AN INVESTIGATION INTO ARCHITECTURE STUDENTS' CREATIVE PERFORMANCE WHILE USING ASSOCIATIVE AND RULE-BASED REASONING STRATEGIES: EXPLORING A DUAL PROCESS APPROACH IN DESIGN EDUCATION

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Batuhan TANERİ

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ABSTRACT

AN INVESTIGATION INTO ARCHITECTURE STUDENTS' CREATIVE PERFORMANCE WHILE USING ASSOCIATIVE AND RULE-BASED REASONING STRATEGIES: EXPLORING A DUAL PROCESS APPROACH IN DESIGN EDUCATION

This study investigates pedagogical strategies of how cognitive aspects of design thinking can be a subject of design education particularly in the first year design education. It focuses on design reasoning and on its two distinct forms as associative and rule-based reasoning. An experimental study composed of three different experiments is conducted to investigate the impact of using certain reasoning strategies on first year design students' creative performance. First experiment indicates that those students who were not directed to use either of the two forms of reasoning performed better. When students are asked to use a specific reasoning strategy in solving a design problem, this might increase students' cognitive load which in turn encumber their creative performance. The second experiment provides insights into the order in which these forms of reasoning can be introduced to students in design studio education. The results indicate that when students first conduct a free exploration of the given design problem before being asked to use one of the reasoning strategies their creative performance is better. It is proposed that familiarization with a given problem freely prepares students for a structured design exploration through either rule-based or associative reasoning strategy. The third experiment investigates the impact of a specially designed instruction to use one of the reasoning strategies. When students are provided with an explicit instruction giving information on two forms of reasoning strategies and their use in design before exploring the design problem on their own, the results demonstrated the utility of providing specific information on these reasoning strategies particularly for associative reasoning strategies. The findings suggest that a dual process approach to design education could be beneficial in developing pedagogical strategies for design learning.

ÖZET

MİMARLIK ÖĞRENCİLERİNİN KURAL TABANLI VE ÇAĞRIŞIMSAL AKIL YÜRÜTME SÜREÇLERİNDEKİ YARATICILIK PERFORMANSLARI ÜZERİNE BİR İNCELEME: TASARIM EĞİTİMİNİN İKİLİ SÜREÇ YAKLAŞIMI İLE ARAŞTIRILMASI

Bu çalışma, tasarım bilişsel unsurlarının tasarım eğitiminin konusu olarak ele alınabilmesi için kullanılabilecek pedagojik stratejileri araştırmaktadır. Bu amaçla, çalışma tasarımda akıl yürütmeye ve birbirinden farklı iki biçimi olan çağrışımsal ve kural tabanlı akıl yürütme biçimlerine odaklanır. Birinci sınıf öğrencilerinin belirli akıl yürütme biçimlerinin yaratıcı performanslarına etkisini araştırabilmek için üç deneyden oluşan bir deneysel çalışma yürütülmüştür. Birinci deney, herhangi bir akıl yürütme stratejisine yönlendirilmeyen öğrencilerin daha iyi performans sergilediklerini göstermektedir. Öğrenciler belirli bir akıl yürütme stratejisi kullanmaya yönlendirildiklerinde, bunun öğrencilerde bilişsel yükü arttırabilir ve dolayısıyla da yaratıcı performansları olumsuz etkilenebilir. İkinci deneyde, bu akıl yürütme biçimlerinin hangi sıra ile öğrencilere tanıtılabileceğini anlamamıza yarayacak sonuçlara ulaşılmıştır. Öğrenciler hernagi bir akıl yürütme stratejisine yönlendirilmeden önce verilen tasarım problemini serbestçe keşfedebildiklerinde daha yaratıcı performans göstermişlerdir. Tasarımı problemi ile serbest bir şekilde yapılan alıştırma, öğrencileri daha sonra gelebilecek olan çağrışımsal veya kural tabanlı akıl yürütme stratejileri yoluyla yapılandırılmış tasarım keşifleri yapmalarına hazırladığı öne sürülmektedir. Üçüncü deney, akıl yürütme biçimlerine odaklanan bir dersin, öğrencilerin bu iki akıl yürütme stratejilerini kullanmadaki yaratıcı perfromanslarına etkisini araştırmaktadır. Öğrenciler kendi başlarına tasarım problemini incelemeden önce bu iki akıl yürütme stratejilerine dair bir ders aldıklarında, çağrışımsal akıl yürütme stratejisinin kullanımında olumlu etkileri olduğu gözlenmiştir. Bu bulgular, tasarım öğrenmede pedagojik stratejilerin geliştirilebilmesi için tasarım eğitimine ikili süreç yaklaşımının faydalı olabileceğini göstermektedir.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table	**Page**

Table **Page**

Table **Page**

Table **Page**

CHAPTER 1

INTRODUCTION

This study investigates whether it is possible to formulate a design learning pedagogy based on research in cognitive science on reasoning and decision making. It specifically inquires into how cognitive pedagogical strategies in design learning could be introduced in the first-year architectural design education. It focuses on design reasoning and on its two distinct forms as associative and rule-based reasoning and poses three related research questions. First, how does employing a particular form of design reasoning strategy affect creative performance? Second, how can students be guided to explore one form of reasoning in conjunction with another one in the first-year design studio education? Third, how does explicit instruction on forms of reasoning affect novices' creative performance?

Creative problem solving is a multifaceted process which involves several phases employing both associative and rule-based reasoning in conjunction in each phase (Graen, 1990). Rule-based reasoning strategies are helpful in making reasoning explicit and the pedagogical use of computational formalisms are instrumental supporting the learning of these strategies. The use of associative reasoning strategies, on the other hand, enhances creativity. Both of these two forms of reasoning are equally important in problem solving and learning (Gentner & Medina 1998). The dual process theory of cognition provides an integrative basis in understanding these two forms of reasoning and their relationship. Specifically, the dual process accounts on reasoning, on creativity, and on learning offer alternative perspectives to elaborate a number of issues underpinning novices' misconceptions about design and ways on how to deal with them in design studios.

In this thesis, three series of experimental studies are conducted with first year design studio students to investigate the effects of associative and rule-based forms of reasoning in design. The experimental studies are conducted to explore how explicit instructions to use a certain form of reasoning affect the creative performance of students. Students' performances were subjected to a product and process-oriented evaluation based on the categories formulated by J.P. Guilford, i.e., originality, elaboration, fluency, flexibility. The set-up of the study provides an opportunity for a comparative analysis on forms of reasoning in design and their respective role in design creativity and its' results have implications for first year design studio learning.

1.1. Problem definition

Design education is a process which facilitates students' transition from complete novice status to the comparatively more experienced status through repeated exposures to different design situations in the design studio environment. Design studio is at the very center of design learning, however, it has shortcomings despite its indispensability as a pedagogical device in architectural education (Boyer & Mitgang 1996; Dutton 1987; Dutton 1991; Ledewitz 1985; Rapoport 1984; Sachs 1999; van Dooren et al. 2014; Ward 1990; Willenbrock 1991).

Oxman (2001) identifies three major paradigms in design education going through history of architectural schooling. The first major paradigm of design education starts with the emergence of the atelier system in the eighteenth century, which also sets the beginning of a project-based learning. The second major paradigm begins with the design education experimentations in the early twentieth century exemplified in the pedagogical approaches of the foundation courses (Vorkurs) of Bauhaus and the Russian State Higher Art and Technical Studios (VKHUTEMAS). Oxman (2001) emphasizes that these courses introduced a non-project oriented sets of design exercises in contrast to the atelier approach and argues that these approaches to design education introduced "an orientation to design education as the derivation of knowledge through the exploration of general design principles - and not on the design process itself" (p. 272-273).

These experimentations set the stage for a variety of pedagogical approaches especially in the first-year design studio, all of which emphasized learning by doing and experiential learning. These experimentations were also in parallel to the pedagogy articulated by the American philosopher and educator John Dewey (1916). Despite its effectiveness for the development of creativity in individuals, the implicit nature of learning by doing involves difficulties especially in the process of drawing associations from prior experience and knowledge because it does not offer deliberate strategies and expect students to develop these strategies on their own. Consequently, one of the main ongoing problems in design education is to define what to teach as a requisite knowledge (Oxman 2004) especially in the beginning years.

Knowing and learning are among the foundations of education. Oxman (2001) points out that the cognitive phenomena of knowing and learning are implicit factors in the development of educational programs. Most studies on learning are focused on "top-down learning" where learning proceeds from learning the generic, verbal, declarative knowledge to turning that knowledge into procedural skills (Sun 2002). In such learning settings, correct input/output mappings are available. However, as in design learning, when individuals are not provided a sufficient amount of prior knowledge, learning proceeds in a different way (Sun 2002). In learning settings such as design studios, it is not possible to provide input/output mappings. Architectural practice and education share the same problem of the absence of "well-defined input" which is a direct outcome of the nature of design problems.

In the absence of well-defined inputs, designers define their 'design inputs". As Schön (1992) states such processes include the construction of "design worlds". Goldschmidt (2019) states that the notion of Schön's design world is similar to the notion of design space. According to her, the notion of design space was coined in artificial intelligence in the 1990s, typically denoting the "the space of possible designs for behaving systems" (Goldschmidt 2019). Newell and Simon (1972) described the notion of a problem space and a solution space already in the 1970s in reference to their general theory of problem solving. The problem space includes a set of knowledge states, i.e., initial, intermediary, and goal states, and operators by which states are changed and chained to each other. In architectural design, the concept of problem space received a wider interpretation and was closely related to the search aspect of the space. Later, it was suggested that the problem space and the solution space co-evolve and could be conceptualized as a single space (Maher & Tang 2003). This combined space is thought of as the design space. Goldschmidt (2019) explains design worlds as incorporating three types of knowledge: cognitive (operational) knowledge, general knowledge, and disciplinary (professional) knowledge.

This research focuses particularly on the reasoning forms used in designing with the three types of knowledge described by Goldschmidt (2001). Goldschmidt (2001) suggests that dual process accounts of reasoning can be useful to enhance our knowledge on design reasoning and learning. Moreover, many theories of learning and thinking have highlighted the distinction between implicit and explicit knowledge and their relation to rule-based reasoning and associative reasoning (Anderson 1983, 1985, 1993; Damásio 1994; Keil 1992; Sun 1994; Sun 1995, 1997). The cognitive characteristics of thinking show features of both associative (implicit) and rule-based (explicit) forms of reasoning (Evans & Over 1996; Sloman 1996; Stanovich & West 2000). Both forms of reasoning are important equally in problem solving and learning.

Schön's (1988) description of designers as, in Nelson Goodman's phrase (1978), worldmakers can provide a starting point in drawing a relationship between the notion of worldmaking and the two forms of reasoning. Schön (1988) investigated how designers use *rules, types,* and *worlds* in a set of experiments representing complex design processes and found that designers actively use rules and types to construct their own design world appropriate for a given design task. From a cognitive standpoint, I suggest that designerly ways of knowing can be described through notions of associations, rules and design spaces which are actively constructed by the designer's own efforts. According to Goodman (1978), worldmaking begins from worlds already at hand, he describes making as a remaking:

> Discovering laws involves drafting them. Recognizing patterns is very much a matter of inventing and imposing them. Comprehension and creation go on together. Knowing is possible through remaking as well as reporting. (p. 22)

In most instances, comprehension precedes production (Wood, Bruner, Ross, 1976) but in areas where learning without awareness (implicit learning) dominates the learning process as in design learning, comprehension and making go together (Goodman, 1976).

For Goodman (1978), one cannot know things that are not linked to what is discovered. In a similar manner, Kolers and Smythe (1984) suggest "all learning has as its base an ability to perceive a similarity between a past event and another present to mind" (pp.306). Rosch (1978) and Carey (1985) argue that we learn to reason about things we perceive by making associations in relation to familiar things. Designers reason in a similar way by making associations through constructing similarities that can generate sequences of moves and guide designing. Woodbury and Burrow (2006) draw attention to previous design experience and state that design precedents are 'used directly or used to infer from them analogous structures and moves that can be applied to other designs' (pp.67) (see Figure 1). Seeing and exploring links, therefore, are crucially important irrespective of what the past object, event, or process represents. Furthermore, seeing connections between things that are not usually connected is a creative act (Johnson-Laird

1989). These ideas indicate how associative reasoning supports knowing, learning, and making new things by operations based on similarity and contiguity.

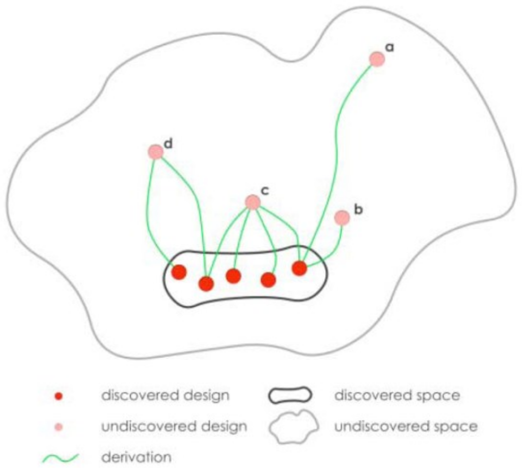


Figure 1. The dimensions of design space accessibility.
(Source: Woodbury & Burrow 2006, p. 67).

The other form of reasoning, the use of rules has had different conceptualizations in machine simulations of behavior and in some human performances. Kolers and Smythe (1984) state that "the principal notion of rule followed by most people is that expressible in a conditional (if-then) relation; however, the relation of rule to behavior is of at least as much importance to a psychological representation" (p. 307). Black (1967) has identified four ways in which that relation may be expressed. First, one may follow a rule directly, as in following a recipe (*rule-invoking behavior*). Second, one's behavior can be described by formulating a rule although he or she is not following the rule deliberately (*rule-accepting behavior*). Third, a rule can be used to describe the behavior even though its effect on the behavior is not immediate or explicit (*rule-covered behavior*; Polanyi's, 1958, description of bicycle riding is an example). Fourth, a rule can be used, sometimes expressed in jargon, as a clue, tip, or guide to action "to aid the exercise of high skill" (Howard 1980, p. 511) (*rule-guided behavior*). Black (1967) does not conclude this set of four as an exhaustive list. The use of rules in the way it is conceptualized in this thesis is to how Stiny (1980) introduces rules in design activities which can be similarly categorized as a rule-guided behavior where rules are employed as guide to action and particular of interest (Gürsoy & Özkar 2015a, 2015b; Knight 1999a, 1999b; Özkar 2011; Stiny 2006).

Evans (2008) draws attention on the ambiguity of the relationship between two forms of reasoning in dual-process theories of thinking. On the relationship between two forms of reasoning in design, they can be interactive and complementary. Schön (1988) states that rules employed while designing are derived from precedents. So, rule descriptions used while designing can be constructs that are derived from existing design worlds.

In the light of Schön's (1988) thoughts, there are two types of interactions between forms of reasoning and design spaces. On the one hand, the elements of a design space may be assembled to produce an artifact. Then this can be a starting point for further associations and design moves. On the other hand, rule(s) can be constructed from existing designed object(s) where its parts and relations inherent among them are broken apart by a designer. S/he may explore the limits and potentials for generating new forms in a design space made up of these parts and relations.

In current design literature, shifts between associative and rule-based form of reasoning are stated as necessary and are needed for success in design (Dym et al. 2005; Goldschmidt 2016; Liu et al. 2003; Tversky & Chou 2011; Vidal 2010). There is good evidence that design reasoning in architecture shows features of both associative and rule-based forms of reasoning (Goldschmidt 2016; Kalay 2004) and studies on their use in design education shows how each supports learning and creativity (Anderson et al. 2011; Casakin & Goldschmidt 1999; Goldschmidt 2001; Ozkan & Dogan 2013; Özkar 2011). Viewing design reasoning as composed of two forms of reasoning is productive; it helps to identify how designers make inferences in at least two ways. The dual process view of reasoning and its implications in design learning, therefore, deserve a close attention in supporting students explicitly and systematically to familiarize themselves with these reasoning strategies central to skilled designing early in their education.

1.2. Aim and Scope of the Study

Oxman (2001) explains the tradition and change in design education through an identification of two major paradigms. The first paradigm relates to the atelier system and project-based learning, while the second paradigm relates to an orientation to design education as learning through the exploration of general design principles and its applications through learning by doing in the design process itself. Oxman asserts that the third paradigm is ‘the education of designerly thought processes in design reasoning and design strategies’ (p. 273). This includes how designers think in employing forms of reasoning. Any design studio that aspires to teach design thinking needs to face the challenge of defining design thinking, not necessarily in any ultimate and comprehensive sense but at least in some practical, operational sense to get students reflect, in the sense it is defined by Schön, on their design actions, thoughts, and process.

The subject of design education should also include the acquisition of cognitive characteristics of design thinking. To be able to achieve this, one of the pedagogical aims in design education should cover forms of reasoning as cognitive content of design thinking (Oxman 2004). To find ways of integrating two forms of reasoning in beginning years of architectural education, this study investigates how two forms of reasoning affect students’ creative performance with an experimental set-up consisting of three different experiments. In addition, the thesis proposes that a design process in which associative form of reasoning and rule-based form of reasoning can be used in conjunction while undertaking a design problem could prove to be more effective and that the beginning year design students need to be familiarized early on with these two forms of reasoning. The set-up of the study provides an opportunity for comparison among the beginning year students of architecture. With this comparison, the research aims to make inferences regarding the effect of two reasoning strategies on students’ creative performance and design studio pedagogy based on the outputs and externalizations of individual design processes.

