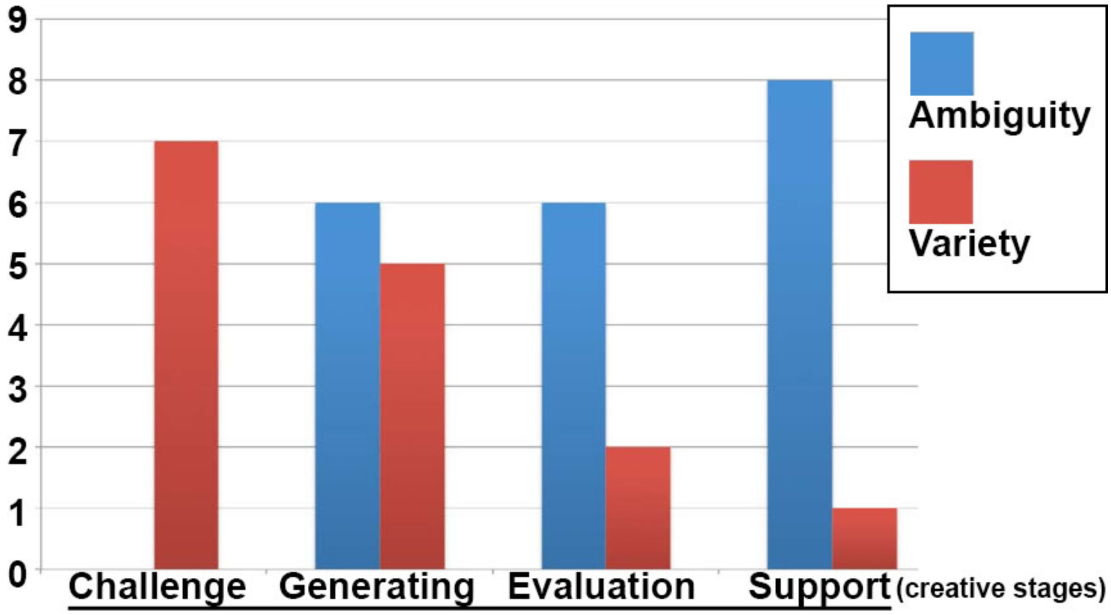


Figure 10.4 Overall Ambiguity/Variety statements

The second, a salient state with an inductive purpose subcategory of design principles, consists of two codes: "Visual Effect" and "Emphasis". It is worth investigating the combinatorial aspects of the relationships between these two codes in more detail. Here, during the analogy construction for experiment using static imagery, both are mentioned twice, "Emphasis", in understanding the challenge and in the idea generation stages, and "Visual Effect", only in the evaluation stage. The notes on sketches for the study using animations almost hold a perfect balance between the two state instances. During the process, the "Visual Effect" statements decrease at a constant rate, while the "Emphasis" statements increase at the same rate from understanding the challenge to idea generation to evaluation and the support stages (Figure 10.5).

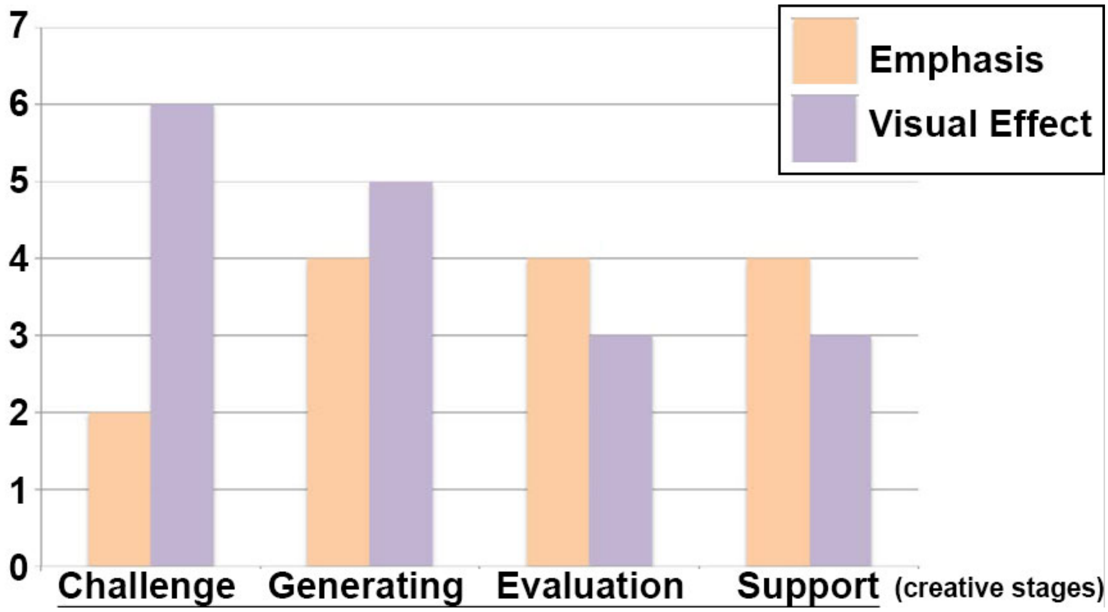


Figure 10.5 Overall Emphasis/Visual Effect statements

It is also worth further investigating the statements made for two subcategories of the "Evaluation" category in these studies. The "Contentment" subcategory and "Amendable" subcategory rate is reversed in each study. The diary notes for both studies were observed by the stages for their creative processes. Understanding the challenge stage is when the artist describes the goals, imagines potential scenes and looks for opportunities to scribble new-born ideas on paper. At this stage, the artist is more concerned with imagining and thinking about new scenes or situations along the principles of design and possible transformations to the mental image. As ideas are sought for implementation, a circular generating sketching stage begins and statements on principles of design and design transformations are more frequently mentioned. These increase at the same rate in both studies to their highest level in the evaluation stage and fall to their lowest rate in the plan for support, and the stage for appraising the tasks. It appears that statements on design tools and design element categories are constantly at the same rate, with a non-significant variation mentioned in the artist's notes during the entire creative cycle. The Similarity category, which includes "Interactions", "Relations of", "Resembling" and "Similar to" subcategorical codes, is referenced at an increased ratio from the initial to the last stage of the sketching process. The notions of "Compositionality" and Composition" appear in many notes in the brief descriptions of the goals. Simplicity – Emphasis – Focus of Attention – Spatial Organisation – Content – Visual Effect and Meaning are mentioned consistently in the artist's notes in all sets of sketches. For example in the "billiard game" (Figure 6.2) note the artist writes:

> "Primitive forms like spheres, which can be mobile and appear on focus would be an idea for now. A kind of game like ping-pong, or billiard? Yes, definitely, a billiard game could work if given a meaning to it…there are enough balls and space on that table to think of a scenario."

The artist seeks inspiration for his sketches from different sources such as books, previous personal work, the work of other artists, and frequently, from nature. Doodling or sketching by playing with lines and shapes of objects, combining and transforming them helps him generate new ideas and through modifications, create other new ones. Taking breaks and going out to watch movies refreshes his thoughts and "eliminates the details and sorts out the order of complex things in his head".

Thinking of scenes from real-life situations or structures, mediating and restating ideas, or the accidental discovery of scenes that are reminiscent of the problem at hand help him to adapt a concept to his tasks, and very often lead to him "working even backwards" (as the artist says in one of his notes). This is because a strategic plan is essential when thinking about many things and answering all kinds of questions related to a problem such as considering it from a different point of view and reassessing its meaning, breaking the whole into parts and bringing it back as a whole in a new configuration.

10.5 Conclusion and Future Work

Design theorists and practitioners have similar methods of analysis such as recording videos, documenting memos, using think-aloud strategies for protocols that provide access to a secret world of non-formal explanation of images as perceptions and actions, in opposition to scientists who use only the formal logic of mathematics. Analysing and reflecting on practices for generating ideas from the notes highlights the differences between a creative philosophy and traditional cognitive processes. Scientists can be inspired by using images as a source of invention (Dundar, 1995; Finke, 1990), in addition to the logical manipulation of linguistic symbols. An important aspect of sketching is that while trying to depict a mental image on a piece of paper, the inaccuracy of transfer or "ambiguity" in the created artefact generates new ideas and thoughts, inviting the practitioner to engage in the integration of cognitive and practical operations. Cheng & Lane-Cumming (2004) investigated the drawing process using a digital pen that records graphic marks stroke-by-stroke. They focused more on the use of technology in service to design education and the gap between traditional and digital art issues, rather than on a deeper analytical examination of the cognitive processes associated with inaccuracies when dealing with such graphic marks.

Although the sketches that were reviewed for both experimental studies suggest that most of the analogies were generated by associations or similarities via structures, principles, actions or relationships between objects (Clement J. J., 2008) and inspired from real life (Patherbridge, 2010), inaccuracy of sketches (Rosenberg, 2008) did play a role in the idea generation process for new analogies. The researcher identified some solution principles that allowed initial sketches to be modified into new analogies.

Discovery of an “inaccurate” line in a sketch leads the creator to make associations with other objects and create a new version of a visual analogy. Based on the results of a single study, and the recognition that the hypothesis records a preliminary solution, we propose to add an “ambiguity” mechanism to the existing models for the idea generation process, as it would enhance the quality and usability of analogies for problem solutions. Dealing with ambiguity, a subjective set of measures (Eisenberg, 1984), leads to different behaviour while still sharing the main features, and this might give people a better understanding of the problem they face and help to generate new ideas to find solutions to the problem. It would also be worth thoroughly investigating the effect of self-satisfaction and contentment/amendable procedures during a creative process on quality and usability of the produced artefact as observations in this study suggest that the more balanced the contentment and amendable concerns are in a creative act, the more likely it is that the product will be of better quality and usability. It may be appealing to further investigate these observations, and particularly, the types of concerns related to the concept and such an investigation may offer surprising results.

11 General Discussion

The primary focus of this chapter is to offer a discussion of the main findings arising from the practice-led research and experimental studies conducted for this thesis, and to revisit the research questions articulated in the Introduction. The main aim of the thesis is to explore the design and evaluation of visual analogies for visual insight problem solving.

The thesis focuses on visual analogies for two well-known visual insight problems: the *8-coin* problem and the *cheap necklace* problem. The design and development of the visual analogies included different formats such as static (e.g., image, storyboard) or time-based multimedia (e.g., animation), and were tested for their effectiveness in five experimental studies.

These visual analogies were iteratively designed and evaluated through these five experiments, targeting increased success rate in the insight problem solving.

11.1 Revisiting the Thesis' Research Questions

To revisit the main question: "How can visual analogies that are able to facilitate solutions in insight and creative problem solving be developed?", we should take a look, first, at the outcome of each experiment for this thesis. The participants' solution rate for problem solving tasks across the five experimental studies (see Figure 11.1) were analysed using two-way ANOVA.

The test for Between-Subjects Effects reveals a significant difference between the *Experiment* conditions yielding an F ratio of $F(4, 355) = 9.081$, $p < .001$, Partial Eta Squared = .093, a medium to strong effect size indicating a statistically significant difference between *Experiment 5* ($M = .784$, $SD = .043$), *Experiment 4* ($M = .462$, $SD = .059$), *Experiment 3* ($M = .295$, $SD = .049$), *Experiment 2* ($M = .374$, $SD = .059$), and *Experiment 1* ($M = .323$, $SD = .080$) conditions. Examining the cells in the sequence for the experimental studies conducted, the result suggests that the constructed visual analogies, as hints for problem solving, generated a consistent incremental increase in participants' solution rates from *Experiment 1* to *Experiment 5*, with the exception of *Experiment 3*, where the solution rate ($M = .295$, $SD = .049$) was lower than for *Experiment 1* ($M = .323$, $SD = .080$).

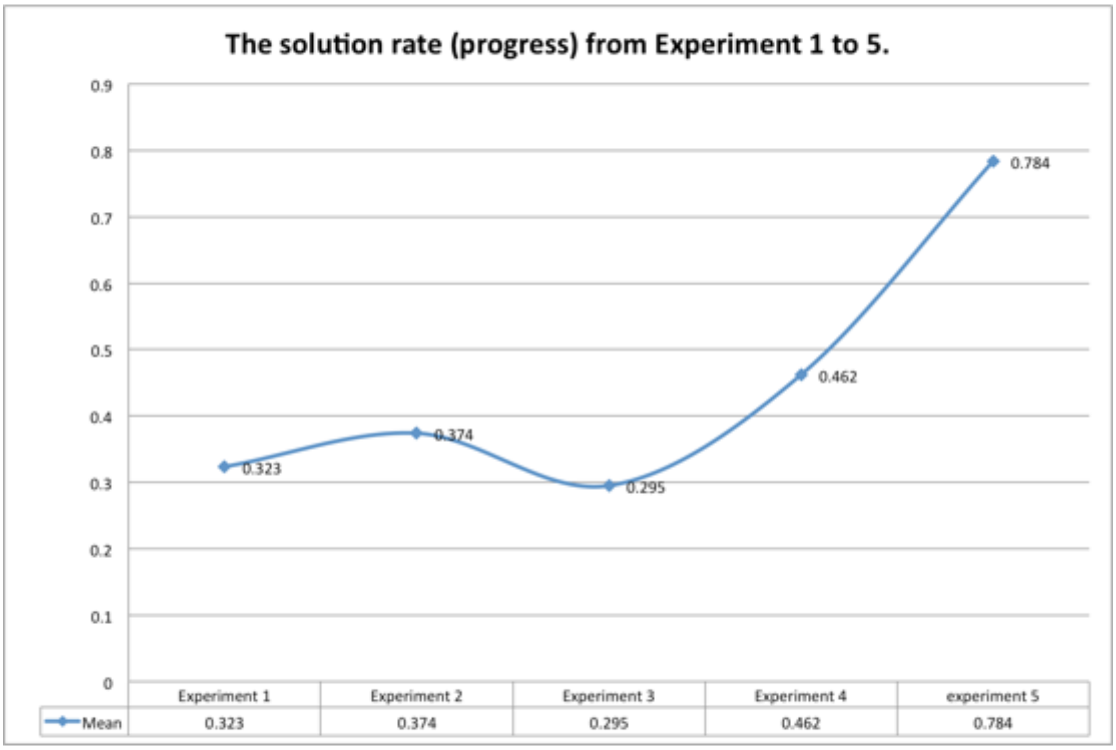


Figure 11.1 Solution rate progress curve from Experiments 1 to 5

A simple explanation for the deviation from the progress curve for solution rates in *Experiment 3* is that its design focused on examining the effects of a constructed analogy that only partially captured the insights of the problem (*Only up* or *Confusing order* for grouping aspects of the insights) between experimental groups. Additionally, *Experiment 3* was a mere extension of *Experiment 2*.

Due to the nature of its design, we did not expect an overall increase in the participant solution rate for *Experiment 3*. Because of the mixed results arising from the partial capture of the insights and confusing order of delivery obtained from the first two experiments, in the third experiment we focused on these more subtle components of analogy so as to better understand which aspects of the insights for the *8-coin* problem work better for problem solving and why.

To answer the main question of this thesis, in the first and each subsequent experiment we focused on a set of sub-questions related to the representational aspects and characteristics of visual analogy which were deemed to be important for the incubation effect for insightful problem solving. Table 23 summarises the research questions, considerations taken into account for the visual analogy development process using the practitioner's practice, and the outcomes of each experiment.

In *Experiment 1*, we addressed the first question: How can structural aspects of problem insights be represented in visual analogies?

During the construction of visual analogies, we considered the structural element of the insights – *stacking+grouping*. We hypothesised that visual analogies capturing both the *stacking+grouping* insights for the problem will generate a higher solution rate than visual analogies capturing either insight alone. Our results confirm our prediction that visual analogies capturing both insights of the problem may help problem solvers to overcome functional fixedness (Smith & Blankenship, 1991; Sio & Ormerod, 2009; Kowaltowski, Bianchi, & de Paiva, 2010; Purcell & Gero, 1998; Dunker & Lees, 1972) or mental impasse (Weisberg, 1988; Chu, Dewald, & Chronicle, 2007) in a problem solving process and suddenly "see" the solution (Gruber, 1989), allowing them to know how to solve it (Mayer R. E., 1999). While some researchers (Weisberg & Alba, 1982; Perkins, 1990; Newell, Shaw J, & Simon, 1958) argue that the solution to a problem occurs in incremental steps rather than as a spontaneous reformulation of the problem, others (Christensen & Schunn, 2009) found that random cues can be both beneficial and harmful in the problem solving process; Dunbar (1995), Bonnardel (2000) and Clement (2008) state that cues such as visual analogy can suddenly lead to the problem solution. Our finding is supported by hemispheric specialization theory (Bradshaw & Nettleton, 1981) which states that the left hemisphere is superior at language processing and sequential organisation and the right hemisphere is superior at perceiving relationships, entire configuration and performing spatial visual transformations.