1.3. Research Questions

Within the scope of the study, the following research questions are developed:

Q1: What is the effect of associative and rule-based forms of reasoning on creative performance when first year students are directed to adopt either one them while designing?

Q2: How does a particular sequence of reasoning strategies affect students’ creative performance when they are directed to exercise two different forms of reasoning in a particular order?

Q3: What is the effect of introducing forms of reasoning in a series of instructions on students' creative performance before students are asked to exercise a particular form of reasoning?

1.4. Contributions of this Research

This study can make three potential contributions. Its main contribution is specific to design studio pedagogy in that it emphasizes the inclusion of multiple forms of reasoning in conjunction in design studio education. This research specifically investigates how forms of reasoning strategies affect creative performance comparatively and how they can be a part of educational content through three different experimental setups.

1.4.1. Implications for Design Studio Pedagogy

Previous research on the use of analogy and its effect on creativity and learning investigated the distance of source analogies, the timing of their introduction to the process and comparisons between novices and experts (Casakin 2004, 2005, 2010; Casakin & Goldschmidt 1999; Choi & Kim 2017; Ozkan & Dogan 2013; Tzonis 1992; Ward 1998). Researchers, adopting of dual process theory of cognition in design studies (Cash & Maier 2021; Daalhuizen 2014; Gonçalves & Cash 2021), conducted a number of studies on elaborating our understanding of a designer's thinking processes and how it changes his/her patterns or mental models. This provided a framework to compare different forms of reasoning and their effect on creativity and learning. The study by Daalhuizen et al. (2014) presents a similar comparison between two different categories of design methods as they refer to them as heuristic and systematic method among graduate students with a large sample. Following these studies, this dissertation argues that learning about these two forms of design strategies can be provided in undergraduate design education as early as in the first year within basic design instruction.

The results may point out a significantly successful sequence of design tasks for ideation which can be utilized as a cognitive scaffolding for learning distinct forms of reasoning strategies which may help students to focus on specific tasks that require specific thinking processes without isolating them. Keeping the design problem the same may provide a process of comparison that can act as a bridge between associative and rule based processes (Gentner & Medina 1998).

1.4.2. Implications for Design Theory

The second contribution of this research is to dualist conceptualizations of design and design methodology. The conceptualization of design with a dual mode model has been proposed by many authors due to the diagnosis of dichotomous categories of notions in design. Dorst (1997) proposes a dual-mode model of design and design methodologies by comparing design as rational problem solving and design as reflective practice. More recently, Daalhuizen (2014) and Daalhuizen et al. (2014) refers to this dichotomy as heuristic and systematic methods. This dissertation particularly focuses on dual process accounts on reasoning, creativity, and learning and highlights the necessity of interaction between types of thinking processes, divergent and convergent thinking, explicit and implicit form of learning. Results of the study may help us understand better the complementary nature of these forms of reasoning in design and that relying singularly on one thinking process usually may lead to "costs" such as low creative performance for novices who has no experience in employing a particular reasoning strategy used in design.

This dissertation also follows the proposition that design problem solving could be considered under the general umbrella of problem solving and focus on the reasoning processes that are introduced by Zimring and Craig (2001). This has the potential to provide a more inclusive understanding of design. Dual process theory of cognition can provide a structure to improve our understanding of specific concepts of divergence and convergence, association and fixation, reflection and intuition and the relation between them.

1.4.3. The Effect of Explicit Instruction on Students' Creative Performance

The third contribution of this research is on how explicit instruction affects creative performance. Two experiments explore this issue using the same design problem. While one focuses solely on an instruction to use a particular design strategy, the second explores how providing a detailed exposition of the particular forms of reasoning strategies before practice with the task. The research on memory, cognition and especially explicit and implicit learning provides an extensive literature on the interaction between explicit and implicit processes. Design learning heavily relies on implicit form of learning and many authors point out the negative effect of explicit procedural knowledge on processes or any visual material (Atman & Bursic 1996; Eastman 2001; Newstetter 1998; Oxman 2003). Going beyond these reservations for explicit instructions in design learning, the dissertation provides a starting point in developing specific content that can be transferred with a lecture in increasing performance of using associative reasoning strategies in design with explicit instruction.

CHAPTER 2

REASONING AND CREATIVE THINKING IN DESIGN: DUAL PROCESS ACCOUNTS ON REASONING, CREATIVITY AND LEARNING

This chapter will review the literature on dual process accounts of reasoning, creativity, and learning. While reviewing the literature, it will set the theoretical background of this thesis while also introducing the thesis hypotheses, grounded in the literature review, that will be tested in the following experiments.

There has been a growing number of studies focusing on the cognitive properties of design for the development of design education (Casakin 2005; Eastman et al. 2001) or models from cognitive psychology adapted for learning to design (Curry 2014). Oxman (2004) points out Schön's (1985) seminal work for emphasizing the importance of design thinking and the role of cognitive studies and empirical research in studying design pedagogy.

One of the ongoing problems in design education is the difficulty to define what the essential knowledge for designing is. Students do not become better designers and do not acquire more design skills by knowing more about designs. The competence in design praxis seems not to be about the quantity of knowledge gained, but about knowing where to find a specific kind of knowledge and how to use it in a particular situation. So, it is rather the development of thinking skills that is critical in design education especially in beginning years. Conceptualization of design should not direct students to design by way of a mysterious innate skill but a skill that can be constructed and developed where each individual can explore and share his/her approaches and methods gradually and incrementally in time. In this regard, design studio education must formulate design as a conveyable knowledge which includes "procedural knowledge about how to design and how to reason about designing" (Goldschmidt 2001, p. 200).

Oxman (2001) describes two ways to incorporate cognitive aspects in design education. The first is adapting subject areas from cognitive studies to design subjects. The second approach is described as identifying the different mental functions of the mind and to exploit their relevant theoretical sources and models in design applications.

This dissertation follows the second approach and adopts the dual process theories of mind and proposes that viewing design reasoning from a dual-process perspective can help enhancing strategies for design reasoning and design learning (Goldschmidt 2001). Design reasoning in architecture shows features of both associative and rule-based forms of reasoning and related studies shows how each supports learning and creativity. Firstly, this chapter describes the relationship between creative thinking and reasoning. Then, it presents dual process accounts of reasoning, creative thinking and learning in relation to design and design education.

2.1. Creative Thinking and Reasoning

Creative thinking has been defined in several ways in the literature (Amabile 1983; Boden 1990; Csikszentmihalyi 1996; Gardner 1982; Guilford 1956; Guilford 1967; Koestler 1964). The creative process has been the focus in many definitions of creativity. Amabile (1983) points out John Watson's definition of the creative process as one of the most remarkable one:

> How the new comes into being: One natural question often raised is: How do we ever get new verbal creations such as a poem or a brilliant essay? The answer is that we get them by manipulating words, shifting them about until a new pattern is hit upon. (Watson, 1928, p. 198)

Koestler (1964) criticizing this behavioristic view of creativity, suggested that creativity involves a "bisociative process" through which two previously unrelated "matrices of thought" are connected to produce a new insight deliberately, but not through random associations. According to him, the process includes "the displacement of attention to something not previously noted, which was irrelevant in the old and is relevant in the new context; the discovery of hidden analogies as a result" (1964, pp. 119-120).

There have been more recent definitions of creative thinking that focuses on the creative process. For example, Kay defined it as "a process whereby the individual finds, defines, or discovers an idea or problem not predetermined by the situation or task" (Kay 1994, p. 117). Nickerson (1999) suggested that "creative thinking is expansive, innovative, inventive, unconstrained thinking. It is associated with exploration and idea generation. It is daring, uninhibited, fanciful, imaginative, free-spirited, unpredictable, revolutionary” (p. 397). Creative thinking involves a process of discovering something novel and useful (Sternberg & O'Hara 1999). Ansburg and Hill (2003) emphasize that creativity involves connecting two previously unrelated ideas.

In discussing the relationship between creative thinking and reasoning, Fasko Jr (2006) points out the lack of research addressing the relationship between them. However, they provide a starting point to describe the relationship between them. A while ago Hitt (1965) suggested that “original thinking” and “logical reasoning” were complementary aspects of creative thinking. He stated that original thinking is “intuitive, imaginative, and involves making guesses [and that] logical reasoning is analytical, systematic, and critical” (p. 127). Other researchers also have made connections between creativity and reasoning. Cattell (1971) proposed a list of over 20 primary abilities which includes abilities such as inductive and deductive reasoning, ideational fluency, originality, and judgment. Sternberg and O'Hara (1999) also reported that the abilities of originality and ideational fluency were associated with creative thinking.

Newell et al. (1962) suggested that "creative activity appears simply to be a special class of problem-solving activity characterized by novelty, unconventionality, persistence, and difficulty in problem formulation" (p. 66). In creative problem solving a solution to a problem may be unique or there may be several possible solutions (Halpern 2003; Loewen 1995). Mumford et al. (2003) suggested that creative thinking is a demonstration of a type of multifaceted problem solving.

Creative problem solving differs from traditional problem solving. Loewen (1995) describes traditional problem solving as a process whereby an individual resolves a problem from a set of conditions. Halpern (2003) states that “a problem exists when there is a ‘gap’ or obstacle between the current state (where the problem solver is) and the goal (where the problem solver wants to be)” (p. 200). Then, as Halpern (2003) noted, discovering how to move from the “current state” to the “goal” becomes the main problem. In traditional problem solving, the solution for a traditional problem that has been encountered previously may have an immediate relevance for the current problem. Compared to traditional problem solving, in creative problem solving a solution to a problem may be unique or there may be several possible solutions (Halpern 2003; Loewen 1995).

Design studies literature offers various views for such problem-solving processes. One of the first models of design from design studies is the conceptualization of design as ill-defined (Eastman 1969; Goel 1992; Simon 1973). Simon (1973) defines design as a problem-solving activity where the actual 'state' is structured through 'analysis' and solved with a proposition of a preferred one by 'synthesis'. Hillier, Musgrove, and O'Sullivan (1972) argued that design is "essentially a matter of prestructuring problems either by the knowledge of solution types or by the knowledge of the latencies of the instrumental set [technological means] in relation to solution type" (p. 7). They argued that conjecturing approximate solutions much earlier in the process compared to the analysis/synthesis model of design allows to structure an "understanding of the problem, and to test out its resistances" (p. 9). The problem-solving activity in design was described as a more solution oriented one where the problem solver makes guesses through "analytical and evaluative" processes to solve a problem.

Lawson's (1979) comparative studies of problem-solving strategies of designers and scientists showed that the two groups used different strategies. Lawson (2006) stated that scientists adopted a problem-focused strategy and the architects a solution-focused strategy. The architects had the tendency to propose a series of solutions, to eliminate them until they found an acceptable one. He also commented that architects learn about the nature of the problem by making conjectures and trying them out. Jones (1970) has pointed out the difficulty of this 'designerly' way of approaching to ill-defined problems and stated that "changing the problem in order to find a solution is the most challenging and difficult part of designing"(p. 12).

Zimring and Craig (2001) suggest that there are empirical studies which indicate that scientists shows similarity to what Lawson (1979) observes designers doing. They indicate a further exemplar study by Nersessian (1999) as an instance for scientists constructing provisional models to be used in developing more abstract theories. While Cross (2007) highlights the particular ways of knowing and thinking in design, in contrast, Zimring and Craig (2001) suggest that the models of design mentioned above do not provide complete and distinct notions of design. They propose 'to treat design problem solving as problem solving in general and focus individually on the reasoning processes that are involved' (p. 142).

In the broad sense, reasoning refers to the total process of figuring things out within a basic structure, and when one has not yet learned a given structure s/he creates it (Paul 1993). As such absence of structures is common for design problems, reasoning processes in design problem solving requires such creation of structures. Paul (1993) states that whenever we are reasoning something through, we are engaged in creative thinking. As an alternative approach, the next section provides a view treating design reasoning as reasoning in general and focuses on the reasoning processes that are involved in the generation of new artifacts.

2.2. On how designers reason

Cross (2007) points out that there are 'designerly' ways of knowing, ways of thinking and reasoning for ill-defined problems which designers tackle with. The emphasis in these propositions is on the constructive and creative nature of designing. Design solutions must be actively constructed by designers' own efforts.

Fischer (2001) states that 'knowing is conceived of as an inferential and active process on the part of the knowing subject' (p. 362). Focusing on operational aspects of knowing as inferring - whether these inferences are logically false or not – he suggests that procedures of inferences enlarge our knowledge of the world. Worlds are made by means of abductive procedures (Fischer 2001). Thus, according to him, abduction is the most important form of cognitive and interpretative process. He adds that all processes operating on symbols are inferential processes and they can be understood as processes of interpretation. Fischer (2001) states that, to the constructivist mind, interpreting is a constructive act, and a construction is knowledge. Goodman (1978) asserts that one constructs his/her knowledge by means of making, remaking, and reporting through use of symbols and symbol systems as in designing. Thus, in our case design thinking can be considered as inferential processes that make use of symbols and symbol systems (Goel & Pirolli 1992) and assign meanings that are not explicitly there (Goldschmidt 1991). Designers construct their design worlds - i.e. design problem spaces - through interlocking processes of perception, cognition and notation (Schön 1988). In order to solve a design problem, the designer formulates the problem by 'framing the situation: set its boundaries, select particular things and relations for attention, and impose on the situation a coherence that guides subsequent moves' (Schön 1988, p. 182).

March (1976) terms design reasoning as abductive considering it does not follow inductive or deductive procedures. Abduction, as it was theorized by Charles Pierce at the end of the 19th century, has been used to understand hypothesis generation in science. March (1976) was inspired by Pierce's ideas on abduction but he was particularly interested in (innovative abduction) 'productive' reasoning (Roozenburg 1993). Roozenburg (1993) asserts that much of the reasoning in design belongs to this category of reasoning, especially "the reasoning that generates or produces tentative descriptions for solutions to design problems" (p. 4). Recently, Dorst (2011) studied the core of design thinking for idea generation, and defined design-derived reasoning patterns, emphasizing abduction as the fundamental reasoning pattern for creative thinking. He states that experienced designers have deliberate and efficient strategies to deal with design problems and these strategies involve "the development or adoption of a frame" (Dorst 2011, p. 524). He also points out that the ways designers create 'frames' and deal with these frames are what make reasoning patterns in design similar to logical pattern of abduction process. Framing can be slow or fast depending on the complexity of the design problem caused by conflicting elements of the problem (Dorst 2011). However, framing activity involves induction and deduction too (Dorst 2011).

Zimring and Craig (2001) state that abduction is not enough on its own to explain the nature of design processes while it is also clear that induction and deduction play a significant role in design. Design involves many processes and it involves much more complex processes to be explained by a singular type of reasoning. As Zimring and Craig (2001) suggest, in reference to Thagard and Shelley's (1997), our conceptualization of design reasoning should be "expanded to incorporate more complex and connected processes like productivity, analogy and visual reasoning" (p. 134).

From this point of view, it is possible to focus on types of reasoning that contribute to the generation of new artifacts (Zimring & Craig 2001). Dual-process accounts of reasoning can help describe the types of reasoning that contributes to the generation of new artifacts. As reasoning can be defined as going beyond the information given (Bruner 1973), Tversky (2005) suggests that there are two ways in going beyond the information: "one is to transform information according to rules" and "the other is to make inferences or judgments from the information" (p. 210).

The following sections will assert that both forms of reasoning are productive and creative while laying out the differences in processes and strategies used in design and how they are important to design learning.

2.2.1. Associative reasoning in design and in design learning

The most studied form of associative form of reasoning is the use of visual analogies in design. An example from architectural design is Le Corbusier's Unite d'Habitation. Le Corbusier conceives the building's spatial concept and many other features by making associations from a multitude of sources: the savage hut, the ocean liner, the winebottlerack, the Greek temple and more (Tzonis 1992). In Figure 2, Le Corbusier explains through sketches the analogical process. The sketches show a selection of examples that comply with the associative form of reasoning. The examples represent three different associations made in solving different design problems in the process. In the process, one solution to one design problem also guides the solution of another one and leads to a chain of interrelated moves.

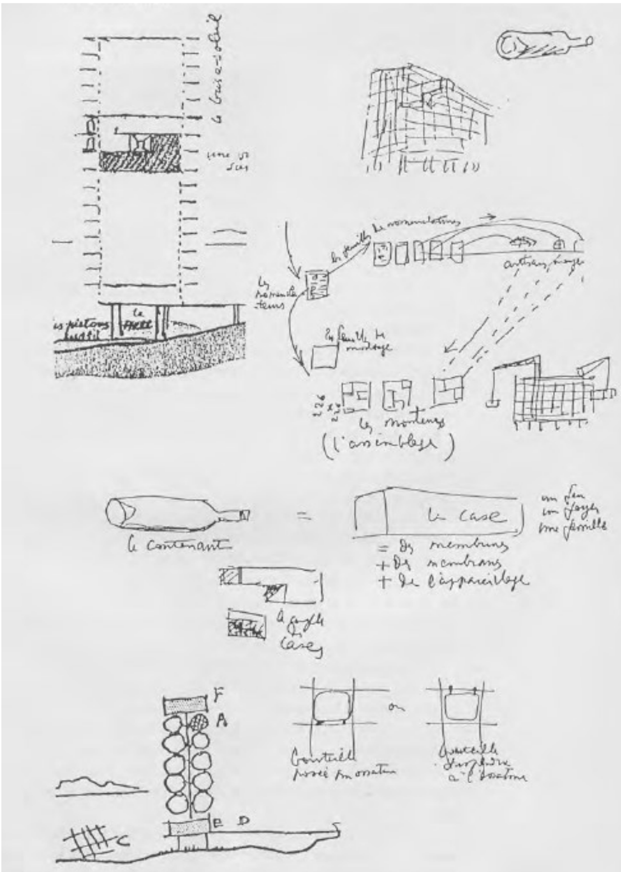


Figure 2. The liner, the winebottlerack.
(Source: Tzonis 1992, p. 145)

The first pair shows how a system composed of a wine bottle and a bottlerack is perceived and abstracted as a system of container and contained. This abstraction is based on an analogical association between the building and the individual apartments in the building and a wine bottlerack. The analogy supports a design solution which consists of an assembly of units and particularly suggests inferences about the relationship between each living unit and the structural frame, which in turn resulted as the fitted solution for the design criteria of the structural independence and flexibility. The selection of ship as a source of analogy fulfills two ideas simultaneously. First, the idea of a deck that provides a commanding view of the surroundings, which is another instantiation of the roof garden idea from his five points. Secondly, the selection of the ship as a source enables the designer to place the living units under the deck allowing a direct mapping of spatial organization of a ship to a building as represented in the section drawing of a ship. The selection of “ship” also seems to trigger the conception of a living unit from a container to a box which also controls the aesthetic and composition qualities. It can be said that this may have also triggered the possibility of the adaptation of the ideas of structural independence and flexibility.

Analogical reasoning is described as central for many cognitive processes (Hofstadter 2001). Many studies have shown its use in problem solving (Gick & Holyoak, 1980, 1983; Novick, 1988; Ross & Kilbane, 1997), in scientific discovery (Dunbar & Blanchette, 2001; Gentner et al., 1997; Nersessian, 2008), in learning (Brown, 1989; Vosniadou, 1989), and creativity (Johnson-Laird, 1989; Ward, 1998).

Analogical reasoning in design and its role in design learning is studied from various perspectives. Many of the studies are focused on the differences between experts and novices. Ball et al. (2004) show that both novice and expert designers use analogies spontaneously. Some researchers have investigated if the differences between novices and experts are rooted in their knowledge structures (Casakin 2004, 2010; Casakin & Goldschmidt 1999; Ozkan & Dogan 2013). Other researchers have focused on the relation between analogical distance and analogical purpose (Ball & Christensen 2009; Kalogerakis et al. 2010). Facilitating the use of analogy (Dahl & Moreau 2002) and the role of timing in its facilitation during design (Tseng et al. 2008) are also shown to have effect on design process. However, there are inconsistent findings among the studies investigating the timing effect. The study by Sio et al. (2015) points out that providing sources for analogy at the beginning of design process has a positive impact on design solutions compared to providing them during the design process. On the contrary to this, Moss et al. (2007, 2011) report that providing cues is more effective after a familiarization with the design problem. Tseng et al. (2008) suggest that near domain exemplars are more beneficial when they are presented at the beginning of the design task. Cardoso and Badke-Schaub (2011) investigated how different types of pictorial representations of sources have an impact on the occurrence of design fixation. Zahner et al. (2010) and (Goldschmidt 2011) demonstrated how re-representing, transforming and abstraction can avoid design fixation.

Ozkan and Dogan (2013) investigated differences in analogical reasoning among first-, second-, and fourth-year students and expert architects. One of the major findings of the study in relation to this discussion, is that the lack of domain and procedural knowledge which is associated with expertise causes the difference during the design solution process. The use of domain knowledge and procedural knowledge to construct abstractions enables experts to see deeper similarities between source and target.

Casakin (2010) asserts that the reason why experts use more within domain analogies relates to their knowledge of previous design problems that experienced designers have over novices and to their ability of retrieving larger chunks of knowledge from memory. Casakin (2004) states that experts are successfully able to select and work with relevant aspects while novices fail to identify relevant features to solve problems because experts have more developed and integrated knowledge structures compared to novices. Analogical reasoning supports creative thinking by the help of existence of a knowledge base. The failure for novices in using analogies and for not benefiting from full creative advantages of analogies can be caused by the lack of such a knowledge base which also prompts novice to rely on intuition and to prefer intuitive approaches to design problem solving.

Expertise is developed by experience and knowledge in a specific field (Finke et al. 1992). According to Casakin and Goldschmidt (1999), in every domain, the development of a knowledge base specific to that domain and the practice of methods require training. Novices are usually aware of analogies' utility in the process of solving design problems (Ozkan & Dogan 2013) however, since they are not experienced in analysis and abstraction, they need repeated experimentation for developing them. Casakin (2004) points out that training novice students in the use of within-domain, and between-domain visual sources can significantly contribute students' ability to utilize analogies in specific design tasks in the architectural design studio.

Another associative form of reasoning is case-based reasoning (CBR). Leake (1999) points out that when compared to rule-based models of reasoning, CBR has various functional advantages. Firstly, he states that it is helpful while generating effective solutions in situations where causal structure is not completely understood since rule-based models' assumption of conclusions are drawn from generalized rules. For rule-based models, the act of learning is composed of activities of deriving and storing new generalized rules for future use. Secondly, using cases could augment generalized knowledge. In addition, although, rule based models can offer a solution, using a proven successful case may also lead to more efficient processing (Leake 1999). Leake (1999) also points out that CBR can be used in creative problem solving because cases stored hold enough detail to be used for novel purposes. Thus, the processing of making combinations for different solutions with the same case provides opportunities for learning. This describes the mechanisms of processes described in combinational creativity.

The CBR processes have been studied for modelling creativity for design tasks. Wills and Kolodner suggests that creativity is composed by strategic control of processes like problem redescription, remembering, assimilation and evaluation and the interaction between these occur in complex ways. Previous design experiences and knowledge of designed artifacts fosters these processes (Goel et al. 1992; Kolodner & Wills 1993; Wills & Kolodner 1994). Flexible retrieval processes are the key mechanisms to generate novel solutions that result in finding novel starting points for solving design problems by constructing novel correspondences through mapping and through flexible case adaptations (Leake 1994).

Especially in the use of case-based reasoning in architectural design, the processes of adapting and modifying an existing solution is crucially important since one design problem can contain and provide many solutions (Schmitt 1993). The role of knowledge and the way learning is defined by Leake (1999) below is in parallel with 'designerly ways of knowing' Cross (2007) describes in terms of how designers know about the artificial world and utilize this type of knowledge.

> Case-based reasoning emphasizes the role of concrete, operational knowledge. Rather than focusing on how basic knowledge can be composed to generate new solutions, case-based reasoning focuses on how large structures - cases - can be modified to fit new situations and views the learning of new cases as an integral part of the reasoning process. (Leake 1999, p. 475)

Using prior knowledge has been recognized as a significant strategy in the creative process of design. Oxman (1994) proposes a computational model for the organization of precedent knowledge in design process and education. Anderson et al. (2011) shows the benefits of employing case-based reasoning as a reasoning strategy to be taught to architecture students in their first year.

One of the challenges of design education is to teach designers such strategies to be better at design problem-solving and to teach prior knowledge to solve design problems (Casakin & Goldschmidt 1999). While the use of analogies is an instrumental strategy for design problem solving, and heavily used in design reviews (Dogan et al. 2018), and a powerful device for the introduction of creative aspects in design (Visser 1996), analogical thinking is also a seminal learning strategy (Brown, 1989; Vosniadou, 1989) and enhances design learning. Design instructors often advise their students to enrich their visual vocabulary through studying masters' projects. Analogical reasoning plays a double role in design learning, supporting creativity and learning simultaneously (Ozkan & Dogan 2013).

2.2.2. Rule-based reasoning in design and in design learning

Rule-based systems are productive due to their ability to encode an unlimited number of propositions (Chomsky, 1968). Productivity as a principle underlying reasoning is mentioned by James (1890/1950) and reasserted by Fodor and Pylyshyn (1988). Sloman (1996) explains that rules can be composed with each other to generate a larger set of propositions and states that 'rules are systematic, in the sense that their ability to encode certain facts implies an ability to encode others' (pp. 5). He states that rule-based reasoning is the form of reasoning where rules are the form of representation that exhibit these properties of productivity and systematicity. According to him, these two properties underlying rule-based reasoning sets up its distinction from associative reasoning.

The discussion about rules will be limited to design rules that can be categorized as in Black's (1967) terms as rule as guide to action. Özkar (2015) describes design rules as "directives that guide the design process towards the product" (p. 693). She adds that they can be numeric, verbal, and most often visual or spatial.

An example from architectural design is Guillermo Jullian De La Fuente's Three French Embassies. Fracalossi (2018) describes a rule-based methodology based on the series of drawings elaborated between 1971 and 1973 which are organized under the title of Yellow Peripherical Distinction (YPD). In this series of drawings, De La Fuente explained his approach to the design process of his projects systematically. Allard (2006) asserts that this series of drawings used in a presentation to Team 10 is an effort "to systematize the concerns around the grid as a mechanism for spatial composition and organization" (p. 164). Allard (2006) explains that "the acronym YPD describes the geometric space of a variable width strip located along the edges of a grid, pre-established to organize any project" (p. 164). This rule-based exploration proposes a method for architectural design. It starts off from three basic components: Spatial Grid (SG) defining and measuring the territory in functional and programmatic terms, Basic Square Cube Unit (BSCU) that defines an area in spatial terms, Connecting Zones (CZ), characterized by circulations and movement.

Basic Square Cube Unit (BSCU) is at the core of the YPD method whose side measures 2.96 metres, the sum of two values of Le Corbusier's Modulor, i.e., 2.26 and 0.70. The thick yellow strip is generated from BSCU by enlarging each side of the BSCU by a 1.40 metre. As in Le Corbusier's Modulor, De la Fuente used the golden ratio $\Phi \approx 1.6180$ to generate the values of the YPD method. This creates multiple even subdivisions (see Figure 3).

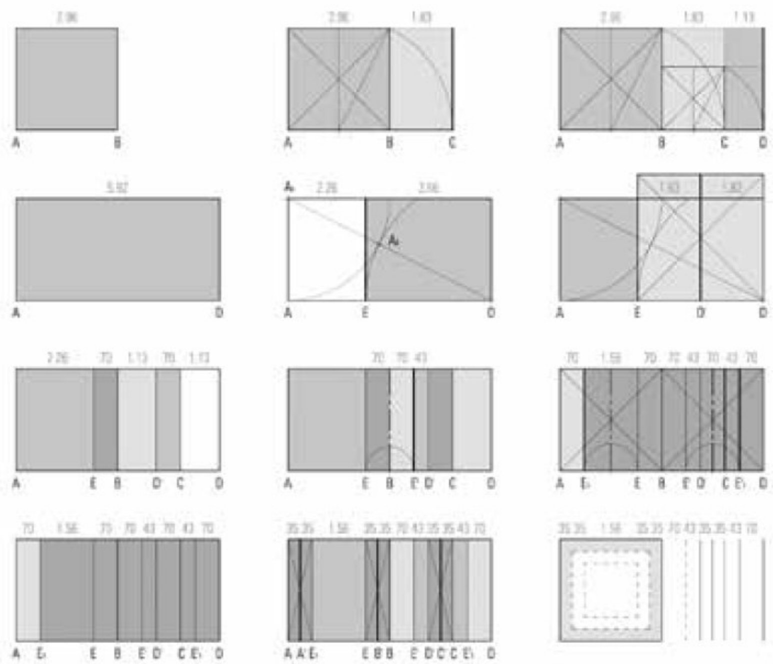


Figure 3. Series of transformations based on the golden ratio from the BSCU to the YPD ruler.

(Source: Fracalossi 2018, p. 228)

Through a series of divisions and additions, a YPD ruler is generated with the key values 43, 70, and 1.56. Then this ruler is used to create the matrix where each value is assigned a color: blue for 43, yellow for 70, and for 1.56 two different colors, predetermining already in this stage of two different hypothetical functions: orange and green. The blue, orange, and green strips are always separated with the yellow strip in between them. The yellow strip which is also the YPD itself, represents an idea of a space which connects the two spaces that is part of two zones at the same time (Allard 2006). Each project is the result of a transformation of a matrix built according to a YPD ruler of colors and values specific to the project.

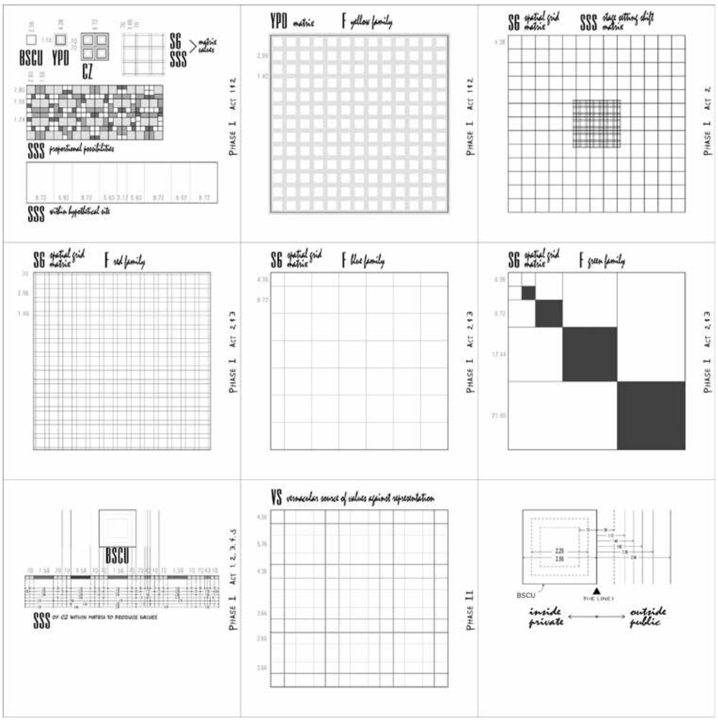


Figure 4. The first eight of twelve sheets of the YPD and of a scheme of the main measures of it.
(Source: Fracalossi 2018, p. 227).

Fracalossi (2018) applies a graphic analytical method to understand the conception of the building and then to clearly show the stages of the composition and its latent possibilities. Based on his analysis, he points out few salient features of De La Fuente rule-based approach to architectural design. First, the YPD method is not a rigid system but rather a rule (Fracalossi 2018) that enables the architect benefit from visual ambiguities. Each element that are connected with YPD presents an interpretation of elements in different planes that guides the formation of plans, structural elements or façades of the building. Thus, YPD is utilized as a generative system of lines that gave birth to a matrix in each project specific to a building which allows the architect an exploration of both spatial and visual ideas. Second, besides the allowance of utilizing visual opportunities, such approach also enables the architect to generate and apply a spatial idea in various ways. The idea of 'courtyard' in three buildings is a primary element of these three embassies. Fracalossi (2018) asserts that it is an emergent spatial component that is resulted from the manipulation of forms which represents masses and empty spaces.

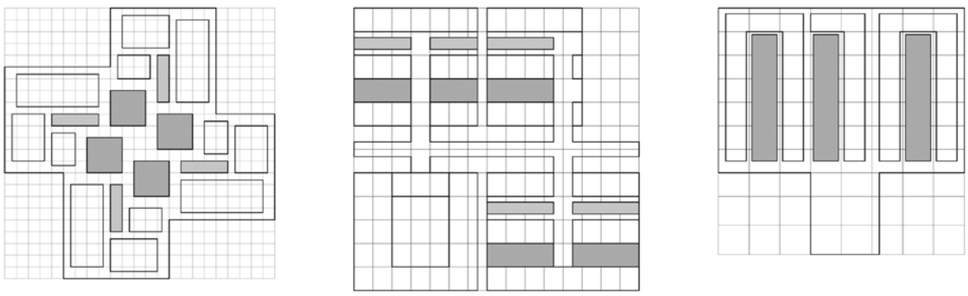


Figure 5. One courtyard
(Source: Fracalossi, 2018, pp. 238.)

Many scholars' works on the integration of shape grammar formalisms in design education has resulted in a series of studies about design rules in design learning. Shape grammars' formalism has been effective for enabling students to recognize the productive aspects of rule-based systems (Ozkar 2010). It also enables students to explore making process explicit in a systematic way.

Flemming (1989) suggests the use formalisms to teach compositional skills with computer assistance. He asserts that "compositional skills are an important part of an architect's expertise and deserve to be taught explicitly" (pp. 31). Flemming (1989) observed that architects produce sketches in a sequential manner especially when they use transparent paper to trace certain features to carry on with new emerging ideas and redraw only those in which they see new possibilities. He conceptualizes this process as “a sequence of operations performed on a symbolic representation of the object being designed” (pp.32) as a form of computation. This view of design as computation has been the foundational perspective that paved the way for many following studies to support design learning.

Knight (2000) advocates for the use of visual rules to express architecture students’ design processes. She (1999) mentions “two exercises in formal composition” by Stiny (1976) as the foundation for many applications of shape grammar in education. The first exercise depicts a way to use shape grammars for original composition. The second exercise showed how shape grammars can be used to analyze existing designs. Knight (1999) conceives these two exercises as complementary to each other as they relate to synthesis and analysis respectively. Knight sums Stiny’s (1980) seven points into two important ones for design education stating that “rules make explicit or externalize a student’s design ideas so that they can be examined, changed, communicated more readily” (p.3). Second, “rules make possible multiple design solutions rather than a single solution” (p.3) which creates the possibility of choosing between different ones. This enables students to exercise the process of evaluating and selecting among different design solutions.