Also, we developed visual analogies capturing the structural similarity of the insight as a process and tested its effects on problem solvers, speculating that participants in the process group would perform better in the problem solving tasks than those in the no process group. Process hints were designed to provide information about the initial problem state and about the transformation process from that to the solution state (see Table 3 Process vs. No Process). The ANOVA test showed showed no significant differences between Process and No Process groups. The results for this experiment refuted our hypothesis, however, observations of participants' behaviour during problem solving tasks prompted a further investigation into the insight as a process represented in a dynamic format.

To answer the second question: "How can the surface aspects of problem insights be represented in visual analogies?", we considered their surface characteristics, such as 2D, abstract 3D or representational 3D, in the development of visual analogies.

Here, we hypothesised that visual analogies capturing surface aspects, such as 3D representations, better support the incubation effect than those capturing 2D characteristics only. From the results, it can be noted that 3D surfaces have a tendency to produce better results compared to 2D surfaces. Our results suggest that three-dimensionality plays an important role in the representation of visual analogy (Stafford, 1999) as well in the use of analogy in learning (Podolefsky & Finkelstein, 2006), and thus promotes a clear focus on the attributes of captured surfaces when it comes to visual analogy development.

On the whole, findings from *Experiment 1* suggest that the most successful hints are a mix of 3D cues, stacking cues and no process cues; and a mix of representational 3D cues, stacking cues and process cues.

In *Experiment 2* four questions relating to dynamism, realism, movement, and transformative aspects of insight in visual analogies for problem solving were addressed.

In terms of which kind of visual analogies are more effective, those that are presented through animation or those presented through a discrete format, we hypothesised that animation would lead to a higher solution rate for the *8-coin* problem. The literature on the benefits of animation in learning has shown mixed results, some claiming a negative effect (Rieber & Hannafin, 1988; Byrne, Catrambone, & Stasko, 1999), while others (Larkin & Simon, 1987; Mayer & Moreno, 2002; Tversky, Morrison, & Betancourt, 2002) claiming a positive one, in particular for comprehension and fostering insight.

The added movement (Paivio & Clark, 1991) in the animation proved to be beneficial in the problem solving process for our experimental study; thus, our outcome is in line with the findings of those who consider animations to be more effective in learning and problem solving than diagrams or static images.

To answer the question of how many details should be captured in the presentation of symbolic elements and correspondences for visual analogy, we investigated two levels of realism: schematic – visual analogies capturing only primary depth cues, and realistic – capturing both: primary and secondary (pictorial) depth cues. Paas et al. (2003) argue that, due to working memory load limitations, when adding extra information to visual material, people may be unable to handle such high information load, thus hindering problem solving and creativity. Tversky et al. (2002) and Tversky (2011), on the other hand, found that when this extra information is accurately presented and understood (*apprehension* principle), it can be effective in enhancing the problem solving benefits of imagery.

Our prediction that adding pictorial depth cues in visual analogies would better support the incubation effect in the *8-coin* problem solving process was confirmed. Both problem insights (splitting and stacking) needed to solve the problem were regarded as being visuospatial, thus cueing was considered to be potentially effective if visual analogies capture the insights in 3D (see the added pictorial depth cues in Table 7) rather than 2D. Adding pictorial depth cues to the depicted elements in analogies causes these elements to be perceived as obvious "wholes" moving in space rather than being perceived as "wholes from parts" (additional task), thus considerably reducing the extraneous load (Mayer & Moreno, 2002).

To answer the third question for this experiment, we tested the developed visual analogies capturing the problem insights through image schemas. Visual metaphors influence the development of visual analogies. Metaphors in visual analogies are useful in that they assist in transferring the meaning in the visual material from the source to the intended target. In visual analogies, two major types of metaphors are predominant: kinetic and kinaesthetic. A better description of these identifies the fact that kinetic metaphors deal more with force-based type of information while kinaesthetic metaphors deal more with gesture-based kinds of information. Both types of image schemas are directly relevant to perceiving and comprehending visual information and, since they are unconsciously employed (Rennie & Fergus, 2006), they reduce the demands of working memory in the creative process and problem solving. We hypothesised that image schemas represented through gestures would be more effective in problem solving than image schemas represented through forces. The results confirmed our prediction, by demonstrating the impact of gesture schemas on the success rate in the *8-coin* problem. Thus, in terms of visual metaphors, it is clear that kinaesthetic metaphors should be used (Sadoski & Paivio, 2004).

Additionally, to answer the question regarding the changes, in the process of solving an insight problem, that can be presented in visual analogy, we investigated the effects of static vs dynamic aspects of visual analogy by implementing the *congruence* principle (Tversky, Morrison, & Betancourt, 2002). The principle state that changes in the animation should map changes in the conceptual model rather than changes in the behaviour of the phenomenon. Our finding, in regard to the congruence principle, is in line with this view and proved beneficial in the visual analogy development process as well.

In *Experiment 3*, we investigated the importance of order as it relates to which type of hint is provided first for the *8-coin* problem: the visual analogies capturing the insights through force image schemas or those capturing the insights through gesture image schemas, as the outcome of *Experiment 2* produced a mixed result on this issue.

Exp.	**R - Research questions**	**P - Practice-led research (considerations, applied activities & strategies in the creative process)**	**F - Findings**
I – Exp. 1 - The *8-coin* problem	**I-R** - What aspects of the visual analogies are most relevant for incubation effect in insight problems? -How can the surface and structural aspects of visual material be represented in visual analogies?	**I-P** - Arrangement of items in the source seems important to be captured in the target as well - Concept reinterpretation - *One-to-one* mapping considered - Primitive shapes that can be matched with forms that are extruded from those shapes - Search for similar abstract structures from real-life situations - Evaluate surface similarities of the generated visual analogy concepts	**I-F** - Visual analogies capturing both insights led to a higher success rate - 3D visual analogies better support the incubation effect than 2D ones, in particular when the problem insights are integrated
II – Exp. 2 - The *8-coin* problem	**II-R** -What kind of visual metaphors are more effective: continuously animated or discrete ones? -What kind of visual metaphors are more effective: schematic or realistic ones? - What kind of visual metaphors are more effective: kinetic or kinaesthetic ones? -How could visual analogies capture the changes in the process of solving the insight problem?	**II-P** - Using invented forms to modify and create new concepts for the insights of the *8-coin* problem - Searching for possible similar schemas that capture visual insights - Using examples of old ideas to create new ones through transformations - Searching for similar arrangements and layouts in the environment - Describing properties and functions and forming combinations to generate new concepts - Using mapping of *one-to-one* relations rather than mapping of *one-to-one* objects - Eliminating extraneous information	**II-F** - Continuously animated visual analogies led to a higher success rate than discrete ones -Visual analogies capturing pictorial depth hints led to a higher success rate than those without - Gesture image schemas capturing the insights are better than force schemas

III – Exp. 3 - The *8-coin* problem	**III-R** - Is the order important in terms of which type of hint is provided first: the visual analogies capturing the insights through gesture or force schemas? - Are the hints more effective when they are presented in a normal sequenced mode or when they capture partially the problem insights and are presented in a reverse mode?	**III-P** - Transforming existing concepts into new conditions - Using modifications in prompts to improve analogy	**III-F** - No, there are no differences in terms of which type of schema is provided first: gesture or force - Visual analogies capturing the stacking insight in the right order led to higher success rate than the ones capturing the grouping insight in a reverse order
IV – Exp. 4 - The *8-coin* problem	**IV-R** - Which point of view is more effective at capturing the insights in visual analogy for problem solving: normal perspective view or bird's eye view? - Which strategy is more effective in constructing visual analogies for problem solving: *one-to-one* mapping of item numbers or mapping the problem insights *one-to-one*?	**IV-P** Considered: - Transformation of space - Using other analogies as prompts to join different parts to generate new concepts - Using design-by-analogy techniques to generate new concepts - Using the feedback of other researchers to modify concepts - Manipulating focal points in imagery to guide attention - Using varied perspective points of view to evaluate the generated concepts	**IV-F** - Both perspective views are effective in capturing the insights compared to the control group, but there is no difference between the two - Mapping the number of items *one-to-one* was not significant compared to using more items than the number of coins in the problem
V – Exp. - The *cheap necklace problem*	**V-R** - Which clusters of image schemas embodied in visual analogy are more effective in the *cheap necklace* problem solving process: gesture, force, or a combination of both? - What is an adequate quantity of hints to be provided to participants to maximise the solution rate in the *cheap necklace* problem?	**V-P** Considered: - Combinations of themes that carry groups of elements with similar functions - Using other analogies as prompts to join different parts to generate new concepts - Focusing on a variety of ideas inspired from artistic activities - Using design-by-analogy techniques to generate new concepts - Using the feedback of other researchers to modify concepts - Using action techniques to capture the problem insights	**V-F** - All three schemas embodied into created animations led to a significant success rate compared to the control group, but there is no difference between the types of used embodied schemas - There is a significant difference between the treatment and control groups; however, there are no differences between the one, two or three hints groups

Table 23 Thesis research question(s), practitioner's practice and findings

Not only is the content of a visual analogy important for capturing insights but, it was hypothesised, so too is the order in which analogies capture them. Earlier, we mentioned that kinaesthetic metaphors should be used. Specifically, metaphors assist us in making effective decisions (Simon, Newell, & Shaw, 1979; Yaniv & Meyer, 1987; Kirsh, 2009; Ball & Litchfield, 2013); therefore, it was predicted that visual analogies that capture the insight through gesture schema and are presented as the first hint will be more effective in problem solving for the *8-coin* problem. Here, our hypothesis was refuted. With this in mind, there is no specific order in terms of which type of schema is provided first as a hint for problem solving; rather, it seems that the quality of the schema for the insights is more important.

Here, the importance of each insight necessary for solving the *8-coin* problem was investigated. We hypothesised that visual analogies capturing only the stacking insight for the *8-coin* problem and presented to participants in the forward sequential order would better support the incubation effect than those capturing the grouping insight and presented in a reversed mode (confusing cue). The outcome confirmed our prediction, accentuating the importance of integrating both insights into the problem in the visual analogy construction process. This is in line with the findings from *Experiment 2* on this issue. This also indicates that visual analogies in an animated format should capture stacking insights in the right order rather than in a reversed one.

Two questions were posed for *Experiment 4*. The first question related to the spatial perspective in which visual elements of analogy might be more effectively presented, and the second related to the application of the *one-to-one* principle (Gentner, 1983) of mapping the same number of objects in the source to the ones in the target. Cognitive science can be used to explain the reasoning behind this element of visual representation. According to Lovett et al. (2007), most humans view representations in the form of qualitative figures. The view of psychological space (Montello, 1993) from which the elements and correspondences of visual material are presented might influence people in understanding and comprehending conveyed information, and consequently hindering decision making and creativity. From the findings of *Experiment 4*, we concluded that visual analogies presented from either a bird's-eye view or a normal view could be used to good effect. Visual analogies capturing the problem insights and presented from these two viewpoints produced a 76.25% solution

rate among participants in the treatment group compared to a rate of only 5% among participants in the control group who did not receive any hints during the problem solving task. However, there were no significant differences between these two treatment groups in terms of the *Type of Perspective* condition (Table 15). Still, the analysis comparing the two treatment groups to which the visual analogy was presented, suggests that certain information, in particular symbolic information, should be visualised from a clear point of view so as to be easily perceived and comprehended.
As for mapping the exact number of objects from the source to the target question, our results show that mapping *one-to-one* objects in combination with the object relationships and their attributes was more effective than focusing on matching the exact number of objects in the target alone.

Experiment 5 tested a new set of visual analogies that were developed based on the literature and learned lessons from previous developmental practices and their effectiveness was evaluated for another insight problem – the *cheap necklace* problem. In this experiment, we addressed two research questions: 1) Which clusters of image schemas captured in visual analogy are more effective in the cheap necklace problem solving process: gesture, force, or a combination of both?, and 2) What is an adequate quantity and quality of hints to be provided to participants to maximise the solution rate in the *cheap necklace* problem? The basic question is in regard to the effectiveness of thr type of clusters (families) of image schemas captured into analogy. Is the gesture or force image schema or a combination of both most effective in problem solving? Based on the views of Mandler and Cánovas (2014), image schemas "can generally be defined as dynamic analogue representations of spatial relations and movements in space. Even though image schemas are derived from perceptual and motor processes, they are not themselves sensorimotor processes". In addition to this, it is said that image schemas, as well as the transformation of image schemas, are an ordinary everyday occurrence (Gibbs Jr., 1996). The main reason they are referred to as schemas is due to their abstract nature of the real situations acquired through body experiences (Johnson M. , 1987; Lakoff, 1993). Participants who received the visual analogies as an aid to solving the *cheap necklace* problem achieved a 78% success rate (even higher than the success rate for *Experiment 4*) compared to just less than a 7% success rate for the control condition (see Table 18).

The results also showed that, in problem solving, using multiple clusters of schemas in the construction of visual analogies was more successful than using each one of them on their own. Here, we also predicted that visual analogy (*Round dance* animation) capturing a family of gesture image schemas would produce more correct solutions than the two other visual analogies (*Pipes circle* and *Design making* animations) capturing a combination of force and gesture image schemas. Although all animated visual analogies capturing three families of schemas (described in Section 9.2.2.1 - Implementation) in the problem insights produced a high solution rate, there were no significant differences between the three. In contrast, gesture showed the lowest success rate among these three families of image schemas. We speculate that this is due to the fact that the *Round dance* animation presents insights for the *cheap necklace* problem in a parallel processing mode, which may increase the cognitive load in people in comparison with the *Making a design* and *Pipes circle* where the insights are delivered in a serial mode.
The second question regarding how many hints it is adequate to provide to participants to maximise the success rate for problem solving remained unclear. We predicted that more solvers would use two visual analogies to solve the problem; however, the results gave no indication to support this hypothesis.

Lastly, in developing visual analogies, we need to look at the creative processes behind them. We shall first start to look at sketching. Forbus and Usher (2002) point to the fact that sketches show the relationship between the visual object and the target in the depictions of the sketch. Visual analogies, apart from being effective in problem solving, also act as learning tools. A simple sketch of an object can offer an explanation of how the various parts of the object relate to each other. Sketching can be seen as a new form of problem solving. In general, ambiguity means that the nature of any object or activity is uncertain. As is the case for visual analogies, ambiguity means there are numerous ways we can express a mental image. In visual analogy, a simple term such as “a smooth red surface” can be sketched and visualized, then generated various interpretations, in other words so as to bring out the discrete nature of image features (Van Gemert, Veenman, Smeulders, & Geusebroek, 2010). As far as developing analogies is concerned, sketching and ambiguity go hand in hand. Ambiguity is a result of inaccurate line sketching and, with it, problem solving can be enhanced too. The other graphic principles useful in developing visual analogies are visual effects and emphasis. Visual effects capture the attention of a viewer while emphasis guides this attention to the most important elements of a visual analogy.

11.2 Analysis of Success Rate and Helpfulness of Visual Analogies in Insight Problem Solving Across the Five Experiments

At the end of each experiment, participants were asked to complete a questionnaire (see Appendix 14-10) relating to the helpfulness of the provided visual analogy as an aid when solving the problem. To analyse the participants' responses, we excluded from the analyses participants who belonged to the control groups, as they were not provided with any hints during the problem solving tasks. The responses, which totaled 386 out of a possible 530 participants for our five experiments, were entered into SPSS and included in this analysis.

A 5 (*Experiment*) x 7 (*Rating*) factorial ANOVA was conducted to test the effect of provided visual analogies in the *Experiment* group at five levels (*Experiment 1*, *Experiment 2*, *Experiment 3*, *Experiment 4*, and *Experiment 5*), *Rating* -– participants' ratings of the analogy helpfulness on seven levels (*lowest, low, moderately low, average, moderately high, high, and highest*), and *Experiment* x *Rating* interaction effect on the rate of successful solutions for the *8-coin* and the *cheap necklace* problems. Further, a significant *Experiment* x *Rating* interaction effect was obtained, F (20, 355) = 5.428, p < .001, Partial Eta Squared = .234, a strong effect. Examination of the mean results indicated that there was a large number of high scores in the rating condition among participants who solved the problem (see Figure 11.2). This indicates that participants who discovered the similarity between the problem and the provided analogy capturing the problem insights were, indeed, helped to find correct solutions to the tested problems.

Very similar graph patterns resulted from feelings of warmth self-ratings and the number of attempts made during the problem solving task for *Experiments 1* to *5*. This similarity in patterns suggests that participants who believed that the provided analogy would help them to find the correct solution to the problem often rated their feelings of warmth higher and consequently, at the end of test, rated the helpfulness of the provided analogy higher, as well (see Figure 11.2 vs Figure 11.3).