Architects think constructively. Both design and design learning are constructive processes. The notion of design as computation captures this constructive dimension (Flemming, 1989) and enables a student to recognize and acquire the constructive process in design and design learning in an incremental manner.

Most of the prominent studies on design points out the visual aspects of the constructive process of design and describe design as a way of visual thinking. The pattern of seeing, acting on it, and then seeing something else during designing has been at the core of shape grammar formulation since the seminal paper by Stiny and Gips (1971). This pattern is also asserted by Schön and Wiggins (1992) as ‘see-move-see’ model. Schön (1983) portrays the designer in a ‘reflective conversation with the situation’ (p. 76). Goldschmidt (1991) similarly proposed a similar pattern described as a dialogue in design sketching between ‘seeing as,’ corresponding to analogical reasoning, and ‘seeing that’ corresponding to reflective criticism.

The two cases presented above, i.e., Le Corbusier and De La Fuente, provide evidence for the existence of two categories of reasoning strategies that are used in design. The use of rule-based methods in architecture can be dated back to Vitruvius’s De architectura while considering the works of architects like Leon Battista Alberti, Andrea

Palladio as individual rule-based design methods (Kalay 2004). Making associations are at the foundation of the use of precedent-based methods that employ knowledge from prior designs or the use of analogies in design.

Reasoning is a creative and fundamental process in design activity whether it is in the form of an analogical reasoning strategy, which involves making associations, or in the form of a systematic and productive reasoning strategy, which involves making rules. While it is apparent that they are determinants of performance for both creative output and creative process of expert designers, how they differ in their impact on creative performance comparatively is rarely discussed in the design literature especially within novice learners. It is important to find pedagogical strategies for students to explore both of these reasoning strategies. Therefore, in the first experiment the thesis will investigate whether these reasoning strategies are helpful and to what extent they are helpful in encouraging students be creative in a simple design task. Following the dual process theory which advocates that associative reasoning, or Type 1 reasoning, is quicker and more intuitive students will benefit from having to use an associative reasoning strategy. And a series of explicit rules might make it easier for students to adopt a more deliberate, or Type 2, reasoning strategy that might alleviate some of the complexity of the creative productive design process. The hypothesis in this experiment (Hypothesis 1) is that employing a particular reasoning strategy will have an impact on the creative output and creative process of novice learner.

Dual process theory of mind can provide a basis to structure a cognition-based approach to these commonly used strategies and particularly a basis to understand how these two ways designers reason affect creativity and learning in design for novices.

2.3. Dual process theory of mind

The idea that there are two distinct kinds of reasoning, one fast and intuitive, the other slow and deliberative, has been around and widespread in philosophical and psychological writing (see Frankish & Evans 2009). Dual-process accounts commonly emphasize the idea that two different kinds of cognitive processing affect inferences and judgements. Evans (2007) states, in his earlier heuristic–analytic theory (1984, 1989), that it is possible to distinguish between “(a) heuristic processes that are pre-attentive and pragmatic and form selective representations of problems, and (b) analytic reasoning processes that are applied to such representations in order to generate inferences or judgements" (p. 5). Other dual-process notions include the idea that there are associative and rule-based processes in reasoning (Sloman 1996).

This distinction has been made by many researchers in many fields, often in ignorance of each other's writings (Evans & Frankish 2009). Even after the start of the cognitive revolution in psychology, dual-processing accounts developed more or less independently in several distinct fields of psychology. There also have been many differences in labelling these processes and in describing the relationship between the two that two forms of processing are competing or combining in order to produce the behavior observed. Evans and Stanovich (2013) call these Type 1 and Type 2 processes, corresponding roughly to the familiar distinction between intuition and reflection. Attributes commonly claimed for the two types of processing are listed in the top part of Table 1.

Table 1. Clusters of Attributes Frequently Associated with Dual-Process and Dual-System Theories of Higher Cognition.
(Source: Evans & Stanovich 2013, p. 225).

Type 1 process (intuitive)	Type 2 process (reflective)
Defining features	
Does not require working memory	*Requires working memory*
Autonomous	*Cognitive decoupling; mental simulation*
Typical correlates	
Fast	Slow
High capacity	Capacity limited
Parallel	Serial
Non-conscious	Conscious
Biased responses	Normative responses
Contextualized	Abstract
Automatic	Controlled
Associative	Rule-based
Experience-based decision making	Consequential decision making
Independent of cognitive ability	Correlated with cognitive ability

In the following sections, dual process accounts of reasoning, creative thinking, and learning is discussed based on the relevant literature in relation to design and design education.

2.3.1. Dual process accounts of reasoning

The cognitive characteristics of thinking show features of both of associative (implicit) and rule-based (explicit) forms of reasoning (Evans & Over 1996; Sloman 1996; Stanovich & West 2000). The implicit versus explicit distinction with regard to types of reasoning is often accompanied with an assertion that explicit reasoning is intellectual and logical while associative is intuitive.

The term “dual processes” was first used by Wason and Evans (1975). According to Evans (1996), Wason and Evans’ study formed one of the main roots of the modern dual process theory of reasoning. Evans’ “two-factor theory” (Evans 1982) is considered a second important root.

Evans (2004) explains that the initial heuristic-analytic theory of reasoning, as first published in Evans (1984, 1989), was formulated to explain the widespread existence of cognitive biases in reasoning tasks. Evans (2004) states that the early heuristic-analytic theory features a kind of “unconscious–conscious thinking distinction which was structured sequentially rather in parallel as implied by Wason and Evans” (p. 251). Evans (2006) summarizes that the heuristic-analytic theory proposed two kinds of cognitive processes: “*heuristic* processes, which generated selective representations of problem content, and *analytic* processes, which derived inferences or judgments from these representations” (p. 378). The theory was presented as a simple two stage sequential model (see Figure 6).

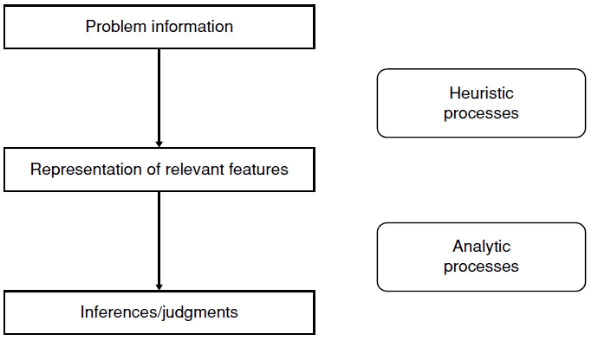


Figure 6. The original heuristic-analytic theory.
(Source: Evans 1989, p. 25)

Evans (2006) presented a revised version of the theory keeping the duality of heuristic-analytic while specifically focusing on the nature of the interaction between the two processes. His revised account on the theory exploits the theory of hypothetical thinking (see Figure 7) asserted by Evans et al. (2003) to comprehend more about "how the analytic (explicit) system works and how it interacts with the heuristic (implicit) system" (Evans 2006, p. 379).

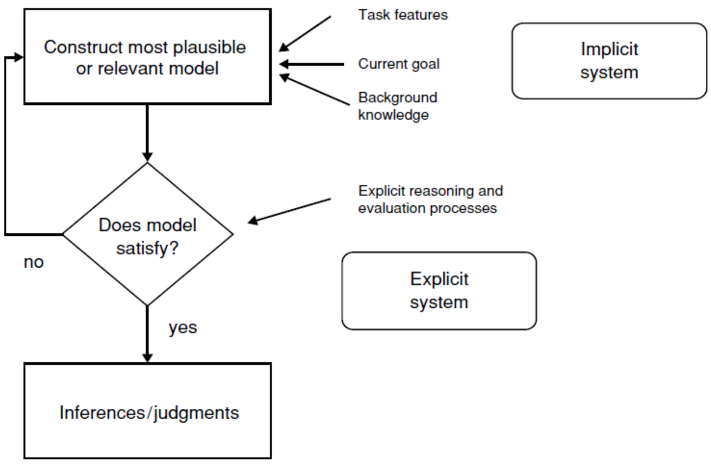


Figure 7. The hypothetical thinking model of Evans, Over, and Handley (2003).
(Source: Evans et al. 2003, p. 5)

The revised theory presents two major inferences based on the evidence presented by Evans (2006). Firstly, as shown in Figure 8, it is explicitly represented that the heuristic system may operate with or without the analytic system's intervention and the interaction between them is no longer structured sequentially. According to Evans (2006), heuristic processes "both focus our attention on selective aspects of presented information and rapidly retrieve and apply relevant prior knowledge" (p. 392). He adds that inferences can be determined mostly by heuristic processes with analytic thinking only translating the outcome of the heuristic processes into responses. In other cases, analytic system can be employed to engage in conscious strategic thinking by inhibiting responses cued by heuristic system. Secondly, it is known that analytic reasoning is slow and sequential and is responsive to verbal instructions whereas it is the opposite for heuristic processes.

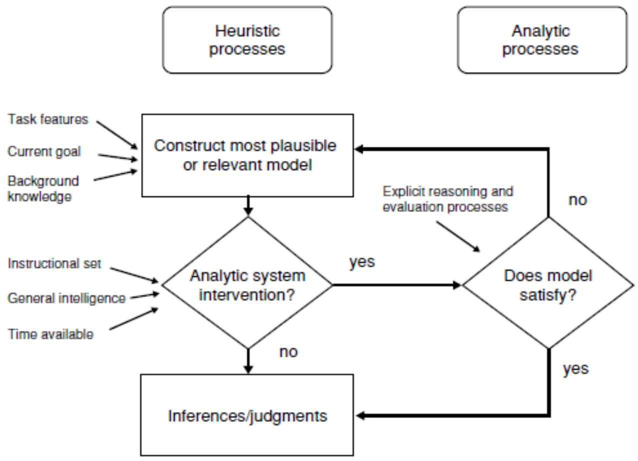


Figure 8. The revised and extended heuristic-analytic theory.
(Source: Evans 2006, p. 381)

Theory of thinking as computation is well established in the cognitive science literature. Sloman's (1996) attempt is one the first theoretical applications of the dual process theory in the field of computational modeling. Sloman discusses the distinction between two different reasoning systems that are distinguished by many theoreticians such as James (1890), Piaget (1926), Vygotsky (1988) and Johnson-Laird (1983). These are 'associative reasoning' and 'rule-based reasoning'. Sloman suggests that these two systems are based on different computational principles. Associative system's computations are based on similarity and reflect temporal and contextual structures while rule-based system is symbolic and its computations are based on rules (Sloman 1996). According to him, associative reasoning is the type of reasoning while creating a design. Reasoning is crucially important in design because 'reasoning helps us out of unprecedented situations' (James 1890, p. 229). Table 2 summarizes Sloman's (1996) characterization of two forms of computation.

Table 2. Characterization of Two Forms of Reasoning.
(Source: Sloman, 1996)

Characteristic	Associative System	Rule-based system
Principles of operation	Similarity and contiguity	Symbol manipulation
Source of knowledge	Personal experience	Language, culture, and formal systems
Nature of representation Basic units	Concrete and generic concepts, images, stereotypes, and feature sets	Concrete and generic concepts, images, stereotypes, and feature; compositional symbols
Relations	(a) Associations (b) Soft constraints	(a) Causal, logical, and hierarchical (b) Hard constraints
Nature of processing	(a) Reproductive but capable of similarity-based generalization (b) Overall feature computation and constraint satisfaction (c) Automatic	(a) Productive and systematic (b) Abstraction of revelant features (c) Strategic
Illustrative cognitive functions	Intuition Fantasy Creativity Imagination Visual recognition Associative memory	Deliberation Explanation Formal analysis Verification Ascription of purpose Strategic memory

Sloman (1996) suggests that these two systems serve complementary functions. The complementarity, he asserts, is that associative operations that are followed intuitively can be source of creativity, whereas more deliberate and formal analysis can provide "a logical filter guiding thought to productive ends" (Sloman 1996, p. 18). Sloman (1996) points out that the distinction is relevant to educational practices. It suggests that students have two tasks by pointing out the features of making associations and using rules:

> Students are expected to master the rules of the domain because rules provide productivity, systematicity, and a means to verify conclusions, and they must develop useful associations between elements of the domain to allow reasoning to become less effortful and more flexible. Useful associations guide the rule learner in the right direction; rule training provides a means to

> check and correct performance. Rule training also provides skills for the associative system to master inasmuch as rule application becomes associative with practice. Both rules and associations play a role in reasoning, therefore in learning, and can be mutually supportive (cf. Ross, 1989). (Sloman 1996, p. 19)

Kahneman and Frederick (2002) adopts the generic labels System 1 and System 2 from Stanovich and West (2000). Kahneman and Frederick (2002) utilize the notion of 'systems' for categorizing families of processes based on the distinctions by their "speed, controllability, and the contents on which they operate" (p. 50). Table 3 shows the characteristics of processes.

Table 3. Two Cognitive Systems.
(Source: Kahneman & Frederick 2002, p. 51)

System 1 (Intuitive)	System 2 (Reflective)
Process Characteristics	
Automatic	Controlled
Effortless	Effortful
Associative	Deductive
Rapid, parallel	Slow, serial
Process opaque	Self-aware
Skilled action	Rule application
Content on Which Processes Act	
Affective	Neutral
Causal propensities	Statistics
Concrete, specific	Abstract
Prototypes	Sets

The particular dual-process model by Kahneman and Frederick (2002) assumes that "System 1 proposes intuitive answers, and System 2 monitors the quality of proposals to endorse, correct, or override" (p. 51). Their assumption for the interaction between these systems is that both System 1 and System 2 can be active concurrently. Kahneman and Frederick (2002) also states that as one gains expertise in certain skills, complex cognitive operations migrate from System 2 to System 1.

Evans and Stanovich (2013) state that all dual-process theories are not the same. Sloman (Barbey & Sloman 2007; 1996) proposes an architecture that has a *parallel-*

competitive form. Evans and Stanovich (2013) explain that Sloman's theories and others of similar structure (e.g., Smith & DeCoster 2000) assume that "Type 1 and 2 processing proceed in parallel, each having their say with conflict resolved if necessary" (p. 227) while their own theories as well as Kahneman and Frederick (2002) are labelled as default-interventionist in structure. Default-interventionist theories assume that fast Type 1 processing produces intuitive default responses with or without the intervention of Type 2 processes (Evans & Stanovich 2013).

As mentioned before both of these two forms of reasoning are equally important in problem solving and learning (Gentner & Medina 1998). In the context of design reasoning, Goldschmidt (2001), following Gentner and Medina's view, adds the assumption that the selection and efficiency of one or the other system (Sloman 1996) depends on the problem at hand. She adds that individual differences affect the reliance on a particular form of reasoning. She concludes that particularly the use of analogical reasoning can be shown through feedback and repeated use. Thus, as claimed by Gentner and Medina (1998), analogical reasoning (similarity-based reasoning) will develop the acquisition of knowledge and the ability to apply it explicitly or implicitly (Goldschmidt 2001). Consequently, Goldschmidt (2001) suggests that repeated use will trigger the process of comparison that may lead to interaction between similarity-based and rule-based reasoning and to the development of rules and use of them.

Coyne and Snodgrass (1991) suggest that, although design may involve both kinds of reasoning, "the importance of intuition in design and its inaccessibility is thought to render design difficult to understand" (p. 126). The idea that cognitive processes can be divided into two main categories which were traditionally called intuition and reason, is now widely recognized and labelled as dual-process theories (Hammond 1996; Sloman 1996) as it is recognized in design studies (Cash et al. 2019; Daalhuizen 2014). The reduction of thinking processes to a straight-forward dichotomy is criticized by many authors (Glöckner & Witteman 2010; Sowden et al. 2015; Stanovich & West 2000). The crucial question, rather, is how the two systems interact and the interplay between processes (Augello et al. 2016).

2.3.2. Dual process accounts of creative thinking

Cognitive psychology has provided evidence of two kinds of thinking processes (Evans 2008; Evans & Stanovich 2013; Stanovich & Toplak 2012). Dual-process models of cognition suggest that there are two types of thought: autonomous Type 1 processes and working memory dependent Type 2 processes that support hypothetical thinking. Models of creative thinking also propose two distinct sets of thinking processes that are involved in the generation of ideas and that are involved in their refinement, evaluation, and/or selection (Sowden, Pringle and Gabora 2015).

Sowden et al. (2015) suggests that Guilford's (1956) Structure of Intellect Model can be viewed as an initial and contemporary dual process model of creative thinking which distinguished between divergent and convergent thinking processes. While several authors have described divergent processes as associative in character which combine the information from the current context in a state of defocused attention with items encoded in memory, convergent processes are seen as analytic in character which control the refinement and evaluation of solutions. Sowden et al. (2015) states that while the mapping of divergent and convergent thinking process onto Type 1 and Type 2 processes are possible, there are also differences to be mentioned. As depicted in the study by Ward (1994), performance on divergent thinking tasks can involve processes that are deliberate and slow. This may imply that divergent thinking does not map onto Type 1 processes. According to the study by Wallas (1926), it may imply that convergent thinking can arise from both Type 1 and Type 2 processes. Thus, a simple mapping of divergent and convergent thinking onto Type 1 and Type 2 processes respectively is not possible.