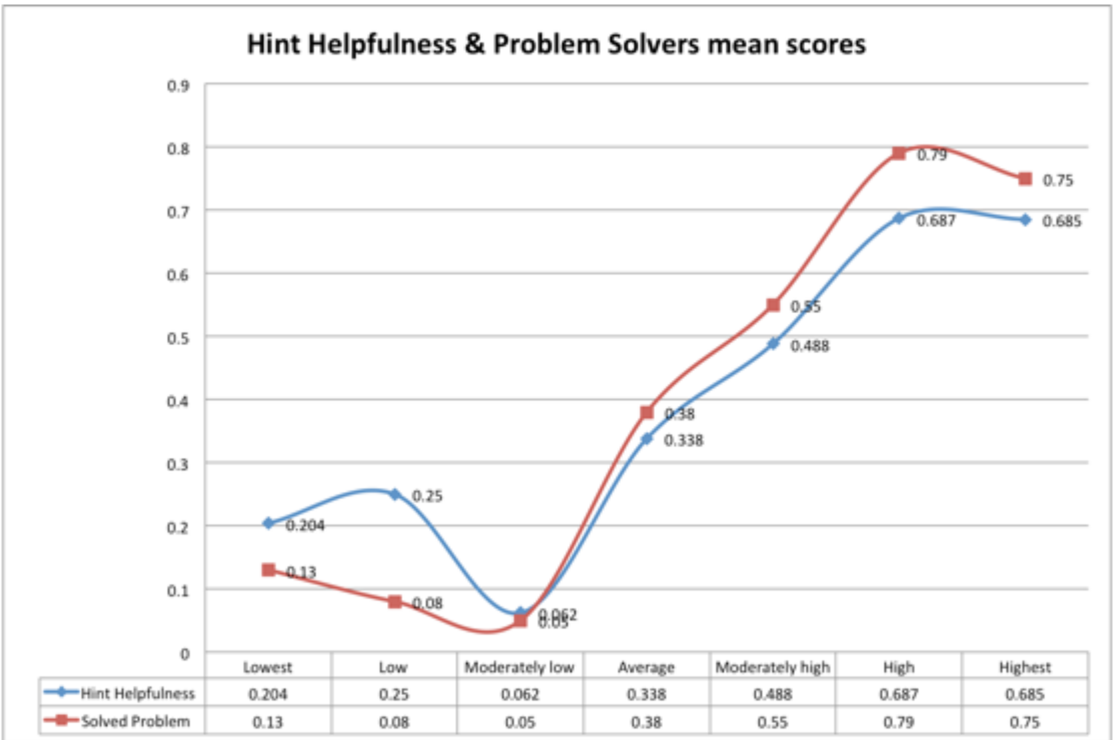


Figure 11.2 Hint Helpfulness vs. Problem Solvers

A significant main effect for *Rating* was obtained, F (6, 355) = 11.329, p < .001, Partial Eta Squared = .161, with a strong effect size suggesting that there is a significant difference between the high scorers and low scorers for solution rate for problem solving tasks. Participants who found correct solutions to the given problems rated the helpfulness of hints significantly higher compared to participants who were not successful in finding correct solutions.

Examining the cells between the *Hint Helpfulness* ratings and *Solved Problem* groups, there is a difference in means for hint helpfulness (M = .25, SD = .112) and solved problem (M = .08, SD = .277) at a low level (Figure 11.2). Analysing the ratings for *Hint Helpfulness* in the hint conditions for each of the five experiments, the researcher's notes, and video recordings led us to the conclusion that a low level rating for *Hint Helpfulness* was generated mostly by participants in the *abstract 2D* condition (see A-2D in Table 3) for *Experiment 1* and *confusing* hints condition (see Confusing animations http://www.luchian.info/html/03_02.html) for *Experiment 3*.

Experiment 1 was the starting point for our exploratory study. Designing simple images capturing primary components of analogy seemed appropriate for testing static imagery first. *Experiment 3* included two conditions that captured the problem insights partially or in a reversed order in a time-based media format. This explains the low solution rate among solvers, as well the increased number of participants that rated the hint helpfulness as low and lowest. In the current study, we focused on the visual analogy development in both static (or permanent) and animated (or transient) visualisations to test and compare them for their effectiveness more comprehensively than in previous studies. For example, Ayres & Paas' (2007) findings suggest that animations were often less effective than static pictures, in contrast to the findings of a recent meta-analysis study by Berney & Bétrancourt (2016), which showed an overall advantage for dynamic and transient images over the static images for many science, technology, engineering, and math (STEM) computer visualisations. Other researchers argue that static imagery could lead to higher cognitive learning, while animations may lead to higher perceptual learning (Wagner & Schnotz, 2017). Based on our results, the increment in rating for high and highest groups in *Hint Helpfulness* for the provided visual analogies for *Experiment 1* to *Experiment 5* is in line with these recent findings indicating that our visual analogies presented in a time-based media format are more helpful in problem solving than analogies depicted in a static one.

11.3 Additional Analyses Across the Five Experimental Studies

We gathered additional data such as feelings of warmth, number of attempts that were made to solve the problem, data on the helpfulness of the provided visual analogy as an aid in the problem solving process, demographics, and visual preferences during and after each test from each individual who participated in one of the five experiments.

11.3.1 Feelings of Warmth Self-Ratings and Number of Made Attempts

This section describes the findings related to the feelings of warmth reported by participants while solving the visual insight problems with the different visual analogies provided as hints.

All participants were allowed as many solution attempts as they liked during the test with the condition that for each new attempt they must start with the original coin arrangement (Figure 5.13). After each attempt of two moves to solve the problem, they were also asked to rate their feelings in terms of how close they were to the solution, i.e. feelings of warmth (Metcalfe, 1986). These ratings were based on a scale of 0 to 10 (i.e. "0" being completely stuck and "10" extremely close to solving the problem). Their responses were noted on the template (Appendix 14-7) by the researcher along with the number of attempts which had been made at the time each attempt was completed.

We predicted that participants with high values for feelings of warmth self-ratings and fewer attempts made to solve the problem would be more likely to solve the problem than those with low values for feelings of warmth self-ratings who made a greater number of attempts to solve the problem.

In the analyses, 530 participants from both treatment and control groups from across the five experiments were included.

Based on the template recorded by the researcher (Appendix 14-7) of attempts made by each participant and self-rating scores for feelings of warmth during the tests, the scores for all participants were calculated by taking the arithmetical mean. Using these scores, the ANOVA procedure was conducted to compare if there was an effect of the *Number of Attempts* and *Self-Rating* scores on the problem solution rate, as well as the interaction effect between these conditions. Analyses show that there is a significant difference between *Self-Rating* conditions $F(86, 388) = 1.880$, $p < .001$, Partial Eta Squared = .294, a strong effect. The main effect for the *Number of Attempts* conditions $F(7, 388) = 1.732$, $p > .05$, Partial Eta Squared = .030 does not differ significantly between the groups. The *Self-Rating* x *Number of Attempts* interaction was obtained indicating that there is no significant effect $F(48, 388) = 1.206$, $p = .173$, Partial Eta Square = .130, as well.

	Total (n=530)		Participants who did not solve the problem (n=297)		Participants who solved the problem (n=233)	
	M	SD	M	SD	M	SD
Self-Ratings	4.7	2.05	4.53	2.02	5.0	2.06
Number of Attempts	3.5	1.71	3.75	1.78	3.17	1.57

Table 24 Self-rating for feelings of warmth and number of attempts made

Table 24 shows the result of mean scores for feelings of warmth self-ratings and the number of attempts made by participants who solved the problem and participants who did not.

The mean scores reveal that participants who rated their feelings of warmth higher (M = 5.0, SD = 2.06) during problem solving for the *8-coin* and *cheap necklace* problems were more likely to find the correct solution to the problem than those who rated their feelings of warmth lower (M = 4.53, SD = 2.02). Even though the number of attempts to solve the problem generated a statistically non-significant result, the examination of the mean cells for this condition shows that participants who made fewer attempts to start working from scratch on the problem (M = 3.17, SD = 1.57) were more likely to solve the problem than those who made a comparable greater number of attempts (M = 3.75, SD = 1.78) to solve it. The result suggests that the more certain the problem solver is, and the fewer attempts s/he makes during a problem solving task, the more likely s/he will solve the problem. Metcalfe (1986), in her experimental study, asked participants to provide estimates of how close they were to the solution to the problems every 10 seconds during the problem solving task, hypothesising that the feelings of warmth ratings would be low and constant until a solution is reached which might drive them to higher values. She found that for 78% of the solvers' group, the progress estimates increased by no more than 1 point on a 10-point scale from the start to the end of the task. Those who did not solve the problem showed more incremental progress. The researcher interpreted this data as indicating that the progressive pattern in non-solvers appeared higher because of a special decision-making strategy, rather than a cumulative problem solving process. Also, a previous study by Janet Metcalfe (1986) had shown that participants overestimated their abilities more in the insight problems than in the non-insight ones. Simon et al. (1979) proposed that using a directed strategy for problem solving might open up more opportunities for people to get “warmer” if the initial state is presented more as a goal state. The visual analogies given to participants in our studies implied ways to reach that goal state.

In our study, participants’ feelings of warmth ratings and each attempt were recorded only at intervals when the participant had exhausted all the allowed moves for the problem and had to return the pieces to the initial configuration to start working on the problem from scratch again. By providing hints as an aid during the problem solving task, the feelings of warmth self-ratings should increase to reflect participants’ increasing nearness to the solution.

To test our prediction, we excluded from the analysis participants who did not receive any hints in the 5 experiments which were conducted. Figure 11.3 shows the progress curve for feelings of warmth *Self-Ratings* from *Experiment 1 to 5.* With the exception of the results for feelings of warmth for *Experiment 3* (M = .365, SD = .059), which showed a decrease in mean score for feelings of warmth *Self-Ratings* compared to

Experiment 2 (M = .584, SD = .051), the overall curve increases consistently from *Experiment 1* (M = .274, SD = .066) to *Experiment 5* (M = .785, SD = .056).

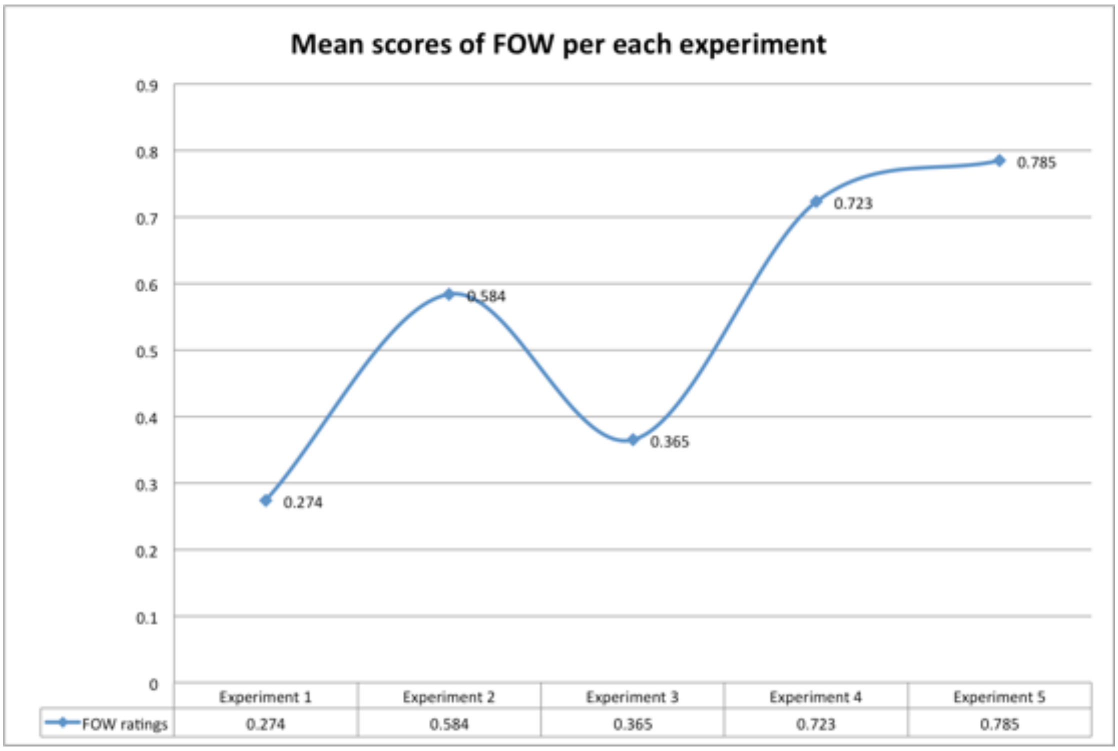


Figure 11.3 Feelings of warmth progress curve from Experiment 1 to 5

Experiment 3 was designed to test confounding factors which are not easily separated from the manipulated ones (i.e., analogies only partially capturing the insight, confusing insights), compared to the previous experiment (*Experiment 2*). Furthermore, the mean scores for the combined *Experiment 2* and *3* were obtained and compared with the other three experiments. Figure 11.4 shows a consistent increment for feelings of warmth *Self-Ratings* from first to last experiment, suggesting that the developed analogies offered to participants as hints affected their confidence in terms of how close they thought they were to the solution. This consistent increment also indicates confidence in the effectiveness of the developed visual analogies as hints for visual insight problem solving.

Our unique approach, exploring revised visual analogies iteratively, allowed us to shed light on a less investigated aspect of problem solving: how visual analogies with different level of effectiveness as hints for insight problem solving impact on people's feelings of warmth.

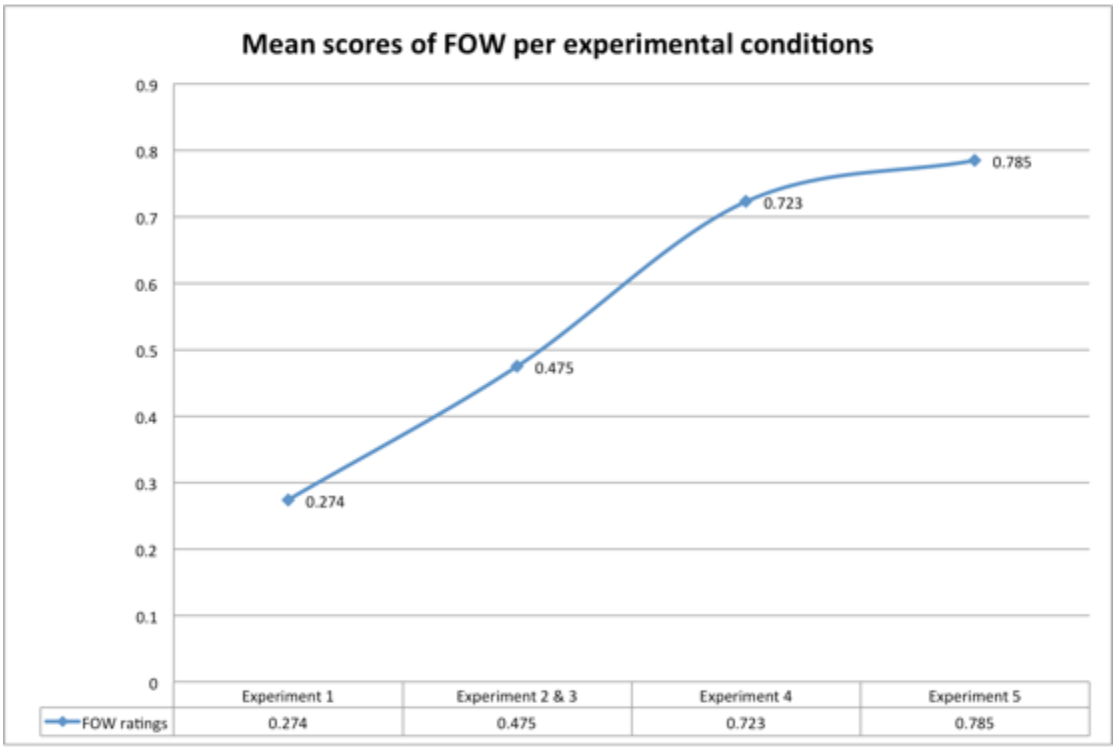


Figure 11.4 Feeling of warmth self-ratings progress curve

Our outcomes suggest that the more effective the visual analogies as a hint, the more accurate the participants were in rating their feelings of warmth (how close they were to the solution) in reference to their abilities and whether the problem would be solved or not. This is in sharp contrast to Metcalfe's (1986) statement that participants in the insight problems overestimated their abilities to a greater degree than for the non-insight problems.

11.3.2 **Visualiser and Verbaliser Cognitive Styles**

With respect to cognitive style, an important distinction relevant to the topic of this thesis is between visualisers and verbalisers (Mayer & Massa, 2003; Massa & Mayer, 2006; Kozhevnikov, Hegarty, & Mayer, 2002). The differences denote individual differences in cognitive styles or people's preferences for different ways of organising and processing information: verbalisers process information by verbal-logical means, whereas visualisers count largely on visualisation. When exposed to information, visualisers are most likely to rely on pictures in the content, whereas verbalisers will focus more on the verbal information. Additional studies (Mayer & Massa, 2003; Massa & Mayer, 2006; Höffler, Koć-Januchta, & Leutner, 2017) indicate that visualisers can be classified into two distinct groups: *object imagery visualisers* and *spatial visualisers*.