As Sowden et al. (2015) indicate a straightforward mapping of divergent thinking and convergent thinking to Type and Type 2 thinking respectively is not possible, disparate models of creativity has been developed related to different dual-process models. Allen and Thomas (2011) present a dual process account of creative thinking in which both types of processes are implicated at each of a five-stage model of creative thinking where its origins can be seen in Wallas' (1926) four stage description of the creative process. In this model, it is proposed that both types of thinking are active in creativity. However, the level of their effectiveness and consequently the nature of their contribution changes according to the stage of the creative process.

Basadur, Graen and Green (1995; 1982) propose the notion of ideation-evaluation cycles which has parallels with the proposal of Allen and Thomas (2011). Three major stages in the creative thinking process are distinguished which are problem finding, problem solving and solution implementation. They suggest that both ideation and evaluation are involved at each stage in varying degrees in relation to the domains that emphasize different stages.

Another dual process theory of creativity is Finke, Ward and Smith's (1992) Genoplore model. In this model, creative thinking is divided into two overarching stages which are idea generation and idea exploration. Each stage is divided into smaller stages involving multiple operations. Generation can involve retrieval of items from memory, formation of associations between items, and synthesis and transformation of the "preinventive" structures which are the results of these operations. Exploration stage can involve operations such as identifying the attributes of these pre-inventive structures and as evaluating their potential function in different contexts. According to Sowden et al. (2015), it is possible to map the Genoplore model partially onto dual-process models of cognition. The operations in the Generative stage correspond to Type 1 processes and the operations in the Exploration stage can be mapped onto Type 2 processes. However, analytic processes may help to form new ideas and insights. Thus, it shows that while the operations in the Generation stage may involve both Type 1 and Type 2 processes, the operations in the exploration phase correspond to only Type 2 processes (Sowden et al. 2015).

The "Honing Theory" of creativity by Gabora (2005) also postulates on the idea that people retrieve items from memory and form associations between items when generating new possibilities, expanding on Mednick's (1962) work on flat associative hierarchies. Mednick (1962) suggested that creative people would be characterized by "a flat associative hierarchy rather than a steep associative hierarchy" (p. 229). The people who generate many ideas in response to stimulus have a flat associative hierarchy. Mednick assumed that such people also would respond relatively slowly. So, as discussed before associative thought can also be slow while it ensures divergence. It may involve Type and Type 2 processes. Gabora's theory differs in how creative thinking is characterized in terms of the structure and dynamics of memory. Memory is rather described as 'a web-like structure' and the items that are assimilated in it are in 'spontaneous adaptive change' (Gabora 2005, p. 271). Associative form of thinking is not described as a search in 'a space of predefined alternatives' (Gabora 2010, p. 1). Instead, in this view, creative people are able to either reassemble the items in relation to the task at hand or re-describe them from different real or imaginary perspectives or contexts until it comes into focus and they can do it spontaneously (Gabora 2005). When a potential solution is recognized, then the thinking process becomes more convergent. The idea is honed by an analytic process that is focused on core features of the idea which also involves testing and elaborating the idea into a final solution. Such thinking involves Type 2 processes.

Gabora's theory of creativity draws attention to the ability of shift from an analytic to an associative type of thought in times of fixation, and from an associative to an analytic process following insight. Computer models also have shown the effectiveness of this shifting (DiPaola & Gabora 2009; Gabora et al. 2013) while there has been not much empirical investigation of this shifting in humans.

In Dual-State model of creative cognition by Howard-Jones (2002), the nature of the relationship between these types of processes is characterized by shifting from analytic to associative thinking. In this model, fixation (the tendency to rely on previous ideas when generating new ones; cf. Maier 1931) is suggested as the starting point for creative thinking. So, Howard-Jones (2002) proposes strategies for shifting from analytic to associative thinking. However, Gabora's (2010) theory of creativity puts forward that this shifting does not have a starting point but instead it occurs back and forth along a spectrum from associative to analytic. The shift occurs from an analytic to an associative type of thought in times of fixation, and from an associative to an analytic process following insight. In her analysis of a creative act, she demonstrates that the outputs of associative thought become input for analytic thought, and vice versa. It also acknowledges that this starting point may vary across individuals as shown in a number of studies (Basadur 1995; Basadur et al. 1982; Epstein 2003; Stanovich 1999).

Nijstad et al. (2010) proposes another recent dual-process model of creative thinking which suggests the emergence of creativity through two pathways: a flexibility pathway and a persistence pathway. As in many other models, generating more categories of ideas is associated with cognitive flexibility. Nijstad et al. (2010) argue that more frequent shifts between different categories of ideas lead to more original ideas. In addition to this, they also argue that exploring a few categories in depth may also lead to increased originality. Sowden et al. (2015) state that the persistence pathway focusing on a few categories of ideas appears to correspond to other models of creativity, such as Honing Theory, which focus on developing ideas. However, the major difference of this model is the emphasis on deliberative processing under conscious control as Nijstad et al. (2010) state that their model fails to explain situations where 'creativity occurs spontaneously without intentional effort' (p. 43).

Two distinct aspects of this model need to be put forward. Firstly, Nijstad et al. (2010) argue that their model describes creative thinking primarily as a product of Type 2 processes which are systematic and focused thinking while noting the degree of executive control differs between their two pathways. Broad and inclusive categories are used in the flexibility pathway by making shifts flexibly among categories and approaches and by establishing remote associations (Nijstad et al. 2010). In the persistence pathway, creative outcomes are achieved by a systematic exploration of possibilities and by making explorations exhaustively into a limited number of categories or perspectives (Nijstad et al. 2010). Secondly, Sowden et al. (2015) points out a distinction from previous "generate and explore" models. The flexibility pathway supports the development of originality and the persistence pathway helps with the elaboration of ideas. Although, creativity seems to be result from the joint operation of both pathways, Sowden et al. (2015) presents a contrary argument in reference to Nijstad et al. (2010). They found that the correlation between their measure of flexibility—the number of categories generated—and their measure of persistence—the within-category-fluency (average number of ideas per category/total number of ideas generated)—decreases over time. Based on this correlation, Sowden et al. (2015) suggest that individuals gain expertise in the processes associated with one particular pathway in time rather than being an expert in shifting between pathways.

Barr et al. (2015) proposes another dual process perspective on creative thinking. They employ an individual differences perspective based on dual-process theories. In this perspective, the main assumption is that people vary in the extent to which they rely on Type 1 or Type 2 processes.

Table 4 summarizes the various elements of two sets of dual-process models: general cognitive models and models of creative thinking and the relationships between them. There is general agreement that both idea generation and evaluation may employ Type 1 and Type 2 processes. As discussed earlier, some recent models of creative thinking, particularly Howard Jones' Dual State Model (2002) and Gabora's (2005) Honing Theory, can be mapped with dual process models of cognition.

Table 4. Comparison of the characteristics of Type 1 and 2 processes with dual-process models of creative thought.
(Source: Sowden et al. 2015, p. 50)

	Dual-process models of cognition (Evans, 2008; Evans & Stanovich, 2013; Frankish, 2010; Stanovich & Toplak, 2012)	
Dual-process model of creativity	Type 1 (autonomous processes)	Type 2 (working memory based and cognitively decoupled) processes
	Experiential (divergent thinking)	
Structure of Intellect (Guilford, 1956)	Divergent thinking	Divergent thinking
	Convergent thinking	Convergent thinking
Ideation–evaluation cycles (Basadur et al., 1982; Basadur, 1995)	Mapping unclear	Mapping unclear
Genoplore (Finke et al., 1992)	Generation	Exploration Generation
Dual State Model (Howard-Jones, 2002)	Generative	Analytical
Honing Theory (Gabora, 2005)	Associative	Analytical
Dual PathwayModel (Nijstad et al., 2010)		Flexibility Persistence

It is also clear that shifting between the different processes is required for creative ideas to develop (e.g., (Basadur 1995; Basadur et al. 1982; Finke et al. 1992; Gabora & Ranjan 2013; Howard-Jones 2002; Nijstad et al. 2010)) however dual process models of creative thinking make different conjectures on whether these processes operate in series or in parallel. The models proposed by Basadur (1995), Howard-Jones (2002), and Finke et al. (1992) and the theory of the emergence of a creative insight proposed by Gabora and Ranjan (2013) suggest shifts between types of thinking occurs in series. In serial models, the nature of relationship between the two types of thinking for creative ideas to develop can be interpreted either as disengaging one type of thought prior to engaging the other, or as shifting along the continuum between analytic and associative thinking (Gabora & Ranjan 2013).

The research on computational models of creativity also start to integrate divergent and convergent processes into broader cognitive frameworks. Mekern et al. (2019) review recently proposed single and multi-process computational models of creative cognition. Single process models mostly focus on either divergent or convergent creativity while multi-process models include dual-process approaches. As reviewed above, actual creative performance resides in the interaction between divergent and convergent processes (Mekern et al. 2019).

In design, the dual mode of reasoning has also been a prominent view, embedded in various models of the design process (see Cross 1994; Fricke 1996; Pugh 1991; Roozenburg & Eekels 1995). Tversky and Chou (2011) state that design problems are complex and involve both insight and incremental problem solving, that is, both divergent and convergent thinking.

In the design literature, frequent shifts between divergent and convergent thinking are also seen as necessary. Vidal (2010) states that design involves “cycling repeatedly through a process of divergent and convergent thinking” (p. 412). Perkins (1992) proposes that two thinking processes could occur together in behavior. He also states that “inventive people are mode shifters (between divergent and convergent thinking)” (Perkins 1992, p. 249). Basadur et al. (1990) support the view that creativity is multifaceted and asserts that creative problem solving requires synchronizing divergent and convergent thinking in each phase. Dym et al. (2005) argue that effective inquiry in design space “includes both a convergent component … and a divergent component” (p. 105) and that this inquiry is “an iterative loop of divergent-convergent thinking” (p. 104). Many studies emphasize that the development of a design concept requires repeated cycles of divergence and convergence through series of steps rather than a single step of generation and evaluation (Dong 2007; Liu et al. 2003; Tversky & Chou 2011).

Gabora’s theory of creativity draws attention to the ability of shift from an analytic to an associative type of thought in times of fixation, and from an associative to an analytic process following insight. Computer models also have shown the effectiveness of this shifting (DiPaola & Gabora 2009; Gabora et al. 2013). Recently, there is also an empirical investigation of this shifting in humans. Goldschmidt (2016) states that two reasoning modes in the form of associative and rule-based roughly correspond to divergent and convergent thinking respectively (see Table 5). She provides empirical evidence for instantaneous shifts between the two modes of thinking and proposes that "the two forms of thinking occur virtually concurrently in the design process" (p.117).

Table 5. Attributes of two modes of thinking.
(Source: Goldschmidt 2016, p. 116).

	Mode 1 (Roughly divergent)	**Mode 2 (Roughly Convergent)**
Basadur (1995)	Ideation	Evaluation
Sloman (1996)	associative, similarity based	symbolic, rule-based
Kahneman (2011)	Fast: Intuitive, based on memory and emotion	Slow: Rational, calculating consequences
Goel (2014)	Lateral transformations	Vertical transformations

As a result, it is proposed that creative thinking emerges through "the joint effects of associative and analytic types of thought" and "the process of shifting between them in response to task demands" (Sowden et al. 2015, p. 46). Then, in addition to recognizing and exercising two types of thinking, it is necessary to exercise shifting between them through repeated cycles since it is described both as a skill of expert designers and as a necessity for creative problem solving.

In design studios, design learning is mainly fostered by self-experimentation and self-discovery with guidance from the instructors. Yet, there are also other teaching aids that can be used to guide students to a sense of conceptual structure of things they observe. Bruner (1977) characterizes such devices as 'sequential programs'(p. 82). These programs provide a certain order of presentation for the materials and ideas in any subject to lead students to an understanding of basic ideas and structures. For exercising two different forms of reasoning, a sequential program can be helpful for exploring the shifts between them. Consequently, in this thesis to inquire what could be a more effective sequential learning program, a second experiment is designed to investigate whether the order in which a particular reasoning strategy is encouraged during designing has an impact on students' creative performances. The hypothesis of this experiment (Hypothesis 2) is that the order in which the reasoning strategies are performed will have an impact on students' creative performance.

Many studies have acknowledged the role of creativity in problem solving since Wallas's (1926) seminal work. The role of implicit cognitive processes has been highlighted by various theories of problem solving and reasoning (e.g., Evans, 2006; Reber, 1989; Sun, 1994; Sun & Zhang 2004). The dichotomous categorization in dual process accounts on reasoning and creativity may be helpful in explaining some phenomena in design process. Another dichotomous categorization is implicit and explicit learning which relies on the categories of implicit and explicit knowledge. The body of research on particularly implicit learning is reviewed in the following sections since design studio pedagogy heavily relies on implicit learning. In addition, the more recent research on the interaction between implicit and explicit processes is presented which may provide insight especially for the pedagogical strategies in design studios. (Hélie & Sun 2010).

2.3.3. Dual process accounts of learning – Implicit and explicit processes

Dual-process theories of learning have been around for many years. The oft-cited account of Reber (1996) has been referred as one of the main source of inspiration in the development of dual-process theories of reasoning and learning. The goal of education whether in the classroom or in the design studio is to carry people from a novice state to a more expert state. Progressing from one state to another involves both knowledge acquired from practice as well as knowledge acquired from explicit instruction.

Dual-process theories of learning propose that there are two distinct forms of learning: implicit and explicit, which lead correspondingly to distinct implicit and explicit forms of knowledge (see also (Berry et al. 1993; Dienes & Perner 1999; Sun 2002; Sun et al. 2005). At a computational level, Evans (2007) state that it is possible to model these two forms of learning "using neural networks for the implicit processes and some form of rule induction for the explicit learning" (p. 168; see Sun et al. 2005). The assumption is that the latter process is explicit and limited by working memory capacity. Sun et al. (2009) suggest that dual-process theories of learning can be mapped on to Sloman's (1996) distinction between associative and rule-based processes in reasoning.

There has been accumulated evidence for implicit learning from several distinct paradigms such as artificial grammar (Reber 1976), tasks involving control of complex systems (Berry & Broadbent 1987, 1988), matrix-scanning studies (Lewicki et al. 1987; Lewicki et al. 1988). However, Sun et al. (2009) state that the notion of dual systems in learning is frequently criticized. They assert that two claims often associated with implicit learning has received great resistance: the notion that it is possible to learn something without being aware of what is being learnt and the notion that implicit learning requires no working memory (Sun 2002).

Arthur Reber’s work has been referred to as a leading influence on research on implicit learning as well as on dual-system theory generally (Evans & Frankish 2009; Sun et al. 2009). Sun et al. (2009) put forward three claims by (Reber 1996) in relation to implicit learning. These are implicit learning “(a) can occur without awareness that anything was learned, (b) occurs automatically, without requiring central resources, and (c) involves abstracting the inherent structure of the stimuli at the time of encoding” (Sun et al. 2009, p. 2).

One of the main debates related to implicit learning has been concerned with whether people can learn without being aware of what they are learning. Lewicki’s (1986) work provides the strongest support for the acquisition of implicit knowledge with a complete lack of conscious awareness. Lewicki’s (1986; 1987) studies includes a training phase where subjects are exposed to an implicit covariation under the story of learning about other relationships. After the training phase, subjects are exposed to new stimuli to see if they use the implicit covariation provided during the training phase. The studies report that subjects use these covariations without being able to report them. In addition, subjects struggle to talk about what they have learned.

Reber (1996) draws attention a particular issue while discussing the flaws of such experimental setting by an inherent uncertainty principle. Reber (1996) points out a methodological error made by Lewicki and his colleagues (Lewicki et al. 1988) in designing the stimulus display pointed out by Perruchet et al. (1990). Perruchet et al. (1990) indicate that there is more than one way to capture the pattern in the stimulus display. Reber (1996) states that the rule that governed the location of the target stimuli on the critical trials corresponds to the rule Lewicki et al. develops. While it is not the only rule that expressed the structure of the display, as Perruchet et al. (1990) shows, the rule used by most of the subjects is not the same rule developed by the authors.

Reber (1996) describes this difference as nonequivalence of rules. In simpler terms, there can be differences among the rules that are used to generate the display, the rules that characterize the order in the stimulus display and the rules that subjects have induced. This situation does not falsify the original conclusion that subjects still engage in implicit learning (Reber 1996). As Reber (1996) emphasizes, this indicates that subjects can learn a complex structure without being aware of both the process of learning and the knowledge acquired.

In the light of the discussions above, this brings to mind that this nonequivalence of knowledge to be acquired can occur in authentic learning environments such as design studios in architecture schools which heavily relies on implicit form of learning. While the plurality in solutions to a problem is a commonly accepted and a well-established feature of design problems, the uncertainty of what is acquired during the process becomes inevitable. The next section discusses how learning without awareness of what is being learnt has been an indispensable feature of design studio.

2.4. The significance and predicaments of learning by doing as a general educational approach in the design studio

This section will present discussions on the implicit nature of the knowledge acquired by learning by doing, how design studio responses to this character of learning by doing and the nature of design learning.

Seger (1994) describes implicit learning as ‘non-episodic learning of complex information in an incidental manner, without awareness of what has been learned’ (p.163). Although learning by doing is a form of learning without awareness of what has been learned, it preserves its effectiveness in design learning by virtues such as learning by self-shaping, trial and error, and discovery. The major effect on design learning is that it provides the opportunity to explore on design activity. The implicit learning occurs during these exploratory activities in learning by doing. The individual experience through this exploration enhances creativity in a student.

Conceptually, the studio is a process of learning by doing, in which students are given a series of design problems to solve. Thus, they learn how to design largely by doing it, rather than by studying it or analyzing it (Lawson 1997). Physically the studio is a place where students gather and work under the supervision of their studio instructors. Learning by doing has two prominent features: doing and direct experience. There are two forms of experience that shapes students’ design learning in the studio. The direct experience involves doing, while indirect experience involves tutor’s passing his/her direct experience to students. Design studios are often said to involve master-apprentice model too. To get the knowledge for successful practice students use both trial-and-error methods or use the method of learning by doing as instructed by an expert designer (Reese 2011). However, the master-apprentice model in design pedagogy does not correspond to learning by doing as instructed. In learning by doing as instructed, direct experience is necessary however the knowledge for successful practice can be acquired indirectly through instructions by an expert. One major insufficiency in this learning model is that students actually never see the relevant expert, in this case the master in the act of designing. So, the transfer of knowledge relies on tutor's communication skills which steer teaching with implicit knowledge. This communication mostly becomes limited to task-relevant questions as instructions inducing students to identify an appropriate action or a relevant aspect of the design situation (Reese 2011).

Teaching design and introducing to the students drawing as an activity for "thinking architecturally" has been the major struggle in architectural education. Schön (1987a) recalls the Meno paradox to explain the nature of design problems and process of learning to design. Simon (1969) who thinks of designing as converting a situation from its actual state to a preferred one, proposes to solve the paradox of Meno by distinguishing between "state" and "process". He states that the change of state that occurs can be described when a problem is solved even though the process that would produce it cannot be described (Simon 1969).

Using Meno paradox, Schön (1987a) states that design activity is to look for something without knowing what it is. According to Schön (1987a), design cannot be defined exhaustively and to teach a student what design is becomes impossible through conventional methods of teaching which follow the premises of conduit metaphor (Reddy 1979). Instead, Schön (1987a) proposes that it is possible to coach students by quoting Dewey:

> He has to see on his own behalf and in his own way the relations between means and methods employed and results achieved. Nobody else can see for him, and he can't see just by being told, although the right kind of telling may guide his seeing and thus help him see what he needs to see. (Dewey, 1974, p. 151)

Correspondingly, Schön (1987a) states that each student must construct for himself/herself the meaning of the others' messages and must design messages whose meanings the other can decipher. Schön (1987a) states three essential features of the dialogue between coach and student. The dialogue takes place in the context of student's attempts to design which creates a familiar ground for student. It also makes use of actions as well as words and it depends on a reciprocal reflection-in-action. So, through designing students acquire the sorts of experience to which the coach's language refers. Schön (1987a) states that the architectural studio is based on an implicit response to the paradox and predicament of learning to design. The student must begin to design before he/she knows what he/she is doing, so that the studio master's demonstrations and descriptions can take on meanings useful to his/her further designing. The weakness of this method of teaching is that it relies heavily on the effective communication skills of the studio master. The messages that the instructor designs play a crucial role. Schön (1987a) states that these messages often refer both to the process of designing and to the process of learning to design.

Alexander (1964) describes the most important aspect of the process of learning by doing as enabling the designer scanning mentally all the ways in which other things have gone wrong in the past. Using this description, he reveals that learning by doing is actually the activity to build history of previous design experience. According to Winograd and Flores (1986), teaching in design education involves guidance for the student building an "unformalized" background. Design studio pedagogy builds such an "unformalized" library of experience since this type of learning is a constructive process in which the learner is building an internal representation of knowledge, a personal interpretation of experience.

One of the weaknesses of the design studio is that students, in paying so much attention to the end product of their labors, fail to reflect sufficiently on their process (Lawson 1997). Students commonly state that they struggle to talk about what they are learning. One possible reason for this may be the "unformalized" characteristic of what is learnt implicitly (Taneri & Dogan 2021). The professionalization of design and thus institutionalization of design education has led design educators focus on the product rather than the process itself. The institutionalization of architectural design education gave birth to modern project-based education and since then, educational models are based on the simulation or replication of professional task performance. Consequently, the measure of learning remains as the evaluation of the end-product rather than the evaluation of increment in learning about design thinking. This brings along helping students to acquire cognitive strategies to be better at problem solving and the use of prior knowledge to solve design problems remain to be as a challenge for design education (Casakin & Goldschmidt 1999).

Learning by doing can foster implicit learning however any education in a domain aims for an explicitness of what is learnt. Considering the literature reviewed above, there are three issues that come forward regarding to the nature of design learning. First, design learning is a type of implicit learning and consequently its content, design knowledge has the character of implicit knowledge. However, it is necessary to make design education more explicit (Cross, 2007). Some of this content can be acquired through explicit representations of individual reasoning processes. Second, pedagogical methods should aim for the acquisition of means for making visual thought processes explicit enabling its transmittance formally since each student constructs a design experience for himself/herself to learn to design. Third, learning by doing promotes activities to build history of previous design experience which has an "unformalized" nature. To help students in dealing with this "unformalized" knowledge, design studio instruction should establish means for interactions between implicit and explicit learning and design studio pedagogy should facilitate the occurrence of such interaction.

2.4.1. Implicit-explicit interactions: Inferences for Design Studio

Some mixture of instruction and experience should be included to be able to acquire design expertise. Design studio education, on the other hand, heavily relies on individual experience to acquire knowledge. Finding ways to integrate activities that enable both explicit and implicit learning to occur is necessary to provide a more educative learning experience in design studio.

The resulting knowledge from learning by doing is often difficult to articulate. Explicit knowledge that can be verbalized typically improves later (Stanley et al. 1989). In all of the tasks in the studies by Stanley (1989), Sun et al. (2001), Sun et al. (2005), the acquisition of implicit skills seems to be easier than explicit knowledge as there is delay in the development of explicit knowledge. Hélie and Sun (2010) suggest that this delay may be an indication of implicit learning triggering explicit learning. Thus, in reference to Karmiloff-Smith (1992), they suggest that this process can be described as delayed explication of implicit knowledge. Sun et al. (2009) stated that people are generally able to learn implicit knowledge through trial and error. Further, they add that explicit knowledge can be acquired from ongoing experience in the world, through the mediation of implicit knowledge (i.e., the idea of bottom-up learning in Sun et al. 2001).

Sun et al. (2009) also suggest that the interaction between implicit and explicit learning is necessary for the development of skills and expertise (e.g. Sun 2002; Sun et al. 2001; Sun et al. 2005). They add that awareness of knowledge acquired implicitly may become possible through the implicit-explicit interactions (Sun et al. 2001).

There have been various studies on ways of making design education benefit more from explicit learning. A significant amount of research has increased the understanding of the cognitive aspects of design. Oxman (2001) states that "the cognitive properties of design learning have never been the subject of design education" (p. 269). She argues that a cognition-based approach can provide a conceptual framework which involves "the explicit learning of design knowledge structures and related cognitive strategies as the main objectives for design education and design learning" (p. 270). This conceptual framework addresses problems of representation of knowledge in design. The representational formalism termed ICF (Issue-Concept- Form) (Oxman 1994; Oxman 1999) represents chunks of knowledge of design and provides explicit linkages between the issues of design problem, however it accommodates only associative forms of reasoning used in design such as the use of analogy and metaphor.

More of these studies are conducted with students from more advanced levels of architectural education. This thesis is particularly interested in the learning of first year students, studies focusing on first year design studio pedagogy are reviewed in this part. A recent group of studies focusing on the integration of computation in first year design education in the schools of architecture set their bases on the teaching methods of basic design instruction. Özkar (2007) states that it is possible to "develop ways for beginner design students to talk about their design process" and to "learn designing as a conscious activity of organizing" by following the framework proposed by Stiny to include the sensorial experience of the subject in computing relations (p. 110). For integrating computational design to design education in the first year, she proposes that "learning by doing can be articulated and rephrased as both learning design by computing and learning computing by design" (p. 110). This study is important in the sense that it enables students forming libraries of design elements and of relations between design elements.

The following studies introduce the notion of 'visual schemas' as pedagogical tools. Özkar (2011) utilizes 'visual schemas' as a means for describing design knowledge conveyable in the first year design studio and she points out that this study can be taken as ‘a preliminary study to place formalism in the studio’. Gürsoy and Özkar (2015a) make use of İlhan Koman’s abstract sculptures by delineating the mathematical concepts in Koman’s ‘‘embryonic’’ approach through visual schemas. These visual schemas are presented as ‘guides and design constraints as well as tools to formalize their design thinking’. In this study, visual schemas are considered as carriers of information described according to what each of them allows and what it acknowledges as cognitive steps. Gürsoy and Özkar (2015b) states that making in design can be defined as a computational process. The study takes computation as a general reasoning process. In this regard, they present a study for developing ways to explicitly include material manipulation in a computational formalism using “dukta” cases. Visual reasoning as a form of design reasoning is endorsed to students participated in the study by the conception of design as a computational visual reasoning process.

Özkar (2011) proposes that integrating shape grammar formalism provides “an efficient and shared way to talk and represent design decisions visually” which is similar to “pointing at the visual composition with a finger and elaborating a visual relation verbally” (p. 115).

Although the studies mentioned above are more concerned with knowledge representation than knowledge acquisition, these studies suggest possibilities for implicit-explicit interactions to occur by creating an explicit representation of individual experience to be reflected on by students and to be shared by others.

The issue for design education also seems to be not whether there is a need for more explicitness (Raelin 2007), it is rather to investigate when to introduce explicit instructions and reflection during design learning to improve students’ creative performance.

Experimental studies investigating the effect of explicit instructions offer two important findings. In the study by Reber and Millward (1968), the procedure consisted of providing one group with concrete instructions and then they were asked to use this explicit information to complete the task. The results were compared to another group without the explicit information. According to Reber (1996), in the post-experimental debriefings, subjects claimed that they found little or no value that they could use in the explicit instructions. In one of the several studies using the grammar-learning procedure, one group was informed about only the existence of a structure (no information about the nature of the structure) to be searched while the other comparable group received no information. Both groups were given the same learning phase. It is found that the performance of the explicitly instructed subjects were poorer compared to the other group which received no instruction about the structure (Reber 1996). Reber (1996) suggests this study indicates that explicit processing of complex materials created a disadvantage relative to implicit processing. He concludes that explicit instructions seemed to have a particular kind of interference effect, based on the analysis of data from Reber (1976).

In a number of studies, the same finding was supported. Berry and Broadbent (1988) reported that explicit instructions were counterproductive. However, when the rules in use were salient, the subjects benefitted from the instructions. Reber et al. (1980) showed that when explicit instructions were presented without any structure, it also caused poorer performance. Howard and Ballas (1980) reported that explicit instructions had detrimental effects when the instructions given provided no systematically interpretable information.

Based on this result by Howard and Ballas (1980), Reber et al. (1980) showed that the performance can be improved by using the instructional set that focuses on relevant aspects of the task in a salient manner and by introducing them during learning.

In the study by Reber et al. (1980), the manner of interaction between explicit learning and implicit learning modes was explored. One group of subjects received the explicit instruction before the task training phase, one group received it during the training phase and a third group received it at the end of the training phase. The main finding of this study was the explicit instructions were more effective when they are introduced earlier in the training phase. The saliency and relevancy of instructions were also important. If the explicit instruction encouraged subjects to distract from the ways of dealing with the task, the instruction had debilitating effect on the performance. Reber (1996) interpreted that the function of the explicit instruction should be providing instructions to direct and focus subject's attention.

Accordingly, Reber (1996) stated that when the explicit instruction was introduced later in the training phase, its effects were different. There were two sources of difficulty. First, there was the possibility of incompatibility between the formalization of structure imposed by the explicit instruction and the way implicit system processes this instruction (Reber 1996). Second, as the instruction was introduced later in the process, the association between the information received during the training and content of instruction became disconnected (Reber 1996).

Recently, Lane et al. (2008) conducted a study to explore ways of facilitating implicit-explicit interactions. They emphasize that much of the research particularly on implicit learning has been focused on isolating a specific type of processing. The main assumption in those studies is that individuals rely on one process during learning. There are a growing number of studies that acknowledge both implicit and explicit types of processes operate in many tasks (e.g., Mathews 1997; Reber 1989; Seger 1994; Willingham et al. 1989). As discussed in the literature on the effects of explicit instruction previously, it is possible to manipulate the learning process in such a way as to emphasize one type over another. In the experiments conducted by Lane et al. (2008), they focus on "the effect of providing partial or full model-based information before training" particularly (p. 158).

Although, most of the previous studies has shown that explicit instructions have detrimental effects on learners' performance, the study by Lane et al. (2008) provides a number of suggestions. Firstly, according to Lane et al. (2008), their results support prior work (e.g., Sallas et al. 2007; Stanley et al. 1989) which suggest that it is possible to combine fruitfully the two types of process to facilitate learning. Secondly, providing guidance where a subset of information about a task is first taught and then allow learners practice subsequently, appears to have more benefits compared to practicing without any guidance. Thirdly, they suggest that structuring the practice itself is important for enhancing the flexibility of knowledge, the ability to apply what is learnt in different problems, conditions, contexts. Lane et al. (2008) concludes that understanding the interaction between implicit and explicit processes have the potential to illuminate mechanisms involved in the development of expertise.

As recent studies suggest, providing explicit instructions have a positive effect on learners' performance compared to practicing without any guidance. While the positive impact of facilitating both explicit and implicit processes in learning is apparent in other domains, its positive effect for reasoning strategies remains to be demonstrated for first year design students. Consequently, to test exactly that the third experiment introduces specially designed instructions to elucidate a particular reasoning strategy. The hypothesis (Hypothesis 3) of the experiment is that instructions to use particular instructions to use particular reasoning strategies will have a positive impact on the creative outputs and creative process of students.

2.5. Summary

Based on the literature review in this chapter, there are three main points to be emphasized. First, reasoning is a creative act. Whenever we reason on a particular problem, we engage in creative thinking as in design problem solving. Second, reasoning is a constructive act. Designers construct by formulating the problem at hand, by setting its boundaries, by selecting parts and by setting relations between those parts. Third, if reasoning is described as going beyond the information given, it is shown by evidence that there are at least two ways for designers to go beyond the initial situation.

The notion of dual processes has been well accepted in several domains including reasoning, creative thinking, and learning. There are numerous studies reporting how either associative (e.g., analogical reasoning, case-based reasoning) or rule-based reasoning strategies (e.g., algorithmic, parametric design strategies) in design problem solving enhance and support creativity and learning in design.

In the light of the literature presented previously, architectural design learning should be based on the acquisition of design skills in design studios through the repetition of exercises dedicated to the introduction and application of these reasoning strategies. While there are several experimental studies investigating dual process models in human cognition in everyday life, as well as in specialized problem solving, more studies are needed to be conducted to find ways for integrating dual processes in design reasoning, in design creativity, and in design learning into design education starting from beginning years. In this study, a series of experiments are conducted to study the following research questions and respective hypothesis related to the question:

- What is the effect of associative and rule-based forms of reasoning on creative performance when first year students are directed to adopt either one them while designing?

  Hypothesis 1: The hypothesis states that employing a particular reasoning strategy will have an impact on the creative output and creative process of novice learner.

- How does a particular sequence of reasoning strategies affect students' creative performance when they are directed to exercise two different forms of reasoning in a particular order?

Hypothesis 2: The hypothesis states that the order in which the reasoning strategies are performed will have an impact on the creative output and creative process of novice learner.

- What is the effect of introducing forms of reasoning in a series of instructions on students' creative performance before students are asked to exercise a particular form of reasoning?

    Hypothesis 3: The hypothesis states that instructions to use particular instructions to use particular reasoning strategies will have a positive impact on the creative outputs and creative process of students.

CHAPTER 3

METHODOLOGY

Creativity is considered as an integral part of design. Thus, understanding its nature and different aspects of creativity is crucially important to enhance its development in design education. This study employs three different experiments with selected groups of first year design students testing three hypotheses: first hypothesis questions whether employing a particular reasoning strategy will have an impact on the creative output and creative process of novice learner; second hypothesis inquires into the order in which the reasoning strategies are performed will have an impact; and third hypothesis investigates whether a lesson about the use of a particular reasoning strategies will have a positive impact on the creative outputs and creative process of students.

Researching creativity, though, presents methodological challenges in addition to challenges related to how to define creativity. Said-Metwaly et al. (2017) recently provide a contemporary overview of approaches for measuring creativity and emphasize that there are still limitations and deficiencies caused by a lack of a consensus on the definition of creativity as a construct to be measured and its components particularly in the quantitative approaches in practice and research. Among others the four-P framework, a four-part division of creativity research proposed by Rhodes (1961), has influenced many researchers of creativity. Rhodes (1961), based on the examination of several definitions, suggests that definitions of creativity can be grouped under four elements that overlap and interrelate. These four elements are: the creative person, the creative process, the creative product, and the creative environment.

There has been ongoing research on measures of creativity since the 1950s. Since then several measurement methods have been developed and studied, (Hocevar & Bachelor 1989; Said-Metwaly et al. 2017; Sawyer 2012). Hocevar and Bachelor (1989) classified over a hundred examples of creativity measurements into eight categories which illustrated the diversity of available measurements: (1) tests of divergent thinking; (2) attitude and interest inventories; (3) personality inventories; (4) biographical inventories; (5) ratings by teachers, peers, and supervisors; (6) judgments of products; (7) eminence; and (8) self-reported creative activities and achievements.