Object imagery visualisers have a preference for processing images that have high resolution and are colourful. On the other hand, spatial visualisers prefer to process schematic pictures as well as looking into different spatial relations that exist between objects (Höffler, Koć-Januchta, & Leutner, 2017; Sadoski & Paivio, 2004). Mayer and Massa (2003) compared 14 individual difference measurements and received, as a result of a factor analysis, four factors, namely: general achievement, cognitive style, learning preferences and spatial ability.

The authors define visual-verbal cognitive style as "thinking with words or images" while "learning preferences are a kind of behaviour, a choice between graphical or textual instructional materials, when learning". The reason we chose the SBLSQ V. 1.0 is that the questionnaire includes distinct characteristics for pictures such as spatial ability, learning preferences, and mental imaging.

All 530 participants in our experiments filled in the SBLSQ V1.0 questionnaire (see Appendix 14-8); thus, after an analysis of this questionnaire, we classified spatial visualisers as visualisers, object visualisers as equal visualiser-verbalisers, and verbalisers as verbalisers. These three visual cognitive styles can be used to describe participants in our experiments. Positive score results indicated a visual cognitive style, equal score results indicated a visualiser-verbaliser while negative scores indicated a verbal cognitive style.

Our hypothesis was that participants identified in our study as visualisers would have a higher solution rate for problem solving tasks than participants identified as verbalisers and equal visualiser-verbalisers.

To test our prediction, a 3 x 2 full factorial ANOVA was conducted to compare the effects of *Visual Styles* at three levels (*Visualiser, Equal Visualiser-Verbaliser*, and *Verbaliser*) and the effects of provided visual hints at two levels (*Control* and *Intervention*) in terms of participants' performance in the problem solving process.

The test of between-subjects shows significant main effects for *Visual Style* factor $F(2, 524) = 7.294$, $p < .001$, Partial Eta Squared = .027, and for *Visual Hints* groups $F(1, 524) = 34.932$, $p < .0001$, Partial Eta Squared = .062, and a significant interaction effect between these two factors $F(2, 524) = 8.918$, $p < .001$, Partial Eta Squared = .033.

Examining the individual results for *Visual Style* factor, the results for the *Visualisers* group (M = .361) SD = .024) were significantly different than for the *Verbalisers* group (M = .186, SD = .041). The pairwise comparisons table shows that the *Equal Visualiser-*

Verbaliser group (M = .206, SD = .094) was not significantly different from both: the *Verbalisers* and *Visualisers* groups. This means that *Visualisers* generated a higher solution rate for the problem solving tasks for our experiments.

Figure 11.5 Visual style effect on solution rate for problem solving tasks

An examination of the individual results for the *Intervention* factor shows that the mean score for participants receiving visual hints (M = .459, SD = .038) was significantly higher than for participants from the *Control* group (M = .043, SD = .059). This means that the provided hints that we developed worked really well for the insight problem solving process, irrespective of participants' cognitive style.
Spatial visualisers tend to do better when it comes to spatial images and visuals whereas object visualisers perform better when it comes to images that contain objects.

Examining the graph from Figure 11.5, we can conclude that our visual analogies were effective hints for all participants, but that visualisers benefitted more from them.

Indeed, we can see that each individual's visual cognitive style influences their success rate in insight problem solving. It was observed that the largest difference in solvers from the *Control* condition and *Hints* condition was between the *Visualisers* group. This suggests that visualisers are more likely to solve problems when provided with visual hints, and less likely to solve them without them. A smaller gap between *Control* and *Hints* conditions is observed in the *Verbalisers* group. They do not solve the problem as often when provided with visual hints; however, without hints they are even better solvers than visualisers. Thus, we can conclude that visualisers depend more on visual material than verbalisers when solving problems.

Our prediction is in line with the findings from Mayer and Massa (2003), Höffler and Leutner (2007), and more recently, Höffler, Koć-Januchta, and Leutner's (2017) studies on cognitive learning style. We can speculate that the cognitive style plays a particular role in learning with imagery, and this might be a factor to be considered in future work on visual problem solving.

We now move on to a discussion from the qualitative analysis described above of the qualitative analysis of participants' preferences for the different elements of the visual analogies across the five experiments.

11.3.3 **Preferences for Key Elements in Visual Analogy**

The visual material developed for our experiments included four key visual characteristics for superficial similarity (Blanchette & Dunbar, 2001): *number of elements, their shape, arrangement*, and *depth*, and three characteristics for structural similarity (Dundar, 1995; Catrambone, Craig, & Nersessian, 2006): *movement*, *force*, and *gesture* (Cienki, 2005). Superficial similarity refers to the resemblance of the objects and their properties to a source and its target (Keane, 1994; Catrambone & Fleming Seay, 2002), while structural similarity can be found in the underlying systems of relations between the objects from the source and those of the target (Gentner & Medina, 1998; Forbus K. D., Gentner, Everett, & Wu, 1997). The role of structural and superficial similarity have been studied extensively over the last three decades (Clement J. J., 2008; Gentner & Medina, 1998; Holyoak & Koh, 1987), demonstrating that these types of similarities are used in different ways in analogical reasoning (Blanchette & Dunbar, 2000); thus, each type is dependent on specific stages in solving an analogy (Gentner & Rattermann, 1991; Gentner, 1986; Catrambone, Craig, & Nersessian, 2006).

Based on these assumptions, we consider that analysing people's preferences for visual elements might shed light on what elements are more effective not only when solving an analogy but when constructing it as well. One of the main purposes of gathering such information from our participants was to gain more insights into the relationship between their expressed preferences for visual elements and the elements embodied in the provided material as hints for problem solving. Even though preference questionnaires are not the best methods by which to investigate the relations of selected preferred visual elements with the elements used in a specific task (e.g., problem solving), we consider that most participants taking part in our study expressed their preferences factually. Without a doubt, there are still biases based on individuality when studying people's preferences (Tversky & Kahneman, 1983; West, Toplak, & Stanovich, 2008) in terms of visual elements (Stafford, 1999) as in other fields using this method (West & Stanovich, 2015).

	Shape	Number	Arrangement	Depth	Movement	Force	Gesture	Total
1st Choice	40	82	139	10	87	8	20	386
2nd Choice	46	95	111	26	79	8	21	386
3rd Choice	59	59	60	33	94	35	46	386

Numbers in the cells are the numbers of participants selecting the elements

Table 25 Participants' preferences for key elements in visual material

While participants' preferences for key elements in visual material can be seen in Table 25, Figure 11.6 shows the mean scores for these preferred elements (*shape, number, arrangement, depth, movement, force,* and *gesture*) as participants' first, second and third choices, and the success rate in solving the insight problem (solved, unsolved). We hypothesised that participants who prefer elements such as movement, depth and arrangement of items in a visual analogy would generate a higher solution rate for problem solving tasks than those who prefer forces and shapes.

To test our hypothesis, a full-factorial model ANOVA test was run. The outcome of the between-subjects effects outlined in Figure 11.6 show no significant main effects and a significant interaction effect between First Choice x Third Choice factors F (22, 284) = 1.819, p = .015, Partial Eta Squared = .123, a large effect size.

Figure 11.6 shows the mean scores for the preferred elements in the visual material that helped participants to look for similarities in the provided hints during the problem solving tasks. An examination of the cell means revealed that more participants who solved the problem chose *depth* (M = .70, SD = .483) as their first choice, *arrangement* (M = .65, SD = .480) as their second, and *number of elements* (M = .63, SD = .488) as their third choice.

A closer examination of the cells reveals that the solvers group selected more frequently *depth* (M = .70, SD = .483) and *movement* (M = .69, SD = .464) elements as their first choice, *arrangement* (M = .65, SD = .480) and *movement* (M = .62, SD = .488) as their second choice, and *number of elements* (M = .59, SD = .495) and *movement* (M = .59, SD = .495) as their third choice. At the same time, the non-solvers group selected *forces* (M = .25, SD = .463) and *shape* (M = .43, SD = .501) as their first choice, *forces* (M = .38, SD = .518), *depth* (M = .50, SD = .510) as their second choice, and *arrangement* (M = .53, SD = .503) and *Forces* (M = .57, SD = .502) as their third choice.

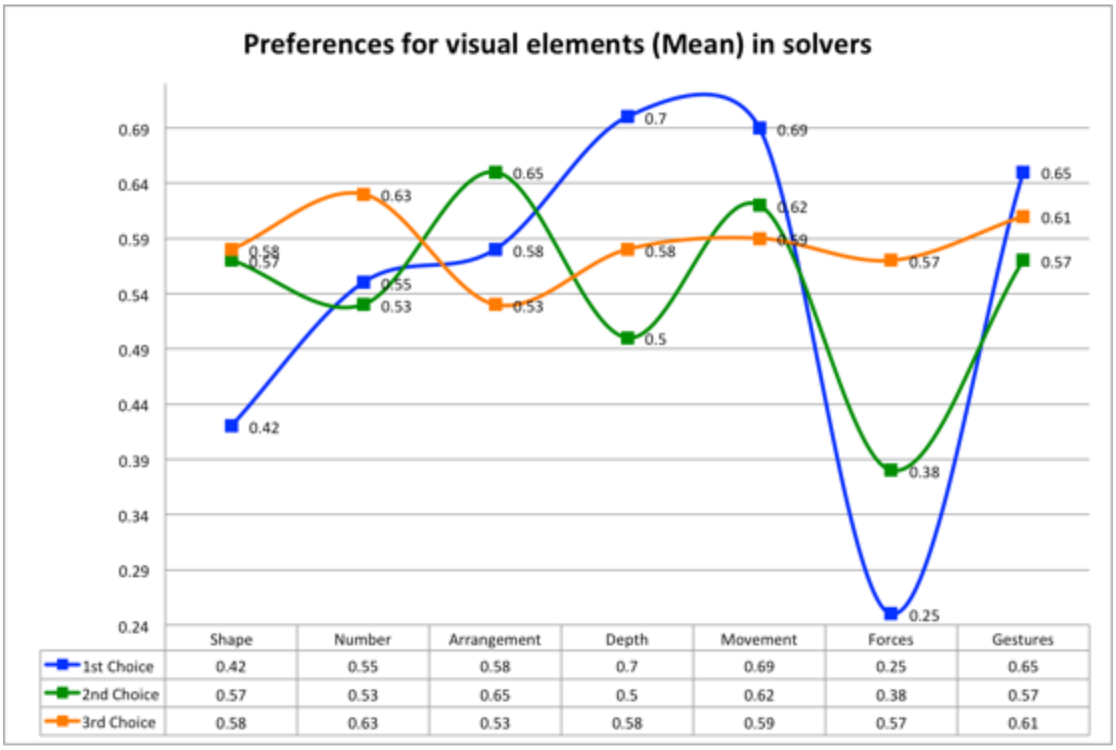


Figure 11.6 Graph for visual elements preferences in solvers

By reflecting on these findings, we can identify some patterns of preferred visual elements in the solvers and non-solvers groups. Participants who solved the problem chose *depth*, *movement*, *arrangement*, and *number* of elements more frequently; however, those who did not solve the problem chose *forces*, *shape*, *depth* and *arrangement* more frequently as preferred visual elements to look for in an analogy. The means for *depth* and *arrangement* among both solvers and non-solvers did not differ significantly. This led us to conclude that participants who prefer to look in visual analogy for elements such as *movement* and *number* of elements are more likely to find solutions to the *8-coin* and *cheap necklace* problems than those who prefer *forces* and *shapes*. This result reveals that imagery captures the problem insights through movement schemas and maps the number of elements *one-to-one*; therefore, a combination of structural and superficial similarity may be beneficial in visual analogy construction.

This conclusion is based on the input of participants in our five experimental studies investigating the effect of constructed analogies for two insights problems. Therefore, it may be influenced by the characteristics of the insights for the *8-coin* and *cheap necklace* problems.

11.4 Demographic Data

Out of the total of 543 participants for all five experiments, 13 of them did not fill out the demographic data for reasons stated in participants' subsections of the method for each study. Some of these participants were either familiar with the solution to the problem from a psychology course taken at the university, refused to engage in the solving process, or did not properly follow the instructions and guidelines for the study; as a result, all 13 were also excluded from demographic analyses.

This left a total of 530 participants: 144 (27.2%) for the control groups and 386 (72.8%) for the intervention groups. The study consisted of 269 (50.8%) males and 261 (49.2%) females, with a median age of 24.1; 31.5% were younger than 21, 60.4% were between 21 and 30, and 8.1% were over 30 years of age. From the total of 530 participants, 192 (36.2%) had received their secondary education in North America and regions in Europe, 264 (49.8%) in Asia, and 74 (14%) in South America and Africa.

A UNIANOVA test was conducted to compare the effects of provided visual analogies as hints for the problem solving tasks in the control and intervention groups. Analyses show that there is a significant difference between these groups $F(1, 528) = 151.86$, p

< .0001, Partial Eta Squared = .223, a very strong effect. The mean score for the intervention group (M = .58) SD = .49) was significantly different to that for the control group (M = .06, SD = .23). This means that participants receiving our constructed visual analogies performed much better than those who did not receive any hints.

Considering the purpose of our study was to gain a better understanding of how analogies work, how to construct them and how they affect people in the problem solving process, we conducted an analysis without subjects participating in control groups, as they were not provided with any visual material. Thus, for the following analysis, we were left with 386 subjects who had participated in the intervention groups for the study.

Our prediction was that participants in the age group between 21 and 30 would perform better when given visual analogies as hints for the problem solving tasks, and that males would score higher than females.

A 3 (Age group) x 3 (Region) x 2 (Gender) UNIANOVA was conducted to compare the main effects of age in three groups (below 21, between 21 and 30, and over 30), the effects of the secondary education they received in three regions (North America and Europe, Asia, and South America and Africa), as well as of gender (male and female) and their interaction effects on the solution rate for the given problem solving tasks.

The test for between-subjects shows no significant difference between the main effects for gender $F(1, 368) = 2.039$, $p > .15$, Partial Eta Squared = .006, age groups $F(2, 368) = 2.167$, $p > .10$, Partial Eta Squared = .012, and region $F(2, 368) = .074$, $p > .90$, Partial Eta Squared = .000 factors; additionally, there is no significant interaction effect between them.

However, analysing the generated plots of marginal means for participants' age, region of received secondary education, and gender factors for correct solutions in the given problems, we will make an attempt to interpret these data from multiple perspectives.

Figure 11.7 shows the results for participants' performance according to age and gender. It was observed that males tended to decline in performance with age, while females did better in the age group between 21 and 30, nearing the males' performance, and then their performance drastically declined, as well. One reason might be that the younger generation are at an advantage by having grown up in the digital age. Information and learning have become more and more dependent on visual material, and they grew up watching TV, browsing the Internet for information and communicating through mobile phones and social media using symbolic images or simplified language. Also, males outperformed females in all three age groups.