Various tests of divergent thinking were developed during the 1950s and 1960s. Guilford's (1959, 1967) Structure-of-Intellect model of the personality included divergent production (today referred to as "divergent thinking") as one of six operations. The other operations were cognition, memory recording, memory retention, convergent production, and evaluation. Guilford proposed that divergent production involved four abilities: Fluency, Flexibility, Originality, and Elaboration. Divergent thinking tests is the most widely used category of creativity tests which are also criticized frequently. Sawyer (2012) in reference to Wallach (1971, 1985) points out that one of the most prominent issue is the criterion validity, but that divergent thinking tests can be used with caution. In support of the use of divergent thinking tests, Barron and Harrington (1981) states that "some divergent thinking tests, administered under some conditions and scored by some sets of criteria, do measure abilities related to creative achievement and behavior in some domains" (1981, p. 447).

Silvia et al. (2008) suggest that divergent thinking may be necessary for novices' creative performance rather than experts. This may be due to the decreasing need for divergent thinking as experts have more domain knowledge (Silvia et al. 2008), however studies with novice and expert designers on design creativity indicate that not only divergent thinking is not necessary but shifts between divergent and convergent thinking through repeated cycles is required in design problem solving (Dym et al. 2005; Vidal 2010). Silvia et al. (2008) conclude that divergent thinking test can be used particularly for beginners or novices as nearly all the samples studied in creativity research involves people who have not been immersed deeply into creative domains.

For creative products, numerous product ratings have been developed. Some of them utilized these in laboratories where a person or several people are asked to generate an artwork as part of the experiments (Sawyer, 2012). For example, the Hall Mosaic Construction Test (Hall, 1972) ask participants to generate an 8 x 10-inch mosaic out of precut 1-inch squares. Seven dimensions of performance are defined. One of them, the number of colors used, is objectively measured. Then the other six aesthetic dimensions are used for subjective scoring by five expert raters.

Along the same line of research, the most used method for product creativity assessment is the Consensual Assessment Technique (CAT). In this method, participants are asked to create a product. Then, each product is rated by two or more experts in the related field. The ratings of the judges are averaged, and this average is used as a measure of product's creativity. In the first use of this technique, Getzels and Csikszentmihalyi

(1976) asked students to produce artworks and then the craftsmanship, originality and overall aesthetic value of each artwork were rated by a panel of five art school professors. Amabile's (1982) study was the first use of the CAT with school children. In contrast to objectivity of creativity tests, CAT is grounded on a consensual definition of creativity. Amabile (1982) introduces two assumptions which are helpful avoiding theoretical and methodological problems. First assumption is that it is possible to obtain a reliable judgment on the creativity of the products in evaluation by employing an appropriate group of judges. This assumption heavily relies on the idea that people can recognize if a product is creative or not although it may be difficult to make a description based on its specific features (Amabile, 1982). Secondly, Amabile (1982) suggests that CAT recognizes that observers can agree on some products to be more creative or less creative than others. As the reliability of these subjective assessment techniques can be questionable, Sawyer points out that multiple studies using this method have shown that the ratings of experts generally have high correlations for good inter-rater reliability (Amabile, 1982; Baer, 1993; Kaufman et al., 2007; Kaufman, Baer, & Cole, 2009).

The empirical research in this thesis attempts to measure novices' creative performance both in terms of product creativity and process creativity. A set of criteria is used based on Guilford's four categories: originality and elaboration for product creativity and fluency and flexibility for process creativity. It utilizes a similar approach to CAT for the assessment of product creativity. Three experimental studies are conducted to observe the effects of two distinct forms of reasoning as associative and rule-based reasoning on students' design processes and products. In each experiment, a design exercise containing the same design problem is given to participants in three different conditions: associative reasoning group (AR), rule-based reasoning (RbR), control group (C) with no particular form of reasoning (see appendix A).

3.1. Participants

Participants of the study (*n=72; female=40, male=32*) are first year students at the faculty of Architecture in İzmir Institute of Technology. The experiments were conducted in the spring semester after a semester of experience in first year design studio course. For Experiment I, participants *(n=30: 14 male, 16 female)* are divided into three groups of ten students: associative reasoning group (AR), rule-based reasoning (RbR), and control group (C) with no particular form of reasoning. In Experiment II, the participants (*n=21; female=10, male=11)* are divided into six groups because of the order in which students repeated the task followed six different sequences are determined by all the possible combinations of the three conditions (C, AR, RbR). Due to the personal reasons and time conflicts, this experiment was conducted with less than five participants for each group. For Experiment III, the participants *(n=21: 7 male, 14 female)* are divided into two groups (I-AR, I-RbR) where all of them received a lesson into the specific reasoning strategy they were going to ask to use before the design exercise. All the participants are distributed according to their first-year design studio course grades of the previous semester to make sure that there was similar grade distribution across groups.

3.2. Design Exercise

A design exercise reported in the studies by Özkar (2005, 2011), which is a variation on the nine grid square problem, is used as a template for the experiments. It involves an assignment to generate a square composition and ends with an assignment which requires students to position nine of these squares to make a new one. The original exercise is composed of seven series of assignments. For time considerations and keeping the design exercise in the experiment clear, the steps 1-5 were removed, and the number of assignments was reduced to two sequential tasks. The serial tasks challenge the participants "to see the continuity in their thought as well as to go through a back and forth process" (Özkar 2005, p. 316). In other words, the serial tasks lead them to go through a cycle of ideation and evaluation until they decide to end the process. Another task is added to the two tasks which requires participants retrospectively report on their reasoning processes and discretely represent the rules, schemas, diagrams that reflect their design activity. The design exercise is composed of three tasks requiring the fulfillment of the previous task. The nine-square grid has been one of the most common exercises in design studio for more than sixty years. Briefly, it is based on "the transformation of a nine-square grid into a series of alternatives, using a pre-defined kit-of parts and a set of rules" (Yazar and Pakdil, 2009, p. 147). Instead of kits of parts, the researcher manipulated how to generate the initial square unit for the research.

Task 1, which involves the design of a x a size composition becomes the starting point of the exercise. Composition, in the context of the study, implies a whole of parts or elements in unity. In Task 2, students were required to bring nine of these together to make a new composition. In this task, they were required to explore transformations of the a x a composition "while adapting them to the new framework through changes in their elements where necessary" (Özkar, 2005, p. 315-316). While one group was kept as a control group receiving no instruction, the other two groups received two different instructions for the design of the initial square unit. One group is directed to use a two-dimensional composition as a source of analogy, the other group is directed to use a set of shape rules. Thus, the exercise is used to investigate if there was a significant effect on students' creative performance when they receive a particular instruction to generate the initial a x a square unit.

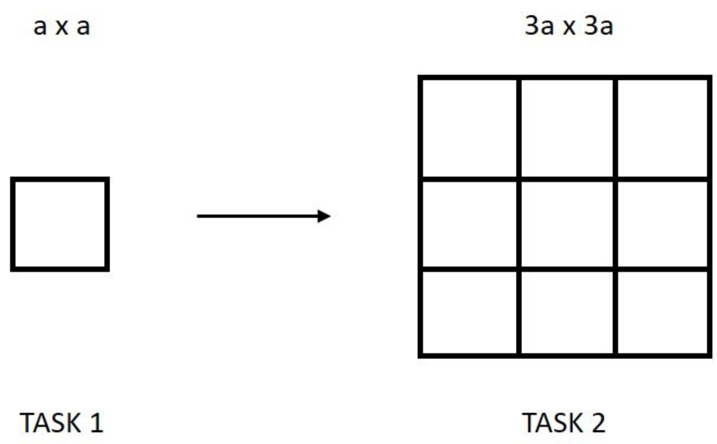
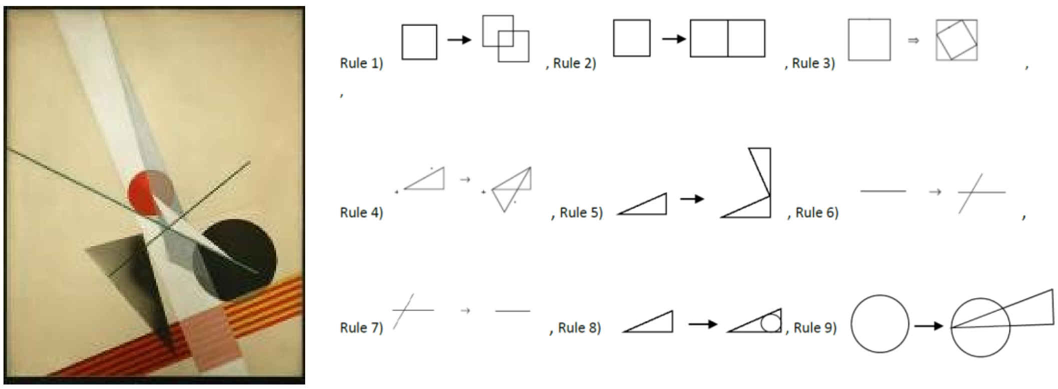


Figure 9. Diagram of the exercise.

The structure of the exercise separates idea generation from idea evaluation. This is due to a number of reasons. Firstly, the tasks are given to first year students who are considered to have limited experience in both design and design education. Thus, it is important to provide separate tasks where they can generate ideas and visually evaluate their designs. Secondly, it is analogous with dual process accounts of creativity which recognizes the division between the processes of generating ideas and evaluating those ideas. Thirdly, as discussed before, both divergent and convergent thinking processes can lead to creative outcomes. Task 1 allows this multiplicity of reasoning strategies. On the other hand, Task 2 leads the participant to a convergent process where transformations of a possible design solution are generated and evaluated. As a result, the two task structure provides a design process as in real design cases where "designers diverge and converge iteratively" (Tversky & Chou 2011, p. 210).

3.2.1. Task 1

First task requires the participants to design a two-dimensional design of size a x a using only black and white colors. This task has three different conditions (see APPENDIX A): one third of the participants (the control group) finished the task without any guidance regarding type of reasoning to be used (C), the second group were instructed to use associative reasoning (AR) while they were given examples to be followed, and the third goup were instructed to use rule-based reasoning (RbR) following a series of rules to be strictly followed. For the control group (C), the exercise does not lead the participant to any predetermined reasoning strategy to be used during designing. In the associative reasoning condition (AR), the exercise contains a source analog to encourage an associative reasoning process. The chosen composition is Laszlo Moholy-Nagy's Composition A XXI (Figure 1a). In the rule-based reasoning condition (RbR), the exercise contains a number of shape rules (Figure 1b) to be used for designing the a x a composition to encourage a rule-based reasoning process. In terms of rule format, all rules are addition rules except Rule 7 (that is, each rule adds a labeled shape).



(a) (b)

Figure 1. a) Source analog given to (AR) group. b) Shape rules given to (RbR) group.

3.2.2. Task 2

In the second task, students were required to compose a design consisting of nine units in the form of 3 x a x a by using the a x a square composition that students designed in Task 1 in the same experimental condition as in Task 1. In this task, participants were encouraged to use rotation, mirroring, and also to interchange the colors assigned to design elements if necessary. Participants were encouraged to explore geometric transformations of their square units while adapting them to the new design problem through changes in their elements where necessary.

3.2.3. Task 3

The objective of the first two tasks was a product-oriented evaluation and inquiry, while the third task was process oriented. In the third task, each participant was asked to report on his/her design process retrospectively by writing and drawing. As a natural outcome of these sequential tasks, the participants were expected to make comparisons between their own stages throughout the exercise.

3.3. Materials

Each participant was given A4 size white blank papers to be used for sketching and for the third task. A black marker was provided to each participant to be used in coloring their compositions. 8 x 8 cm white note papers were delivered to each participant to be used in both the first and second task. The reason for the selection of these note papers is to speed up the process of making the nine-square composition and enable the participants do the transformations easily and fluently. A 35 x 50 cm white paper and glue were provided to each participant to design the 3 x a x a composition.

3.4. Experiments

Three different experiments are conducted to observe the effect of two forms of reasoning strategies on students' creative performances in different experimental conditions.

3.4.1. Experiment I

Experiment I was devised to test Hypothesis I, that there would be differences in the creative performance scores of participants directed to exercise a particular form of reasoning. In the experiment, participants *(n=30: 14 male, 16 female)* were divided into three groups: associative reasoning group (AR), rule-based reasoning (RbR), control group (C). The participants were distributed to each group according to their grades of previous semester's design studio course.

3.4.2. Experiment II

An experimental study is conducted to test Hypothesis II, whether the order in which these forms of reasoning is enforced or not enforced has any impact on students' creative performance, design process, and design learning. In the experiment, participants *(n=21: 11 male, 10 female)* were divided into six groups. Each student was asked to perform the same design task three times in three different conditions: either without any guidance (C), or using associative reasoning (AR), or rule-based reasoning (RbR). The order in which students repeated the task followed six different sequences determined by all the possible combinations of the three conditions, namely C-AR-RbR, C-RbR-AR, AR-C-RbR, AR-RbR-C, RbR-AR-C, RbR-C-AR.

3.4.3. Experiment III

This experiment was devised to investigate Hypothesis 3. This third hypothesis was that there would be an effect of introducing forms of reasoning through focused lessons on students' creative performance before students are asked to exercise two particular forms of reasoning strategies. The participants *(n=21: 7 male, 14 female)* were divided into two groups as I-AR and I-RbR. Before the exercise, a presentation about the particular form of reasoning strategy the group was asked to use was given. The duration of the presentation was approximately 45 minutes.

Cases of analogical reasoning strategies used in architecture as a subcategory of associative reasoning was shown by providing architectural design examples. Throughout the presentation, the mappings between all the source analogs and the products were explicitly presented both visually and verbally by the researcher. The first group examples focusing on Santiago Calatrava's work, who is a leading Spanish architect, were used to introduce the notions of similarity, analogy, and metaphor. The second group of examples used one of Mondrian's compositions, The Schröder House by Gerrit Rietveld, and Case Study House no:8 by Charles and Ray Eames. By using these, it is emphasized that a single source analog can lead to different design ideas. Lastly, the Unite d'Habitation in Marseille by Le Corbusier and sketches (see

Figure 2) taken from the article by Tzonis (1992) were used to show that a design problem can be composed of several interconnected problems thus more than one analogy can be used in design problem solving. In the part about rule-based reasoning, the representational system of shape grammar rules and how they are used to generate compositions with additive rules in a beginner level were introduced. A short exercise for five minutes is conducted to familiarize the participants with the workings of such additive rule-based approach and its representations. The presentation included a section on how reasoning process can be represented by using shape rules. The lecture also exemplified a number of strategies to utilize a visual display to make a new composition.

3.5. Data Collection

The data collected is composed of three types of outputs. These are 'a x a' (n=135) and '3a x 3a' (n=135) compositions which are outputs of the first and second tasks. Reports of individual design processes with text and drawings are outputs of the third task. Sketches and drafts from their process were also collected as data to be used in the analysis.

3.6. Assessment

There are seven criteria used in the assessment of product creativity. The first criterion "overall creativity" measures each rater's individual assessment of artifact's creativity without breaking down the rater's judgment into subscales. The criteria "novelty", "unity" and "complexity" are based on the previous studies in the literature on the product creativity (Besemer 1998; Besemer & Treffinger 1981; Christiaans 2002; Demirkan & Afacan 2012; Hasırcı & Demirkan 2003; O'Quin & Besemer 1999; Olguntürk & Demirkan 2011; Runco 2004). The criteria "shape emergence", "shape recurrence" and "shape variation" are concepts based on Özkar's (2011) study on the design exercise utilized in the experiments. The seven criteria used in the rating form are as below (Table 6).

Table 6. Items for product creativity assessment.

Overall creativity	Originality	Elaboration				
	Novelty	Shape emergence	Shape recurrence	Shape variation	Unity	Complexity

Christiaans (2002) suggests that creativity of the product seems to be one of the most important criteria for performance quality in design. To relate the present studies on design reasoning to creativity, the designs generated by the students were rated according to a number of indicators of creativity. These indicators included the number of ideas (fluency), the number of categories of ideas (flexibility) and overall creativity (Demirkan & Afacan 2012; Kreitler & Casakin 2009). Although, these indicators are used to assess individual differences in creative thinking, they may provide a measure to degree to which there is a difference between the measures of the products of the process and the measure for the final product in relation to the instructed form of reasoning strategy.

The study also employed a number of criteria which are considered as "the hidden dimensions of creativity" (Demirkan & Hasirci 2009). The 'Shape' as a criterion has a particular relevancy due to the nature of design exercise used in the experiments however Demirkan and Afacan (2012) found no evidence for the interaction of shape with the creative product characteristics. Instead, shape emergence, shape recurrence and shape variation are proposed as criteria for the assessment because these are also proposed as notions that are “part of the foundational design knowledge to be primarily conveyed in basic design exercises” (Özkar 2011, p. 116). While Stiny (2006) points out to the simultaneity of them as parts of visual reasoning in design, in the context of the study, these notions are considered as belonging to both cognitive and artifact characteristics since they are also highly associated with design creativity (Oxman 2002).