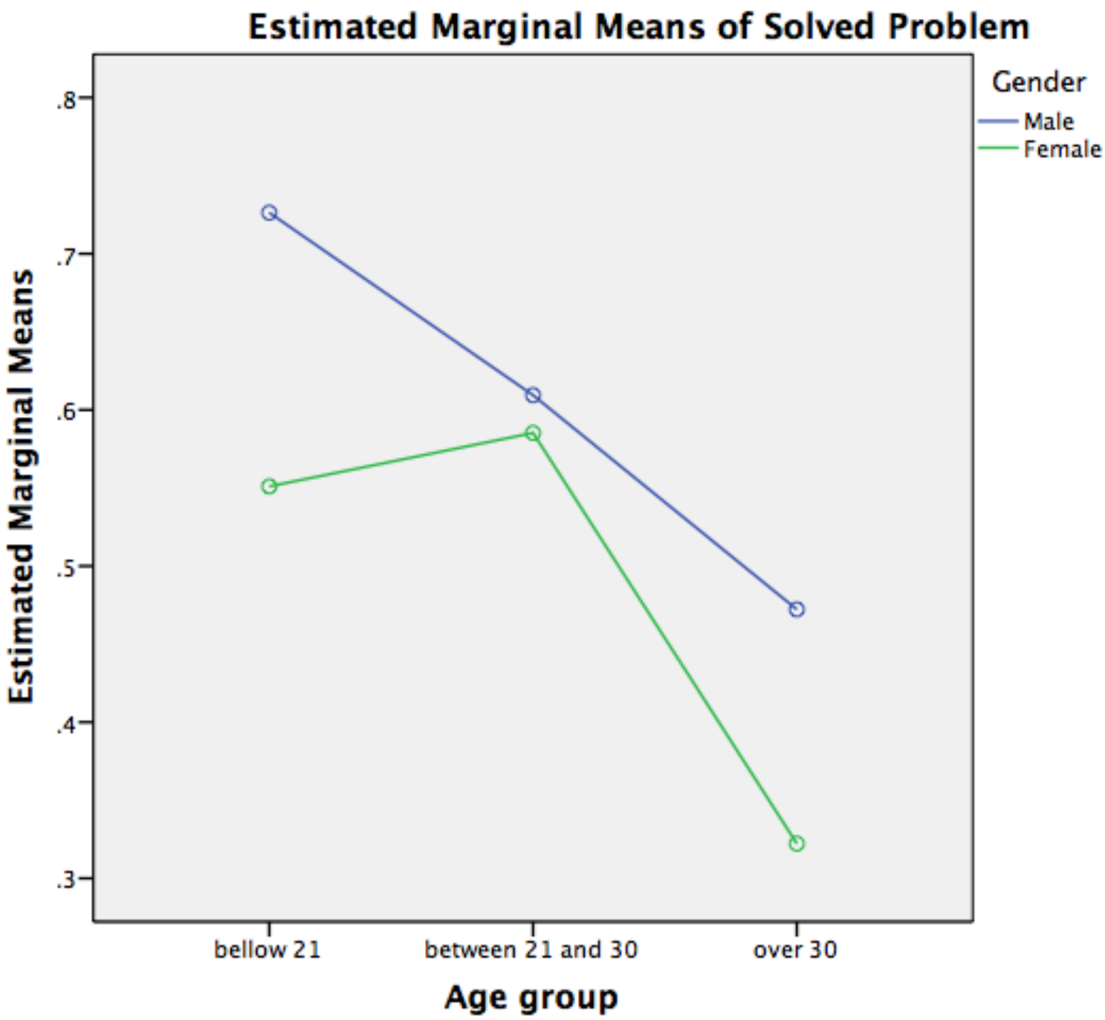


Figure 11.7 Plot of mean scores for solvers by age and gender

Comparing the graph lines for participants' performance in problem solving according to regions and age groups (see Figure 11.8), we observed the following: overall, the age group below 21 from the North America-Europe and Asia-Oceania regions scored higher than their colleagues from the South America-Africa region. Meanwhile, the group of participants who were over the age of 30 produced the lowest solution rate in problem solving tasks, although older participants educated in the South America-Africa and Asia-Oceania regions still performed sequentially better than those from Western countries.

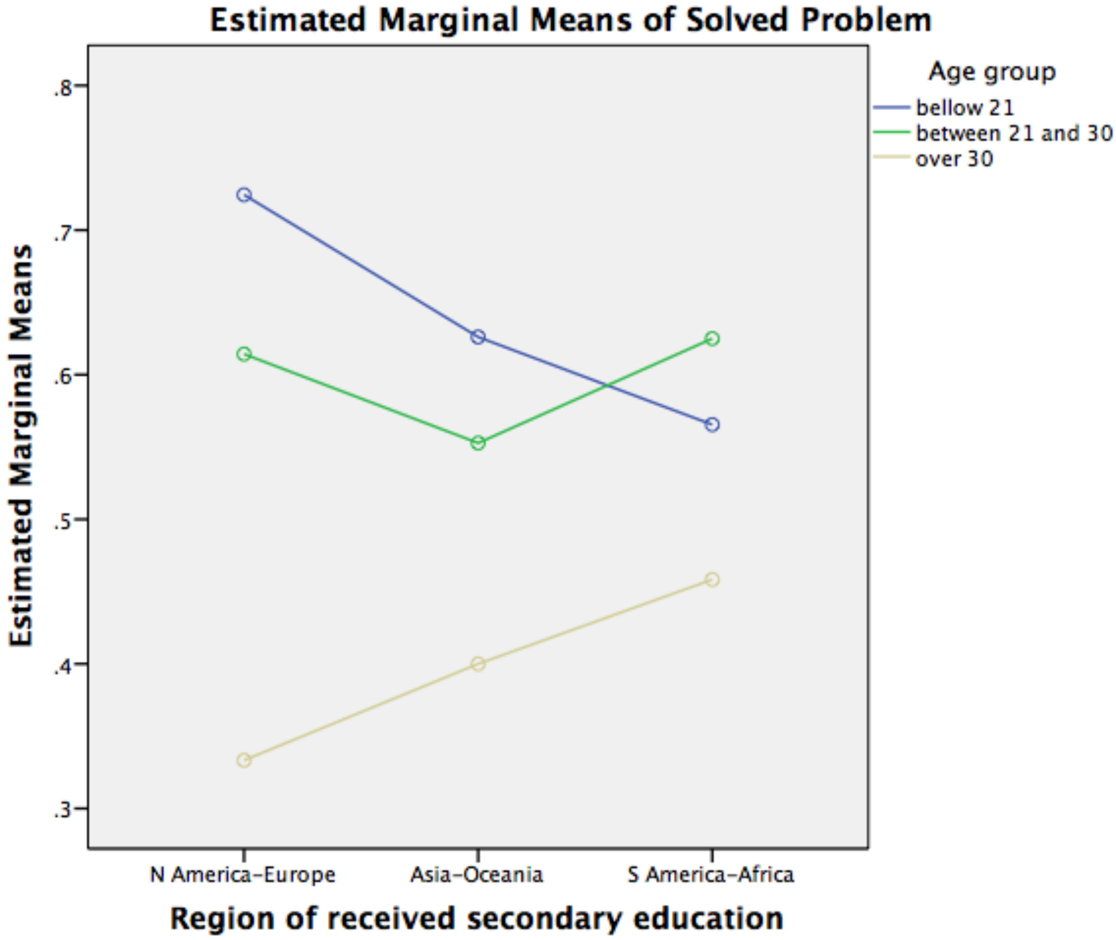


Figure 11.8 Plot of mean scores for Solvers by Region and Age

Interestingly, the largest solution rate disparity between age groups is predominant in the Western world, followed by the Asia-Oceania and South America-Africa regions. Also, this graph, like the previous one, suggests that our provided visual analogies as hints were less effective in the problem solving tasks for the older group of participants in the study.

Figure 11.9 shows the graph for gender and regional factors in relation to participants' performance in the problem solving tasks. Admittedly, if a significant difference between the groups had been found in our analyses, we could firmly have claimed that males performed better than females in both problems: the *8-coin* and *cheap necklace* problems; however, according to the graph, we can only speculate. In this graph, the largest disparity in performance between male and female participants by region is observed in the North America-Europe region, followed by the Asia-Oceania and South America-Africa regions.

Are females less visual than males?

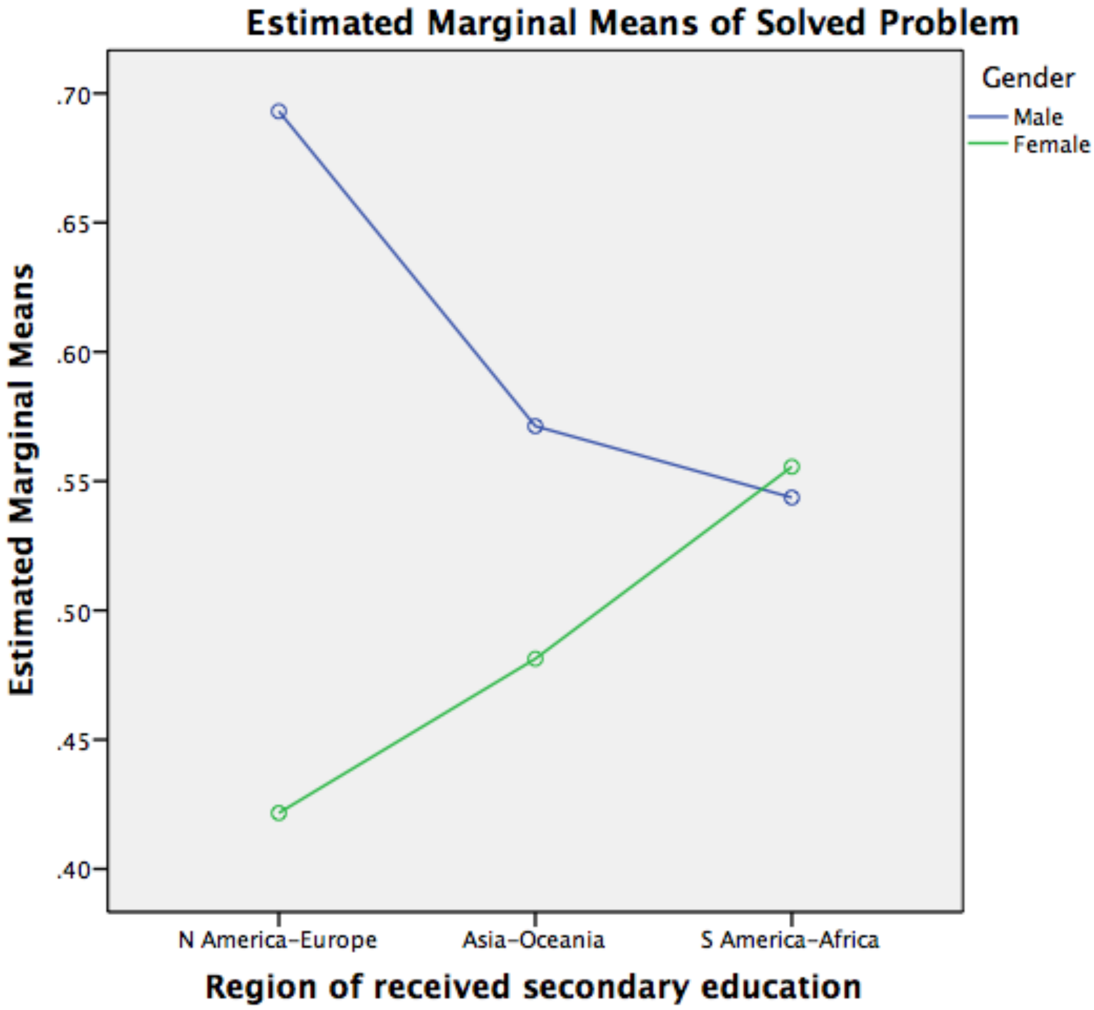


Figure 11.9 Plot of mean scores for Solvers by Region and Gender

11.5 The Practice of Designing Visual Analogies

In both well-defined and ill-defined problems, cueing plays an important role in most stages of the creative process. Adequate cueing facilitates problem solving and creativity. Findings from the practice-led research in this study suggest that hand sketching and drawing plays an important role in the ideation/generation and illumination stages of the visual analogy development process and we can learn from practising artists how to design and present them. Practitioners dealing with visual representations valued and placed great importance on drawing in their artistic quests. In her book titled *What is Drawing?*, Erika Naginsky (Gunning, 2003, p. 153) discusses the role of drawing in Leonardo da Vinci's life, describing it as "part of a process which is constantly going on in the artist's mind; instead of fixing the flow of imagination it keeps it in flux". The successful development of a product depends on successful concept generation. The ideation phase, or often called the concept generation stage of development, is intended to generate a broad variety of concepts from which to choose and create the final product. Analogical reasoning plays an important role in idea generation in art, engineering, and design fields. Many studies have confirmed the use of analogies in both near and far domains (Ball, Ormerod, & Morley, 2004; Christensen & Schunn, 2005; 2009). Visual analogies have been used as a reference and inspiration for novices and experienced professional designers and engineers to generate new ideas (Casakin & Goldschmidt, 1999), and to prompt new concepts (Holyoak & Thagard, 1996).

In the visual analogy development process that effectively overcomes fixation, a number of issues are put into perspective. Table 23 summarises the questions, observations from practice, and findings from this research including the issues which were dealt in each experiment.

Critical among these issues is the incubation effect in visual insight problems. To better understand insight and creative problems, we must take a prime interest in dual coding theory (Paivio A. , 1971). The theory states that two different channels are used to process visual and verbal information. The oral systems deal with information that is disseminated via word of mouth while other non-verbal systems deal mostly with the perception of information. According to this, the brain tends to encode more visual images than spoken words. This is mainly because, unlike with oral information, we tend to encode images as having multiple representations. The theory was first developed to examine the influence the brain has on verbal and nonverbal information. This has, over the years, been extended to include differences in areas of cognition. The theory is critical in providing a combination of the account of events used in decoding, comprehending and responding to various aspects of an image (Sadoski & Paivio, 2004).

The practice-led method allowed me to practice several design strategies to create visual analogies for problem solving, observe, reflect, evaluate, and make concluding notes on their effectiveness for insight problem solving. Each set of generated visual analogies for an experiment and the experimental outcome pointed me in the direction of the next experiment in this research.

I generated a variety of concepts and created the entire portfolio of sketches and final versions of visual analogies used in experimental studies for this thesis. Being an experienced artist practitioner and educator, I adopted multiple strategies when generating and designing them, which are described in more detail in the visual analogy development subsections of the materials section for each experiment. From the analyses of these practices, three main strategies emerged:

a) The first was a mixture of analogical thinking technique (Finke, Ward, & Smith, 1992; Holyoak & Thagard, 1996; Casakin & Goldschmidt, 1999) focused on biomimicry (Benyus, 1997; Eryildiz & Mezini, 2012) or the environment (Christensen & Schunn, 2009) and the case-based reasoning technique (Ball, Ormerod, & Morley, 2004; Kolodner, 2014) focused on transforming old designs into new concepts (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995).
b) The second strategy was problem reformulation (also called problem finding and problem framing) (Csíkszentmihályi, 2014; Runco, 2007), applied in particular to concepts with unclear design tasks that emerged from ambiguous sketches (Goel, 1995; Suwa & Tversky, 1997; Gunning, 2003; Patherbridge, 2010) in the generation stage of the development. During this process, I often returned to evaluate these sketches and reframe them (Do & Gross, 1996; Tversky B. , 1999) in a new way according to the problem constraints.
c) The third most used strategy was a mixture of designer's method (Gero, 2000) and the WordTrees design-by-analogy method (see 3.4) by Linsey et al. (2008) whereby I used the problem functions and actions as descriptors so these could be re-represented in a new way to satisfy the target solution.

Additional strategies that I used frequently in the visual analogy development process included transferring information from familiar situations in order to formulate new ideas (Ball, Ormerod, & Morley, 2004; Christensen & Schunn, 2009; Rao, 2014), the synectics technique (Gordon, 1961; Finke, 1990), analysis of the functions and flow of the problem (Wood, Stone, McAdams, & Hirtz, 2002; West & Stanovich, 2015), formulation of new analogical concepts through forced modifications (Hummel & Nadolski, 2002; Hummel & Holyoak, 2005), and the TRIZ strategy to identify the problem contradictions and modify its concept (Altshuller, 1998).

11.5.1 Guidelines for Developing Effective Visual Analogies for Problem Solving

To sum up the final part of my research, I outline the main practical guidelines for developing effective visual analogies for problem solving. Developing visual analogies often raises the question: how can creative processes be guided or taught in the first place? Indeed, developing visual analogies cannot happen in one and only one way. Nevertheless, it can be learned, practiced and enhanced in the same way as any skill, craft or practice. A beginner can be guided through the creative processes of visual analogy development and learn new ways of looking at the problem and consequently searching for the solution for that problem. A professional designer can find sources of inspiration and new ways of applying new strategies to visual analogy developmental processes. These creative processes can be supported and enhanced by design practitioners, teachers, or mentors. The guidelines are given in general terms, often with overlapping steps that offer the user a choice of preferences, working styles or strategies for developing visual analogies. The guidelines also include some visual analogy development strategies that are based on theories and were tried by me in practice. My goal in these guidelines was to identify ways to create effective visual analogies for problem solving rather than focusing on who is creating these analogies; thus, some of the points in the guideline stages might sound like known procedures, suggestions and repeated tasks, or they may resemble designer's tricks or suggested actions to be made. The guidelines are dynamic in nature. The creative process in visual analogy development evolves and its stages are cyclical. Depending on one's skills and preferences, one can skip steps, or return to any stage in this process if it seems right to do so. I do not claim the guidelines as a proprietary piece of work, but merely an attempt to evaluate existing theories applied in practice and organise the creative process into stages and steps according to the results of that practice.

Guidelines for Developing Visual Analogies for Problem Solving

Stage 1 - Problem assessment *(structural-rational)*

In this initial stage, the focus is on the evaluation of the problem and interpreting the chain of the problem components, relationships between these components and their functions including the environment at the conceptual, structural, and relational levels. The stage is divided into two parts: *descriptive* and *investigative*.

a) Descriptive:

- Describe the initial state of the problem.
- Describe the main components and the relationships between each component of the problem.
- Describe the function of components and their relatedness to the problem.

b) Investigative:

- Find weak and strong links between components and their relations including functions.
- Reformulate the problem, recombine and rearrange the main components and their relationships explaining how their functions are changing.
- Reconstruct components and relationships in different ways.
- Decompose the problem into sub-problems, wholes into parts; re-evaluate the relationships between the components of the problem and their functions.

Document your thoughts by making notes or gesture sketching.

Stage 2 – Visual analogy ideation (*structural-intuitive*)

This stage is focused on constructing thinking strategies. As Nigel Cross (Watt, 2009) states: "Imagine something on how something might be, not just how it is."

- Brainstorm for similar components, relationships, and functions with similar structures (both abstract and superficial) that resemble the problem.
- Search for them from the environment, past experiences, situations, or other sources of inspiration.
- As starting points use situations found in nature, familiar objects, typical chores around the house. (For example, if the problem is related to a home, then one might look for insights to this problem by looking for correspondences with similar structures in a community.)

Document your ideas by making notes, scribbling, gesture sketching, drawing plans.

Stage 3 - Generating analogy (*synthetic-intuitive*)

This stage synthesises and interrogates ideas and processes for selecting the best candidates from the rest and incorporating related ideas into meaningful wholes for modifications.

- Combine components and relationships in new ways.
- Reframe and interpret the new combinations, their relationships and functions and if the outcome does not solve the analogy, then

- Seek similar correspondences in things that surround you; retrieve these from memory, imagination, or seek for similar scenarios in the environment and blend the pairs to obtain new correspondences.
- Extend the search to different domains that solved similar problems.
- Look for similar correspondences and their relationships between the source problem and desired target by extending the search from micro to macro analogues pairs (e.g., anthill -> house -> city ->country).
- Visualise and sketch new and prominent concepts, letting your freehand drawing play with the dots, lines, shapes, forms and text.

Make notes, doodle, describe and sketch associative components of the problem and relationships between them.

<u>Stage 4</u> – Recording and refining stage (*structural-intuitive*)

This is the testing and refining stage. The designer tests the generated concepts, analyses the outcomes and refines analogical concepts by iterating components, relationships, or the function of the concepts.

- Interpret the concepts from the drawings.
- Simulate problem solutions using combinations of correspondences from drawn concepts.
- Replace weak correspondences with stronger candidates from the generated pool of concepts.
- Use persuasive visual effects from the familiar situations.

Use notes and observations made about your practice-based experience (exploring by doing) from previous stages to get insights into how to refine the concepts.

<u>Stage 5</u> – Selecting analogical concepts (*synthetic-rational*)

This stage revisits the analogical constraint, compares concepts and identifies the best analogical concept for future visualisation.

- Compare the relationships between the pairs of concepts.
- Breakdown the primary components and their relations into individual units and functions.
- Select prominent concepts with similar structures, relationships between components and rules that might give insights into and solve the problem.

Seek inspiration from examples of biomimicry, synectics, and from similar systems of the natural world.

Stage 6 – Analogy evaluation and validation (*structural-rational*)

The evaluation and validation of an analogical candidate are cyclical and intended to communicate and interpret the result.

- Compare structural similarity of mapping the elements *one-to-one* in the source and target.
- Compare similarity of correspondences through mapping of distinct symbolic relationships in the source and target.
- Compare the results from the two above similarities to measure the transient effect of bridging analogy (Clement J. J., 2008).

Analyse the findings based on what works and what does not and what could be improved.

We hope that if the proposed guidelines for developing effective visual analogies for insight and creative problem solving do not challenge the domain's current practices, at least they offer some valuable insights into and enrich our understanding of these two important faculties, namely problem solving and analogizing, that the human brain is continuously pondering.

12 Conclusion

When it comes to searching for answers to the question "Are there any formulas for constructing visual analogies that would solve various problems at hand?" it becomes clear, as Clement (2008) noted, that a predictive model is still in its early days of development. The goal of this study has been to distinguish particularities of visual stimuli in the insight and creative problem solving process by creating a portfolio of visual analogies, testing them, analysing them and formulating guidelines on how visual analogies can be developed. The processes involved in the visual analogy development by the artist/researcher have been described for each experiment in the study. The main purpose of this study was to explore ways of constructing effective visual analogies for insight problem solving through analogy-making practices (as a practitioner), testing their effectiveness for problem solving tasks, analysing, improving and refining these analogies to test them again to elicit common patterns in the process and using them to formulate guidelines for future users.

The impact of visual analogies on the solution rate for tested problem solving tasks progressed incrementally from *Experiment 1* to *Experiment 5* (Chapters 5 to 9), which demonstrates that the quality of the developed visual stimuli constantly improved and that we have gained a deeper understanding of how to construct an effective analogy for insight problem solving leading to guideline formulation. Providing participants with visual analogies capturing enough insights into given problems improved their performance. The findings were integrated within a visual analogy continuous development process throughout the study. Presenting people with effective analogies proved that they could better understand a problem, relate to it, make inferences and solve it. Adding embodied mechanisms into the visual analogy led to a higher solution rate in our study, which could be an asset in visual imagery detection for computational systems and development for instruction and learning. These implemented mechanisms in visual representations could help learners better understand and interpret visual concepts in STEM as well as in non-STEM disciplines.

I hope that this study, and possibly other studies that deal with problem solving and creativity, will pave the way for incorporating visual analogy training into the curriculum for multimedia design and visualisation studies. This may help train better, more creative, and more productive visual artists and software engineer designers.

12.1 Thesis Contribution

The main question of this thesis is: How can we design effective visual analogies that can facilitate solutions for visual insight problems?
Based on the aims and objectives of the research, the contributions of this thesis are divided into two parts: the first one discusses the contribution in terms of advances in the academic knowledge concerning visual analogies, insight problem solving, and visual design, while the second part lists the supporting material developed as the research progressed and how this material can be used for future applications in a variety of contexts.

12.1.1 A Richer Understanding of the Qualities of Effective Visual Analogies for Insight Problem Solving

In the construction of visual analogies for the replicated *8-coin* and *cheap necklace* problems, we drew support from the structure-mapping theory using alignable and *nonalignable* differences in both the surface and structural aspects of an analogy. Using a practice-led method allowed us to implement, in the final versions of the visual analogies generated, the principles of systematicity, *structural consistency* (in both static and animated analogies), *congruency*, and *apprehension* (in animated analogies) which assured the distinction between manipulated variables in experiments including the problems' insights.
Our work makes important theoretical contributions to the understanding of visual analogies, visual representation of concepts and insight problem solving. In addition, the visual analogies that we constructed could also be extended to other visual insight problems that share similar insights, i.e. *three trees or six matches*.

12.1.1.1 The Use of Image Schemas in Visual Analogy Representation Can Be a Powerful Strategy in Analogical Reasoning and Computational Systems

Our findings suggest that the grouping and stacking hints needed for insight could be suitably visualised as forces and gestures. *Experiments 1* and *2* (Chapters 5 and 6) and their outcomes showed that the analogies capturing kinetic and kinaesthetic cueing schemas were more effective in problem solving than those which did not.

The visual analogies developed capturing kinetic and kinaesthetic cueing schemas for Experiments 4 and 5 (Chapters 8 and 9) led to an even higher success rate than the analogies used in the first two experiments. The lessons learnt from each experiment showed us the path of implementing new features, thus visual analogies improved from experiment to experiment. The results from Experiments 4 and 5 confirm that visual analogies capturing the problem insights through image schemas (kinetic or kinaesthetic) in proper order, represented in 3D, and presented in time (as continuous animations) are the most effective.

The first implication derived from these results is that using embodied schemas (Cienki, 2005; Johnson M. , 1987; Lakoff & Johnson, 1980), inspired from embodied cognition literature (Christensen & Schunn, 2009; Barsalou L. W., 1999; Blanchette & Dunbar, 2000; Borghi & Cimatti, 2010) in visual analogies, better supports analogical processes and insight in problem solving. This benefit may be due to the potential of image schemas to activate the mirror neurons (Gallese & Lakoff, 2005; Rohrer, 2005), which prompt sensory-motor systems to automatically retrieve similar experiences.

The second implication is that using image schemas in visual analogies makes it easier to understand the conceptual relationships not only between the presented analogy, the problem we face and the desired solution, but also the relationships between how we perceive that visual analogy, how the body acts and how the mind interprets it. Duit (1991) states that image schemas embodied into analogy provoke and motivate us. Current computational systems that generate imagery of concepts mostly focus on perceptual characteristics (e.g., colours, shapes, form, etc.) to represent concepts visually, and less attention is given to conceptual features (affordances) (Kristensen, 1999; Gibson J. J., 1977) that relate directly to the purpose and usage of such imagery (Hedblom, Kutz, & Neuhaus, 2015). In addition to perceptual characteristics, conceptual features (image schemas) should be considered in computational systems in order to improve the visualisation of the concepts. They can be modelled by integrating perceptual characteristics with image schemas in visual representations. A similar idea is suggested by Falomir and Plaza (2019), who, in their research, investigate the effects of image schemas in computer icons as a tool for agents to use to interpret the spatial information in order to recreate new blended representations.

They propose a new approach to computationally model the understanding of such conceptual integration by a receiver agent.

We presented examples of visual analogies embodying various image schemas that have proven their effectiveness in the problem solving process throughout our experimental studies.

Future work could explore the value of these outcomes for creative design problems with potential implications for computational creativity support tools, for multimedia design tasks that are rich in kinetic or kinaesthetic content.

12.1.1.2 **Dynamic Visual Analogies Can Be More Effective in Problem Solving than Static Ones.**

The findings from *Experiment 2* (6.3) confirm that animated visual analogies illustrated by computer simulations lead to a higher success rate in problem solving than discrete visual analogies illustrated by a sequence of key static pictures.

Graphics of all kinds, including animation, benefit comprehension and foster insight (Larkin & Simon, 1987; Mayer & Moreno, 2002; Tversky, Morrison, & Betancourt, 2002); however, literature has presented mixed results on the benefits of animation (Rieber & Hannafin, 1988; Byrne, Catrambone, & Stasko, 1999) even though it is, in principle, an ideal format for conveying change over time (Schnotz & Grzondziel, 1999). Both animated and static visual analogies align with the *systematicity* principle (Gentner, 1986) which states that high-order relations, such as causality, facilitate mapping. While both animated and static images reflect high-order causality relations through the depiction of actions and their effects on the elements of the settings, static images can increase the cognitive load because they demand inferring motions, i.e. mental animation (Hegarty, 1992). Gibson (1977) argued that perception is action-geared. The action can be detected by the changes of an object in time; thus, animated visual representations may be more effective than still imagery in concept visualisation.

Multimedia and human-computer interaction designers may benefit from using animated imagery to engage users to interact with the displayed representation.

The outcome is also in line with the *structural consistency*, *one-to-one mapping, congruence, and apprehension* principles.

12.1.1.3 Adding Pictorial Cues to the Depth of the Visual Elements Used in an Analogy Representation Increases the Success Rate in Insight Problem Solving

The results of *Experiment 2* (see 6.3) have also shown that added secondary depth (pictorial) cues in the image or the animation lead to a higher success rate in problem solving than those that capture only primary depth cues, which suggests that adding pictorial (i.e., light and shadows, gradient, and atmospheric perspective) depth cues to the visual analogy plays a significant role in designing effective analogies for problem solving. A clear conclusion that can be drawn is that using pictorial depth cues as a source may facilitate identifying or retrieving similarities between possible relations in the target. This added depth information could, in fact, be more beneficial when the analogical transfer is about the spatial relationship.

Designers and architects widely use the visual simulation of the artefacts. Designs are imagined, represented, and communicated pictorially in art, architecture, and engineering. It is clear that, in computer software design systems as well, there is a need for pictorial and symbolic representations to coexist.

12.1.1.4 Problem Insight Integration in a Visual Analogy

The findings from *Experiments 1* and *3* (see 5.3 and 7.3) suggest that, in visual analogies, insight cues are most beneficial when integrated.

The result of these experiments confirm that visual analogies capturing the stacking insight are more effective in generating more correct solutions for the *8-coin* problem when they are provided in the appropriate sequential order. However, as per suggestions from the discussion notes for *Experiment 1* (see Section 6.4), a strong bond between the two insights appears to be a prerequisite for solving the *8-coin* problem. The assumption that the stacking insight is more important than the grouping one may be because participants failed to detect the grouping hint presented in a reversed order (see 7.4) through moving objects (balls, people). Thus, grouping may not be considered a determinant insight in finding the solution to the *8-coin* problem, but the stacking insight action is clearly significant. When the stacking insight is prompted during the problem solving task, they both occur simultaneously depending on each other's next moves, thus the integration of problem insights in the visual representation is important for successfully solving that problem.

12.1.2 The Portfolio of Visual Analogies for Visual Insight Problem Solving

We explored how visual analogies are developed using a practice-led method to create a series of visual analogies for problem solving in both static and dynamic formats. Haiying Long's (2014) review on research methodologies and methods in creativity studies, published in five most prestigious creativity journals between 2003 and 2013, showed that ~83% of these studies were quantitative, ~13% qualitative, and less than 5% employed mixed methods. There is, however, limited research on the practitioner's experience and his/her practice in creating visual analogies or representations for insight problem solving.

The developed portfolio of visual analogies for the two insight problems, *8-coin* and *cheap necklace* problem solving (see www.luchian.info), results from employing the practice-led and experimental methods. The impact of visual analogies on the solution rate in problem solving progressed incrementally from the first to the last experiment, indicating that the quality of the visual analogies developed as hints for problem solving constantly improved and, that with each new experimental study and its specific research questions, we have gained a better understanding of how to construct more effective visual analogies for insight problem solving.

Findings support the benefit of our methodological approach, and one of its long-term benefits is that it allows for a shift in the emphasis, from exploring if the hints work to *which* ones work and, and more importantly, to *why* they work.

The developed visual material for the first two experiments (Chapters 5 and 6) has served us in the research to test current theories (see 2.3.1) that are relevant to visual analogy and problem solving. Thus, we do not consider these as a contribution to the field. The concepts and finished versions of the visual analogies for Experiments 4 and 5 that showed a consistently higher success rate in problem solving may be claimed as good examples of using conceptual features (image schemas, timing, problem insight integration) blended with perceptual characteristics of the objects (pictorial depth and perspective) in the development process of visual representations. These are described more in detail in sections 8.2.2.1 and 9.2.2.1 of Chapters 8 and 9, including how these features were implemented in visual representations, and what was taken into consideration in their development.

The portfolio of visual analogies could be used by researchers as an aid to explore concepts of visual thinking for problem solving. For example, software engineer designers might use these visual analogies as instruments to investigate the effects of gazing time, points of interest, relations between objects and analogical correspondences that solvers look at during the problem solving process. By using eye-tracking devices in their research, they could get a better understanding of how to use these visual elements and principles in the development of new multimedia and graphic design software.

Some of the limitations potentially linked to other researchers using this portfolio are related to the role of the constructor and analogy solver. Harpaz-Itay and colleagues (2006) reinforced the idea that there is a difference in the dependency for the task in the context of and situation between the two roles. For example, when solving an analogy, a problem solver is more likely to focus on solving structural mapping (Gentner, 1983), the number of relationships (Halford, Wilson, & Phillips, 1998), and the familiarity of these relationships (Goswami U. , 1992; Chen, 2002), while an analogy constructor is more likely to focus on self-explanation and analogical comparison (Nokes-Malach, VanLehn, Belenky, Lichtenstein, & Cox, 2013) which are more dependent on prior knowledge and cognitive style (Mayer & Massa, 2003). So, what is the message for researchers/designers?

12.1.3 Guidelines for Developing Effective Visual Analogies for Insight Problems

The documentation through the diary approach was used in data collection, data analysis and interpretation along with the generated sets of visual analogy concepts. These notes described what the investigator/practitioner thinks while developing analogies for insight problems. They captured the creative process, the practitioner's experiences or relations to ideas, feelings, perceptions, or the practitioner's preferences on shapes or forms in the entire development process of analogies for each experiment (not only in the generation stage which used the second type of diary method - documentation). These notes are included in the materials/stimuli subsection of the method section of each experimental study.

Firstly, the notes were analysed and interpreted with the purpose of selecting the best concepts for experimentally testing specific components of visual analogy in problem solving, and secondly, to find out what these notes could reveal about the practitioner's strategies and creative processes in the practice-led stages of this research. The multiple strategies, known, acquired as a researcher, or adopted, and applied by the artist in designing visual materials for this thesis were analysed and interpreted. The most frequently practiced strategies (described in section 11.5 of Chapter 11) by the artist/researcher in the development process and the visual analogies that generated higher rates of success in the problem solving process (Chapters 8 and 9) were analysed, integrated, and interpreted, which led to guidelines for developing visual analogies for insight problem solving.

Such guidelines are generic and could potentially be applied to constructing visual analogies based on appearance, relationships between objects and their attributes, as well as on embodied schemas. We provide a connection between practice-based exploration and the theoretical framework for visual analogy construction for insight problem solving which could help overcome the current limitations of existing theoretical models (Blanchette & Dunbar, 2000) that ignore the importance of blending perceptual characteristics with conceptual features in the development of visual representations.

The developed guidelines for constructing effective visual analogies for perceptual insight problems are intended to support professionals from a variety of backgrounds, especially computer artists and multimedia, human-computer interaction, and software designers, in creating visual material for problem solving, creative thinking, concept visualisations, and interactive visual displays.

12.2 Reliability, Validity, Generalisability and Limitations

Throughout this thesis, the development of visual analogies for insight and creative problem solving was investigated by practice (practice-led), both qualitatively and quantitatively.

12.2.1 The Reliability of this Research

The reliability of the research is gained by combining practice-led, documentation and quantitative data analyses.

Through a systematic process of making analogies (practice-led), consistently testing them in laboratory settings (quantitatively), integrating and interpreting the data by reflecting on the visual analogy development process (qualitatively) we gained a better understanding of which components work and how we might create better visual analogies and visual material to use in everyday problem solving processes, artistic practices, computing and communications systems, and learning.

This mixed-methods study used two different groups of people for practice-led and documentation, and quantitative studies, where participants in the quantitative research were not the same individuals who provided the core of practice-led and documentation data such as creating, selecting, finalising, interpreting the outcome and revising the visual material for this thesis. Practice-led and documentation data was obtained primarily by using the researcher's skills as an artist and 4 experts in analogical reasoning, while quantitative data was obtained using a larger sample.

12.2.2 **The Validity of this Research**

To strengthen the validity of research evaluation and findings the data was collected through several sources. The artist's practice (who is also the researcher of this study) was used intentionally and purposefully as a tool in the investigation. At this stage the artist's creative processes during the analogy development were documented. The artefacts created were rigorously evaluated by a panel of experts in analogy. The expert evaluators' findings were intended to inquire whether or not a created visual analogy generated enough information for suitability regarding its effectiveness and appropriateness for experimental studies. The following quantitative method was used to test the effects of the analogies created in the problem solving process and to collect additional data such as demographics, feeling of warmth, likeness and perceptibility of the problem insights captured in the artefacts. This quantitative data confirmed or rejected the findings from the practice-led and documentation stages of the research; then the results of the data collected were integrated and interpreted and a new direction for the next experiment of the study was established. In a quantitative research, validity is determined by whether one can draw general conclusions on the design used and the data collected, as well as whether results may be generalised to other large samples, time and environment. To strengthen the part of quantitative research validity, a good research design and instrumentation were applied in this study including knowledge and clarity in its logic.

The study highlights how the result of the experimental component is informed by the exploratory findings from the practice-led and documented components in conjunction with the literature sources. The approach allowed for greater involvement of the practitioner, experts and participants in refining the study's visual materials and potentially raising its validity as an effective tool in the problem solving process. We consider that the choice of methods was suitable to address the study question, which follows a consistent rationale, data collection and a feasible analysis.

12.2.3 The Generalisability of the Findings

The mixed-methods research involved the collection, analysis, and integration of practice-led, qualitative (documentation) and quantitative data within a coordinated series of studies that promote confidence in the generalisability of our findings. A systematic integration of different methods has emerged as a pillar of the evidence-based practice research. Firstly, our experiments were an intentional replication of two studies in problem solving using analogies as hints, yielding systematic confirmatory evidence of the effectiveness of the developed visual analogy in problem solving, as well as revealing new constraints that hinder their development. Secondly, the quantitative method helped us understand how to refine and revise the concept of analogy-making and the conditions under which this conceptualisation holds.

The practice-led method engaged the researcher in the analogy-making process revealing particular concepts from observations that generate interpretations and make inferences to construct meanings. Documentation and reflexivity about the setting, the participants, and the data collected throughout the study gave us insights that contributed to a generalised understanding of the analogy-making process and the guidelines for developing an effective visual analogy for insight problems (Section 12.1.3).

Our findings suggest that integrating image schemas, pictorial depth, and a proper order of capturing the problem insights with the perceptual characteristics of objects that form visual imagery leads to a better understanding and conceptualisation of visual representations. The inclusion of image schemas, pictorial depth and proper order of the problem insights into current concept visualisation models can help researchers and multimedia creators from various domains and fields improve concept graphical representation and visualisation technology.

For example, employing image schemas into concept representations, multimedia and human-computer interaction designers might facilitate a stronger engagement of its users with the content of the imagery. Experimental results (Tversky, Morrison, & Betancourt, 2002; Larkin & Simon, 1987; Pressley, 1977) show that various forms of active engagement with visual material lead to a very positive outcome in learning.

Also, adding pictorial depth to the imagery will help users identify the visual elements and spatial relations between objects, which often can be very difficult to read without them. An artefact, which has successfully captured these visual features in the objects represented and their spatial relationship, reduces the cognitive effort of building a visual representation of the concept or system (Paivio A. , 1971).

Features such as image schemas, pictorial depth and the order of the insight can be considered as effective strategies for multimedia designers in the creative process of their work, and used by human-computer interaction designers as tools to facilitate user-engagement and interaction with the content of visualisation, and as an effective way to represent complex data in scientific visualisation.

12.2.4 **The Limitations of this Research**

One limitation of the study is that we did not use any brain measurements to assess whether provided visual analogies activated the mirror neurons of the human brain during the problem solving tasks, or similar embodied mechanisms (Brucker, Ehlis, Häußinger, Fallgatter, & Gerjets, 2015) that were explored in this study.

The second limitation is that, throughout the entire visual analogy development process, I was guided by my own observations and the notes taken during the tests on problem solving, as well as observations of video recordings, which appeared to contain enough information to draw conclusions. However, observations of the researcher (myself) might be biased due to individual's beliefs rather than being based on what was presented to me; thus, there is a need for further testing and comparing of the results of this thesis with the work of other researchers for their feasibility and the practicability of the proposed guidelines.

Thirdly, the surveys of participants' preferences on visual material may have been biased based on the final outcome of the test/activity (e.g., after finding a correct solution to a problem, participants tend to rate or evaluate the problem, its processes, used materials and environment more positively, as opposed to having a less positive view when they do not solve it). For example, eye tracking techniques to determine exactly what people are looking for in visual material, how long they look at a specific element, and how that affects their decision making may lead to more accurate measures of this phenomenon.

A fourth limitation concerns the potential difficulty of generalising these findings, assuming that the guidelines can serve to assist in the construction of analogies for all kinds of problems without being aware of the characteristics and specifics of the problem at hand. The tasks used in our study were specific and involved only two insight problems to measure the progress of the developed visual analogies and their effect on performance in problem solving tasks from which we could draw conclusions. However, our findings could be extended in future research to any discipline involving vision, computing, perception, learning, problem solving and creativity.

12.3 Future Work

Future studies could be extended to an investigation into the different stages of the development process of visual stimuli for creative problems to access their more definite and precise effects on product or artistic activity creation.

As technology advances and taking the lead in information distribution, visualisation becomes a powerful tool in education, arts and scientific discovery and innovation. There is a need for further investigations into how to construct visual analogies using different methods to those employed in this study, and there is also a need to test the proposed guidelines for feasibility in terms of other designs and media makers.

After all, people are increasingly relying on visual insights to understand concepts, foster critical thinking and judgement, and develop the faculty to recognise, define, assess, and apply conceptual patterns to new problems. visual analogy serves more than these functions; it is also a bridging tool across the disciplines, facilitating imagination, intellectual play and creativity. Ricci and Pritscher (2015, p. 47) quotes Albert Einstein, who said: “After a certain high level of technical skill is achieved, science and art tend to coalesce in aesthetics, plasticity, and form. The greatest scientists are always artists as well.” Then, why do we separate problems into logical and intuitive and not integrate them in order to find the best-suited solutions. We can learn from analogy how to balance conformity and diversity in designing investigations into unknown phenomena. Thus, there is a need to develop new research methods that support image creators to conceptualise, research and design analogy for insight and creative problem solving.

Another aspect is the need for a broader investigation into how the gesture and force (image schemas) can be implemented in computing. Computers, in particular, understand less than humans how to interpret the symbolic meaning of gestures and forces. Therefore, there is a need for an interdisciplinary inquiry integrating technology and sciences with fields such as dance and performance where gesture and movement are at the core.

All these future directions derived from the original outputs of this thesis. They could be used in creative and appropriate ways to produce new knowledge that opens up creative and critical thinking related to analogy visualization and visual representation across a variety of disciplines, in particular those in computing (e.g., human-computer interaction, multimedia), visual art, psychology and design fields.

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14 Appendices:

Appendix 14-1 Announcement

List of experts in analogy and analogical reasoning

1. **Dr. Linden J. Ball, PhD**

is currently a Professor of Cognitive Psychology & the Dean of School of Psychology at the University of Central Lancashire, United Kingdom.
He is also the Research Director for the Faculty of Science and Technology - an expert in the psychology of thinking, reasoning and problem solving. He conducts lab-based studies of fundamental thinking processes and real-world studies of reasoning in domains such as design. He is past Chair of the Cognitive Psychology Section of the British Psychological Society (2011-2014), and is Associate Editor of Thinking & Reasoning and Journal of Cognitive Psychology. He is also Series Editor for the Current Issues in Thinking & Reasoning book series published by Psychology Press. (Extracted on 15/11/2018 from: https://www.uclan.ac.uk/staff_profiles/professor_linden_ball.php).

2. **Dr. Bo T. Christensen, PhD**

is a Professor in Creative Cognition in the Department of Marketing at Copenhagen Business School, Denmark.
His main research area concerns the study of creativity in domains such as design, marketing, engineering, cuisine, architecture and software design. Using video recordings of creative teams at work he studies the underlying cognitive processes and mechanisms of creative work. Furthermore, Bo utilizes experimental research and quasi-experimental research methods to study both the generation and selection of creative ideas. He also studies what forms of technology that may be brought into play for support of creative processes. Finally, Bo studies the evaluation of creativity; how to select the right ideas for progression at gates in innovation processes; how is creative evaluation handled in various domains; how do consumers or users come to perceive a product as creative or innovative. (Extracted on 15/11/2018 from: https://www.cbs.dk/en/research/departments-and-centres/department-of-marketing/staff/bcmarktg).

3. **Dr. Corina Sas, PhD**

is a Professor in the School of Computing and Communication at Lancaster University, United Kingdom.
Her research interests include human-computer interaction, interaction design, user experience, designing tools and interactive systems to support high level skill acquisition and training such as creative and reflective thinking in design, autobiographical reasoning, emotional processing and spatial cognition. This work explores and integrates wearable biosensors, life logging technologies and virtual reality.
Professor Sas has co-authored over 60 peer-reviewed publications on topics such interaction design, user experience, cognitive and computational models, as well as design education. Dr. Sas has been an active member of the HCI community, acting as general co-chair of the 21st British HCI conference in 2007, as well as co-chair of several CHI workshops (2006, 2008, 2009, 2010). (Extracted on 15/11/2018 from: http://www.lancaster.ac.uk/scc/about-us/people/corina-sas).

4. **Eric Luchian, MFA**

Is a PhD student in the School of Computing and Communication, Lancaster University, UK and an Assistant Professor in the Department of Visual and Performing Arts at Elizabeth City State University, NC, USA - https://www.ecsu.edu/faculty-staff/profiles/eric-luchian.html and freelance artist: http://www.luchian.net/
His research interests include creativity, creative practice, problem solving and fine arts.

Appendix 14-2 List of experts in analogy and analogical reasoning

Participant Information Sheet

Study of Creative Problem Solving using artistic representation

Dear Participant,

You are cordially being invited to participate in a user study regarding creative problem solving using artistic representations. But before we ask you to make any decisions, please take some time to carefully read the information presented in this document in order to understand why the research is being done and what it will involve.

- Part 1 explains the purpose of this study and information regarding your participation.
- Part 2 provides you with more details regarding the conduct of the study.

Please do not hesitate to contact us if any information is unclear and feel free to take your time to decide whether or not you wish to take part.

Contact Details: Eric Luchian – R/A, PhD student; e-mail: e.luchian@lancaster.ac.uk
Dr. Corina Sas – Lead Supervisor; e-mail: corina@comp.lancs.ac.uk

<u>Part 1</u>

What is the purpose of this study?

The research forms part of a PhD project in the field of Creative Design conducted by Eric Luchian and supervised by Dr. Corina Sas – School of Computing & Communication, Lancaster University.
As researchers in Creative Design, we are interested in finding novel methods and techniques for creative problem solving. A field we are particularly interested in is the use of artistic representations in Creative Problem Solving.

What will the study involve?

You will be given to solve the 8-coin problem - a test in creative thinking.
During the test you'll be asked to wear an armband that records certain physical information – specifically to arm movement and skin conductance and your hands movements will be video recorded for further analysis.

Do I have to take part?

Your participation is entirely voluntary and you may refuse to participate or withdraw from the study at any time. If you decide to participate, you may keep this information document and be asked to sign a consent form (find attached at the end of this document).

Expenses and payments:
For your co-operation, you will be remunerated with £5 per participant.

Will my participation be kept confidential?
Yes. Confidentiality and participant anonymity will be strictly maintained. All information gathered will be used for statistical analysis only and no names or other identifying characteristics will be stated in the final or any other reports. All data from individual participants will be coded so that their anonymity will be protected in any project reports and presentations that will result from this work. If the information in <u>**Part 1**</u> has interested you and you are considering participation, please continue to read the additional information in <u>**Part 2**</u> before your decision.

<u>Appendix 14-3 Participant Information Sheet – Part I</u>

Part 2

What will the study involve?

We would like to observe your normal behaviour during the 8-coin problem test, the project that we are currently working on, and after the test to fill in a questionnaire. In addition, we will ask participants to wear a device during the test - an armband that records certain physical information – specifically to arm movement and skin conductance in order to record some aspects of your experience during the problem solving test. The experimenter will help participants to put on, use and remove the device, and will be happy to answer any questions that you may have about how the device operates.
We will video record your arms movement that will be used for further analysis.
We estimate that the total time of your participation will be ~25 minutes.

Basis of Participation:
In agreeing to participate in the study, please be aware that information verbally given may be recorded in forms of researcher's notes and you might be asked to confirm their accuracy.

Problems and Complaints
If you have issues or complaints about any aspect of this study, please speak with the researcher. If you remain unhappy and wish to complain formally, you can do this through the lead supervisor Dr. Corina Sas (email: corina@comp.lancs.ac.uk).

Additionally, if you come across any problems during the experimental study, please feel free to voice your concern.

What will happen to the results of the research study?

The results and findings will be analysed by the researchers and followed by a report of the entire study. You will not be identified in any report/publication unless you have consented to release such information. All information provided will also be kept genuine and accurate.
The participant can request a copy of the information document and a photocopy of the signed consent form to keep should they so wish.
Thank you for your interest and time.

Consent Form

I agree to take part in the above study. I agree to wear the provided armband and be video recorded during the test. I agree to the use of anonymised quotes in publications.

__________________________ ____________________
Participant' Signature Date

__________________________ ____________________
Investigator' / Researcher' Signature Date

Appendix 14-4 Participant Information Sheet – Part II & Consent Form

Instructions:

Rearrange the coins displayed in front of you, moving two coins only, so that all eight coins are touching exactly three others.

If after moving two coins you did not solve the problem, the coins must be returned to their original positions and another attempt could be made.

You can make as many attempts as you wish.

After a total of 6 minutes of attempts the result will be marked and this stage of the test ends.

Finding the solution to the puzzle, you may end the test at any stage by announcing the experimenter.

Using the provided tablet PC you'll mark your feelings about how close you are to the solution from "Hot to Cold" on its Slider. You are free to use it anytime you feel your feelings changed.

Thank you for participating in our experimental study!

(Instructions how to use the tablet will be provided by experimenter before starting the test)

Appendix 14-5 Instructional sheet for control group (Experiment 1)

Instructions:

Rearrange the coins displayed in front of you, moving two coins only, so that all eight coins are touching exactly three others. If after moving two coins you did not solve the problem, the coins must be returned to their original positions and another attempt could be made.

You can make as many attempts as you wish.

If you cannot find the solution in 2 minutes, you will be given the first visual image containing a hint to the *8-coin* problem.

After another 2 minutes of unsuccessful attempts, we will provide you with a second image containing an additional hint in finding the solution.

After a total of 6 minutes of attempts the result will be marked and this stage of the test ends.

Finding the solution to the puzzle, you may end the test at any stage by announcing the experimenter.

Using the provided tablet PC you'll mark your feelings about how close you are to the solution from "Hot to Cold" on its Slider. You are free to use it anytime you feel your feelings changed.

Thank you for participating in our experimental study!

(Instructions how to use the tablet will be provided by experimenter before you start)

Appendix 14-6 Instructional sheet for conditional groups (Experiment 1)

Participant Nr. ____________

Table												
Attempts		Rate your feelings how close you are to the solution										
Nr.	Time	0	1	2	3	4	5	6	7	8	9	10
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
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20												
21												
22												
23												
24												
25												

Appendix 14-7 The template used to record the feelings of warmth

Santa Barbara Learning Style Questionnaire (SBCSQ, Version 1.0)

Please place a check mark indicating your level of agreement or disagreement.

I prefer to learn visually.

○	○	○	○	○	○	○
Strongly agree	Moderately agree	Slightly agree	Neither agree or disagree	Slightly disagree	Moderately disagree	Strongly disagree

I prefer to learn verbally.

○	○	○	○	○	○	○
Strongly agree	Moderately agree	Slightly agree	Neither agree or disagree	Slightly disagree	Moderately disagree	Strongly disagree

I am a visual learner.

○	○	○	○	○	○	○
Strongly agree	Moderately agree	Slightly agree	Neither agree or disagree	Slightly disagree	Moderately disagree	Strongly disagree

I am a verbal learner.

○	○	○	○	○	○	○
Strongly agree	Moderately agree	Slightly agree	Neither agree or disagree	Slightly disagree	Moderately disagree	Strongly disagree

I am good at learning from labeled pictures, illustrations, graphs, maps, and animations.

○	○	○	○	○	○	○
Strongly agree	Moderately agree	Slightly agree	Neither agree or disagree	Slightly disagree	Moderately disagree	Strongly disagree

I am good at learning from printed text.

○	○	○	○	○	○	○
Strongly agree	Moderately agree	Slightly agree	Neither agree or disagree	Slightly disagree	Moderately disagree	Strongly disagree

<u>Appendix 14-8 Santa Barbara Learning Style Questionnaire (SBLSQ V. 1.0)</u>

Complete the questionnaire, please:

<u>Date Of Birth</u> | | | | (optional)

<u>Age:</u> _______ (skip if entered DOB)

<u>Height:</u> _______ (~m/cm) _______ (~feet/inches)

<u>Weight:</u> _______ (~kg) _______ (~pounds)

<u>Gender:</u> | M | F | (circle one)

<u>Smoker:</u> | Yes | No | (circle one)

<u>Year of study:</u> (circle current year)

Undergraduate: | 1 | 2 | 3 | 4 | |

Postgraduate Masters: | 1 | 2 | |

Postgraduate PhD: | 1 | 2 | 3 | |

Others: ______________________________

<u>Area of study:</u> ____

<u>Did you hear about 8 coin-problem before?</u> | Yes | No |

<u>Did you know how to solve it?</u> | Yes | No |

<u>Did you discuss the 8 coin-problem with other participants?</u> | Yes | No |

Thank you very much for your participation!

Participant Nr. __________ **date** __________ **time**__________

<u>Appendix 14-9 Survey of participant demographic data</u>

Visual Material

1. Did you find the provided visual material helpful?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

2. Did you see any similarities between the provided visual material and the eight coins problem and its solution?____

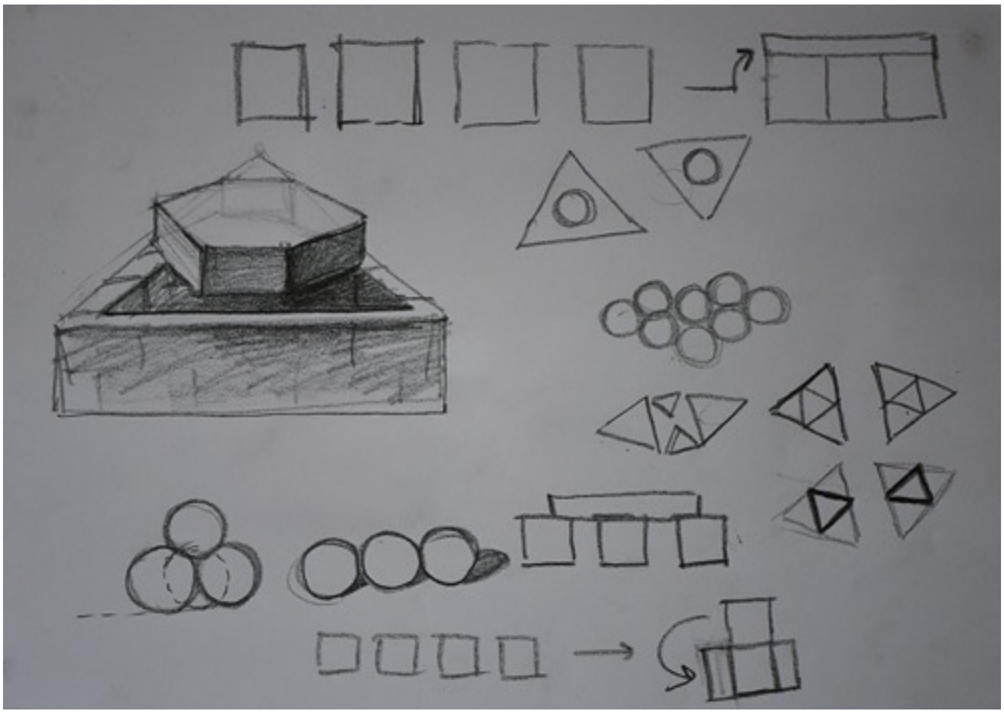
____

Any others? ____

3. The most important elements in the visual material that helped you to look for similarities of the provided hints with the problem solution.

| shapes | number of the elements | arrangements of the elements | depth | movement | forces | gestures |

Appendix 14-10 Survey of helpfulness of provided visual material



Appendix 14-11 Brainstorming sketches for visual cues (1.1)

Understanding the challenge	1.	Understanding the task
	2.	Brief description of the goals
	3.	Promising opportunities to pursue
	4.	How am I going to do it
Generating ideas	5.	How can the problem be stated differently
	6.	What can be changed to achieve the set goals
	7.	Explore the alternative possible solutions
	8.	Consider the possible solutions in different context
Analyse, evaluate and refine promising solution	9.	Examine the most promising ideas
	10.	Analyse the possible best solutions for the task
	11.	Choose the best solution from the explored and state why
	12.	Is there something to change in the chosen version
Plan for support, appraising the task	13.	Analyse and examine the possible outcome of the created
	14.	How can the chosen idea be strengthen
	15.	Examine the actions and forms of implementing the idea
	16	Are you satisfied with the sketched idea?

Appendix 14-12 Reflection-on-action questionnaire

1.	To look for shapes and forms that reminds of coins… Could be objects, animals, people, or scenes.
2.	Need to come up with some generalizations of forms and a sort of relationship between them. Let's see some man activities or situations involved with some objects.
3.	Carrying something or stacking. Some buckets. But where he's stacking them? Might be stacking them to show his craft, at a showcase, or simply at a market.
4.	I'll start by trying to compose the scene first. I'll place an individual on the side of a bunch of buckets, and then in the second frame I might make two groups of buckets with the person in the centre after the action is done.
5.	At the market will be more interesting of course, as I can show him in foreground together with the buckets.
6.	The angle could be changed and also I'm thinking how to draw the scene more abstractly so to hide its immediate given
7.	I have the freedom to move and stack these cylindrical forms in any way I want. So, I could adapt systematically the sketches to meet the requirements for problem insights, from frame to frame, of these buckets through the individual's actions.
8.	A show at a circus with buckets juggler. That could be something
9.	Probably simpler actions, in a show, market or on a circus stage of a man manipulating the buckets to capture the insights of the problem.
10.	Eliminate the background, or the audience in case of a circus-show, and draw the objects and person in a schematic way, without too many details will emphasize the actions and changes from one frame to the next.
11.	The cylinder definitely looks like an extruded circle, so I guess that'll be a great clue to the problem.
12.	I'll try to play with the visual effect of zooming in and out to see how that looks on a bigger size paper.
13.	If I can show the required changes, through a sequence of frames, then I can create also an animated scene without changing the camera and use it as multimedia hint.
14.	Simple buckets, without any handlers would save time and keep the bucket form closer to that of the coin
15.	So, let me have a go: in the first frame will be shown (or not shown) a person with several buckets (probably 8 in total), aligned in 3 rows and seen from a frontal view, then the individual enters the scene and picks up a bucket from the centre and stacks it on the other 3 ones on the side.
16.	I anticipate this scenario will work. The idea could be developed further by doing more sketches especially in accentuating the position and changes of the bucket rather that the individual's actions.

Appendix 14-13 Example of answers to reflection-on-action questionnaire

Instructions: (ctrl group)

The cheap necklace problem

The cheap necklace problem is as follows. There are four chains, each consisting of three links (see Fig. 1).
It costs 2 pence to open a link and 3 pence to close it again.

Your goal is to connect all four chains so as to form a complete closed necklace (Fig. 2) at a cost of no more than 15 pence.

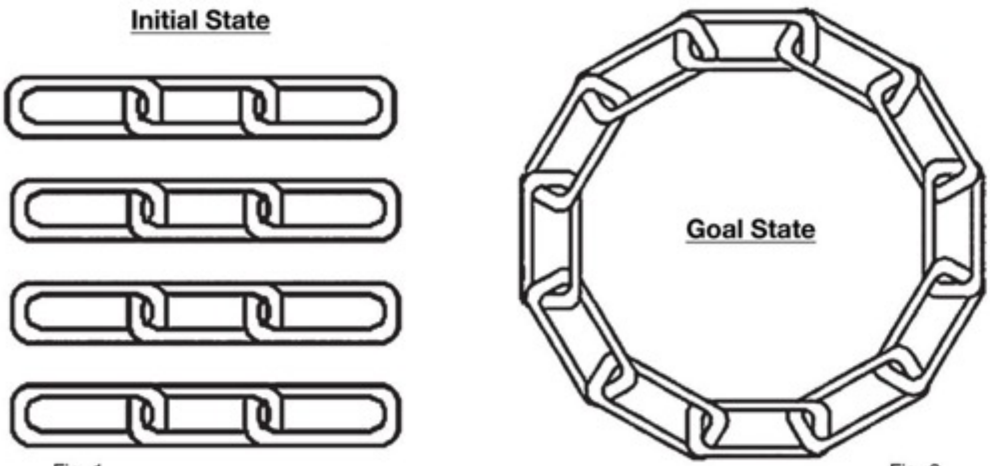


Fig. 1 Fig. 2

During the test, please rate your feelings about how close you are to the solution on a scale from "0" to "10" by saying loudly the number so experimenter could record it.

Please rate your feelings after each attempt. You can make as many attempts as you wish.

After a total of 8 minutes of attempts the result will be marked and this stage of the test ends.

Finding the solution to the problem, you may end the test at any stage by announcing the experimenter.

(You may ask the experimenter additional questions about the procedure before the test)

Appendix 14-14 Cheap necklace problem instructions for the control group

Instructions: (1st group)

The cheap necklace problem

The cheap necklace problem is as follows. There are four chains, each consisting of three links (see Fig. 1).
It costs 2 pence to open a link and 3 pence to close it again.

Your goal is to connect all four chains so as to form a complete closed necklace (Fig. 2) at a cost of no more than 15 pence.

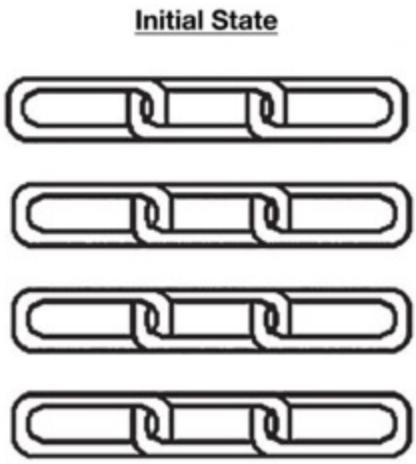


Fig. 1

Fig. 2

During the test, please rate your feelings about how close you are to the solution on a scale from "0" to "10" by saying loudly the number so experimenter could record it.

Please rate your feelings after each attempt. You can make as many attempts as you wish.

If you cannot find the solution in 2 minutes, you will be given a visual material containing hints to the solution of the problem.

After a total of 8 minutes of attempts the result will be marked and this stage of the test ends.

Finding the solution to the problem, you may end the test at any stage by announcing the experimenter.

(You may ask the experimenter additional questions about the procedure before the test)

<u>Appendix 14-15 Cheap necklace problem instructions for treatment group 1</u>

Instructions: (2nd group)

The cheap necklace problem

The cheap necklace problem is as follows. There are four chains, each consisting of three links (see Fig. 1).
It costs 2 pence to open a link and 3 pence to close it again.

Your goal is to connect all four chains so as to form a complete closed necklace (Fig. 2) at a cost of no more than 15 pence.

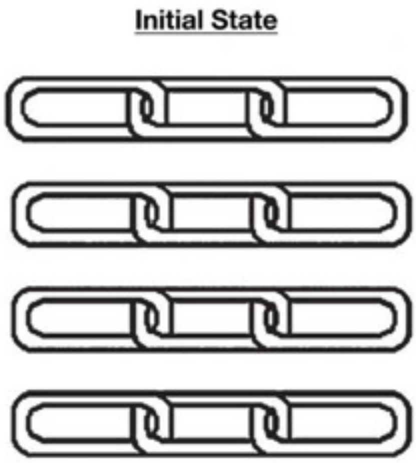


Fig. 1

Fig. 2

During the test, please rate your feelings about how close you are to the solution on a scale from "0" to "10" by saying loudly the number so experimenter could record it.

Please rate your feelings after each attempt. You can make as many attempts as you wish.

If you cannot find the solution in 2 minutes, you will be given a first visual material containing hints to the solution of the problem.

After another 3 minutes of unsuccessful attempts, we will provide you with additional visual material containing hints in finding the solution.

After a total of 8 minutes of attempts the result will be marked and this stage of the test ends.

Finding the solution to the problem, you may end the test at any stage by announcing the experimenter.

(You may ask the experimenter additional questions about the procedure before the test)

Appendix 14-16   Cheap necklace problem instructions for treatment group 2

Instructions: (3rd group)

The cheap necklace problem

The cheap necklace problem is as follows. There are four chains, each consisting of three links (see Fig. 1).
It costs 2 pence to open a link and 3 pence to close it again.

Your goal is to connect all four chains so as to form a complete closed necklace (Fig. 2) at a cost of no more than 15 pence.

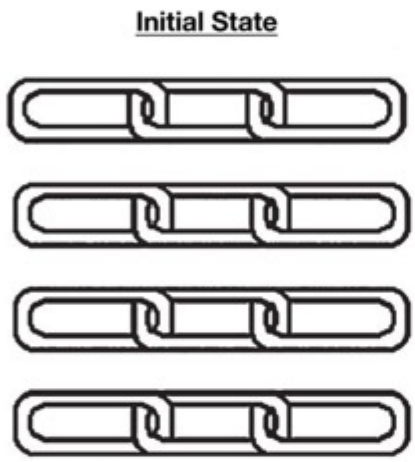


Fig. 1

Fig. 2

During the test, please rate your feelings about how close you are to the solution on a scale from "0" to "10" by saying loudly the number so experimenter could record it.

Please rate your feelings after each attempt. You can make as many attempts as you wish.

If you cannot find the solution in 2 minutes, you will be given a first visual material containing hints to the solution of the problem.

After another 2 minutes of unsuccessful attempts, we will provide you with additional visual material containing hints in finding the solution.

The third hint will be provided to you after a total of 6 minutes of working on the problem.

After a total of 8 minutes of attempts the result will be marked and this stage of the test ends.

Finding the solution to the problem, you may end the test at any stage by announcing the experimenter.
(You may ask the experimenter additional questions about the procedure before the test)

Appendix 14-17 Cheap necklace problem instructions for treatment group 3

Eric Luchian - contribution statements to the published papers

Authors:

1. Erroneous Features in Freehand Sketching: Opportunities to Generate Visual Analogies

Eric Luchian Conceived the original idea, carried out the study, developed categories grounded in the text, processed the data, contributed to the interpretation of the results by writing the draft and final paper in consultation with Corina Sas.

Corina Sas Supervised the project, verified the methods and interpretation of the results and approved the final version to be submitted.

2. Image Schemata in Animated Metaphors for Insight Problem Solving

Eric Luchian Designed the study, developed the visual material for the experiment, carried out the experiment, contributed to the analysis and the interpretation of the results, drafted and wrote the final version of the paper to be submitted, as well, designed the research poster in consultation with Corina Sas.

Corina Sas Supervised the project, contributed to the analysis and the interpretation of the results, verified the methods and calculations, and approved the final version of the paper to be submitted.

3. Develop and Evaluate Visual Analogies to Support Insight and Creative Problem Solving

Eric Luchian Designed the project, collected data and materials in support to the presented idea, analysed and interpreted the data, drafted, wrote and revised the final version of the paper and poster to be presented.

4. Investigating Visual Analogies for Visual Insight Problems

Corina Sas Planned and drafted the paper, performed the analysis, aided in interpreting the results, supervised the project, provided feedback and approved the final version of the paper to be submitted.

Eric Luchian Conceived the idea, developed the visual material in consultation with Sas and Ball, designed and performed the experiments, collected the data, processed the experimental data and wrote the paper with input from all authors.

Linden J. Ball Contributed to the implementation of the research, aided in interpreting the results, and approved the final version of the paper to be submitted.

Appendix 14-18 Author contributions