3.6.1. Dimensions of creative performance

The most often cited criterion of creativeness is originality. Guilford defined it as "statistical infrequency" (Guilford 1950). This criterion may be thought of as newness, novelty, remoteness, or unusualness. Besemer and Treffinger (1981) report that seventeen sources offered criteria related to originality as a major component of creativity. These included: ingenious (Eichenberger 1972); less than logical consistency with other experiences (Jackson & Messick 1965); novelty (Carlinsky 1976; Jackson & Messick 1965; Martinson & Seagoe 1967; Mednick 1964); original (Barron et al. 1973; Eichenberger 1972; Helson 1978; Koestler 1964; Maltzman 1960; Martinson & Seagoe 1967; Maslow 1959; Taylor & Sandler 1972; Ward & Cox 1974); produced independently (Rhodes 1956); personal newness (Brogden & Sprecher 1964); unusualness (Guilford 1968; Jackson & Messick 1965; Ward & Cox 1974); and student's own idea (Eichenberger 1972). The criterion selected in this study is “novelty” due its use in studies on creativity assessment with design students (Demirkan & Afacan 2012; Hasırcı & Demirkan 2003).

The tasks in the experiments require participants to combine elements into a coherent whole or unit (Besemer & Treffinger 1981). While this can be evaluated with various criteria, the study focuses on two of them regarding to the nature of the design exercise used in the experiments. These are “complexity” and “unity”. The criterion of complexity includes several types of complexity such as technical, ideational and phenomenal (Barron et al. 1973). This criterion is selected to take place in the rating form since it has also been described as gradation of values and variety in shapes or patterns (Burkhart 1962).

The other criterion named as “unity” is defined as “the extent to which a product has an organizational unity or comprehensiveness and completeness about it” (Besemer

& Treffinger 1981, p. 172). It also has been described in various ways. These include integrative (Maslow 1959); spatial, organizational unity (Burkhart 1962); comprehensiveness (Brogden & Sprecher 1964); aesthetic sense of unity and organization of complex disorder from nature (Eichenberger 1972); and a coherent whole (Battcock 1973). This criterion is selected to take place in the assessment/rating form and named as "unity" since it communicates in a clearer and more comprehensible way. It also corresponds to the designerly term "unity" which is commonly used in first year design education content regarding to composition.

Besides these four criteria, three more criteria "shape emergence", "shape recurrence" and "shape variation" are proposed to be used in the assessment form. Emergence, recurrence and variation are discussed as parts of design knowledge which are embedded in the specified exercise as visual computations to be explored (Özkar 2011). Thus, these three concepts can be utilized as criteria to assess each outcome since they are specific to the exercise employed in the experiments. They may also offer a vocabulary for further discussion in relation to visual cognition, visual computation, design reasoning and creativity. These three concepts have the potential to communicate in a clearer and more comprehensible way for both among instructors and students compared to traditional concepts like "harmony", "balance", "rhythm" etc. which are usually introduced as the content basic design education. The use of such concepts presents a problem for design students in their beginning years (Arpak 2016). Especially when first year design students are told their design need improvement by using such terms, these concepts are hard to comprehend and visualize. In other words, the traditional concepts are hard to represent visually other than providing an example, however shape grammar representations are able to provide inherently the concepts like emergence and recurrence with their abstract quality independent of an existing precedent.

3.6.2. Scoring

In order to assess outputs of Task 1 and Task 2, three independent raters experienced in first year design education were asked to rate each product on an ordinal scale (1 = poor; 2 = poor-average; 3 = average; 4 = average-excellent; 5 = excellent) for each seven criteria. For flexibility and fluency measurements, the researcher counted the number of ideas and the number of types of ideas.

3.6.3. Inter-rater Agreement

Rater 1 has six and a half years of experience in teaching first year students. Rater 2 has 10 years of experience in teaching first year students and involved in designing content for the first-year design studio. Rater 3 has six years of experience in teaching first year students and involved in coordinating the first-year design studio and designing content for the course.

A computer screen was used to show each artifact to be the raters. A slide show with a time limitation of one minute was set to show the artifacts to the raters to provide equal amount of time of assessment for each artifact. A pilot study was conducted to determine the amount of time needed for each artifact's assessment. A rating form was printed out and handed to each rater.

Since the number of artifacts to be evaluated was 270 in total (Task1 = 135, Task 2 = 135) for each rater and belonged to two different tasks, each rating session is divided into two main sessions according to two tasks. The researcher was present at each rating session for the set-up and organizing time-breaks. After the completion of the assessment of 45 artifacts (45 minutes), the slide show was paused, and the raters took 10 minutes of break. Each rating session was conducted with each rater independently, thus the possibility of affecting each other while assessing the artifacts was eliminated.

After three rating sessions were completed, the Delphi method was used to determine consensus among the three independent raters. All ratings with SD (standard deviation) less than one were considered as similar. In the first round of rating for the products of Task 1, there was 71% agreement for overall creativity, 74% agreement for novelty, 79% agreement for shape emergence, 80% agreement for shape recurrence, 80% agreement for shape variation, 64% agreement for unity, 67% agreement for complexity ratings among the three independent raters. Following the first round, the raters were presented with the ratings for which there was significant disagreement and were asked whether they would reconsider their initial rating. In the second round of rating for the products of Task 1, there was 96% agreement for overall creativity, 93% agreement for novelty, 98% agreement for shape emergence, 96% agreement for shape recurrence, 98% agreement for shape variation, 96% agreement for unity, 98% agreement for complexity ratings among the judges. In the second round of rating for the products of Task 2, there was 99% agreement for overall creativity, 96% agreement for novelty, 99% agreement for shape emergence, 96% agreement for shape recurrence, 98% agreement for shape variation, 96% for unity, 99% for complexity ratings among the three independent raters.

3.6.4. Inter-rater Reliability

The two-dimensional compositions which are output of Task 1 and Task 2 were evaluated by three independent raters. While inter-rater agreement is used to understand to the extent to which different raters assign the same score for each product being rated, inter-rater reliability needs to be tested whether the ratings of different raters are consistent between different items on a measurement scale (Gisev et al. 2013). Intra-class coefficient (ICC) was used to assess the inter-rater reliability for ratings given by the three independent raters. ICC estimates and their 95% confident intervals were calculated using SPSS statistical package version 20 (SPSS Inc, Chicago, IL) based on a mean-rating (k = 3), absolute agreement, 2-way mixed-effects model for Task 1 and Task 2. A two-way mixed-effects model was used for the calculation since the selected raters were the only raters of interest. The results of this model only represent the reliability of the specific raters involved in the experiment (Koo & Li 2016). Values less than 0.5 indicate poor reliability, values between 0.5 and 0.75 indicate moderate reliability, values between 0.75 and 0.9 indicate good reliability, and values greater than 0.90 indicate excellent reliability (Koo & Li 2016).

A good degree of reliability was found between measurements. For Task 1 (see Table 7), the average measure ICC was .813 with a 95% confidence interval from .751 to .862 ($F(134,268)= 5.351$, $p<.001$).

Table 7. Results of ICC calculation for Task 1.

		95% Confidence Interval		F Test with True Value 0			
	Intraclass Correlation[b]	Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.592[a]	.501	.675	5.351	134	268	0.000
Average Measures	.813[c]	.751	.862	5.351	134	268	0.000

For Task 2 (see Table 8), the average measure ICC was .798 with a 95% confidence interval from .560 to .891 (F(134,268)= 7.648, p<.001).

Table 8. Results of ICC calculation for Task 2.

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.568[a]	.298	.731	7.648	134	268	.000
Average Measures	.798[c]	.560	.891	7.648	134	268	.000

3.7. Analysis

The analysis of the collected data consists of both quantitative and qualitative analysis. Quantitative analysis is composed of two parts which are product oriented and process-oriented evaluations. The qualitative analysis presents the participants' reasoning processes and their design moves through illustrative examples from the retrospective reports in Task 3.

3.7.1. Quantitative Analysis

Kruskal-Wallis one-way ANOVAs were conducted for each experiment including three or more experiment groups. Mann-Whitney U test were applied between pairs of experiment groups to determine where the difference lies between the groups. Differences between experiment groups were considered significant at a level of 95% ($p < 0.05$).

In the quantitative analysis, the ratings of overall creativity, novelty, shape emergence, shape recurrence and shape variation, unity, and complexity for both Task 1 and Task 2 were examined with Kruskal-Wallis one-way ANOVAs for each criterion to test if there is a significant difference among experiment groups. Differences between experiment groups were considered significant at a level of 95% ($p < 0.05$). Mann-Whitney U test were applied between pairs of experiment groups to determine where the difference lies between the groups.

Another quantitative analysis was conducted by counting the frequency of design proposals is produced (fluency) and how many types of design proposals (flexibility) in both Task 1 and Task 2. A comparison was made based on these counts among experiment groups.

For Experiment I, these two measurements were used to determine if there is a difference between the measures of the products of the process and the measure for the final product in relation to the instructed form of reasoning strategy.

In addition to Kruskal-Wallis one-way ANOVAs in Experiment II, the ratings of overall creativity, novelty, shape emergence, shape recurrence and shape variation, unity and complexity for both Task 1 and Task 2 were also examined for order effects within each criterion.

To investigate the effect of explicit lesson, a comparison between the experiment groups in Experiment I and III was conducted. The ratings of overall creativity, novelty, shape emergence, shape recurrence and shape variation, unity, and complexity for both Task 1 and Task 2 were examined with Kruskal-Wallis one-way ANOVAs for each criterion. Differences between experiment groups were considered significant at a level of 95% ($p < 0.05$). Mann-Whitney U test are applied between pairs of experiment groups to determine where the difference lies between the groups.

3.7.2. Qualitative Analysis

The qualitative analysis presents the participants' reasoning processes, and their design moves through illustrative examples from the retrospective reports in Task 3. A thematic analysis with a data-driven approach (Namey et al. 2008) is conducted where the notions related to dual process accounts on reasoning and creativity in the experiment is utilized as separate themes for the qualitative analysis. First, the researcher used two structural codes to make the large qualitative data set more manageable. These two codes refer to task-based codes for identifying whether the content of the textual data reports on the processes in Task 1 or Task 2. In further analysis, a data-driven approach is used. In this step, three subthemes under idea generation and three subthemes under idea evaluation are coded as exemplified in Table 9.

Table 9. Data extract, with codes applied.

Theme	Sub-theme	Explanation	Data extract
Idea Generation	Elemental adaptation	Transformational operations upon the elements of the composition in the source image to achieve a new design	I tried to make a composition by using the circle that I took from the image.
	Schema adaptation	Maintaining the organizational features of the composition in the source image and its transfer to achieve a new design	When I looked at the given image the first thing I noticed was the linear elements intersecting as in the shape of a "X".
	Making rules	The use of self-generated rules to achieve a new design	I continued by coming up with a rule. My rule is that, if you start from the first square, you'll see that the amount of black colored areas reduces.
Idea evaluation	Occurrence of a new shape	Ending the design process by seeing complementary parts of a desired shape.	I placed the small units in such a way that when the triangle come side by side with another, they form a square.
	Continuity of lines	Aligning an element of in a unit across multiple units	I placed the units in such a way that when I combined them as the axes continue.
	Ideation without substance	Absence of evaluation	In the second part of design (referring to Task 2) I produced enough number of units and I brought them together on the first impulse.

CHAPTER 4

RESULTS

Kruskal Wallis H tests and Mann-Whitney U tests are used to determine if there are statistically significant differences across groups in three experiments. This chapter is divided into two subheadings following Guilford's four partite creativity measurement: originality, elaboration, fluency, flexibility. Under the heading "Product Oriented Evaluation" that includes originality and elaboration, the results for the analysis of individual assessments evaluated by three expert raters will be reported. Under the heading "Process Oriented Evaluation" that includes fluency and flexibility, the results of the frequency analysis will be presented.

4.1. Product Oriented Evaluation

This section presents the results of individual assessments of three expert raters in terms of overall creativity, originality, elaboration and their sub-items.

4.1.1. Experiment I – Task 1

Kruskal Wallis H test is applied on the measurement criteria to determine the statistically significant results for Experiment 1 Task 1, which asked students to design a unit (a x a). The results indicate that one criterion among seven were significant: unity (T1C5, $\chi2(2) = 6.822$, $p = 0.033$), which partially confirms Hypothesis 1.

Table 10. Kruskal Wallis H test statistics for Task 1 in Experiment I.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Chi-Square	1.840	4.772	.923	2.721	.153	6.822	2.228
Df	2	2	2	2	2	2	2
Asym. Sig.	.399	.092	.630	.256	.926	**.033**	.328

4.1.1.1. Unity

A Kruskal-Wallis H test showed that there was a statistically significant difference in unity score among groups, $\chi 2(2) = 6.822$, $p = 0.033$, with a mean rank unity score of 49.22 for control group, 35.77 for associative reasoning group (AR) and 51.22 for rule-based reasoning group (RbR).

Table 11. Ranks for Unity in Task 1 in Experiment I.

Groups	N (number of products)	Mean Rank
RbR	10	**51.22**
C	10	49.22
AR	10	35.77
Total	30	

Among pairwise comparisons, there were two statistical differences in unity score. A Mann-Whitney U test indicated that there was a significant difference ($U = 319.000$, $p = 0.045$) between AR group that starts to design with a precedent compared to the C group that received no intervention.

Table 12. Mann-Whitney U test statistics for experiment groups C vs AR.

	unity
Mann-Whitney U	319.000
Wilcoxon W	784.000
Z	-2.006
Asymp. Sig. (2-tailed)	.045

The products in C group have a higher mean rank (mean rank = 34.87) than the products in AR group (mean rank = 26.13) suggesting that they are more successful in achieving a sense of unity in Task 1.

Table 13. Ranks for Unity criterion for experiment groups C vs AR.

Groups	N	Mean Rank	Sum of Ranks
Control	30	34.87	1046.00
AR	30	26.13	784.00
Total	60		

A Mann-Whitney U test indicated that there was a significant difference (U = 289.000, p = 0.013) between AR group that starts to design with a precedent compared to the RbR group that were asked to start to design with a list of shape rules.

Table 14. Mann-Whitney U test statistics for experiment groups RbR vs AR.

	unity
Mann-Whitney U	289.000
Wilcoxon W	754.000
Z	-2.482
Asymp. Sig. (2-tailed)	.013

The products in RbR group have a higher mean rank (mean rank = 35.87) than the products in AR group (mean rank = 25.13) suggesting that they are more successful in achieving a sense of unity in Task 1.

Table 15. Ranks for Unity criterion for experiment groups RbR vs AR.

Groups	N	Mean Rank	Sum of Ranks
RbR	30	35.87	1076.00
AR	30	25.13	754.00
Total	60		

4.1.2. Experiment I – Task 2

Kruskall Wallis H test is applied on the measurement criteria to determine the statistically significant results for Experiment 1 Task 2 data. This task required students to design 3 x a x a composition from the a x a units designed in Task 1. Chi-Square results indicate that six criteria among seven were significant: overall creativity (T2C, $\chi 2(2) = 12.012$, p= 0.002), novelty (T2C1, $\chi 2(2) = 13.182$, p= 0.001), shape emergence (T2C2, $\chi 2(2) = 12.611$, p= 0.002), shape recurrence (T2C3, $\chi 2(2) = 12.773$, p= 0.002), shape variation (T2C4, $\chi 2(2) = 9.684$, p= 0.008), unity (T2C5, $\chi 2(2) = 16.704$, p= 0.000) which does not confirm Hypothesis 1.

Table 16. Kruskal Wallis H test statistics for Task 2 in Experiment I.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Chi-Square	12.012	13.182	12.611	12.773	9.684	16.704	5.112
Df	2	2	2	2	2	2	2
Asym. Sig.	**.002**	**.001**	**.002**	**.002**	**.008**	**.000**	.078

4.1.2.1. Overall creativity

A Kruskal-Wallis H test showed that there was a statistically significant difference between the different forms of reasoning, $\chi 2(2) = 12.012$, $p = 0.002$, with a mean rank overall creativity score of 58.18 for control group (C), 36.55 for associative reasoning group (AR) and 41.77 for rule-based reasoning group (RbR).

Table 17. Ranks for Overall Creativity in Task 2 in Experiment I.

Groups	**N (number of products)**	**Mean Rank**
C	10	**58.18**
RbR	10	41.77

(cont. on next page)

Table 17 (cont.)

AR	10	36.55
Total	30	

Among pairwise comparisons, there were two statistically different results in overall creativity score. A Mann-Whitney U test indicated that there was a significant difference (U = 232.000, p = 0.001) between AR group that starts to design with a precedent compared to the C group that received no intervention.

Table 18. Mann-Whitney U test statistics for experiment groups C vs AR.

	Overall creativity
Mann-Whitney U	232.000
Wilcoxon W	697.000
Z	-3.339
Asymp. Sig. (2-tailed)	.001

The C group has a higher mean rank (mean rank = 37.77) than the AR group (mean rank = 23.23) suggesting that the products are assessed to be more creative in Task 2.

Table 19. Ranks for Overall Creativity criterion for experiment groups C vs AR.

Groups	N	Mean Rank	Sum of Ranks
Control	30	37.77	1133.00
AR	30	23.23	697.00
Total	60		

A Mann-Whitney U test indicated that there was a significant difference (U = 287.500, p = 0.013) between RbR group that were asked to start to design with a list of shape rules compared to the C group that received no intervention.

Table 20. Mann-Whitney U test statistics for experiment groups C vs RbR.

	Overall creativity
Mann-Whitney U	287.500
Wilcoxon W	752.500
Z	-2.490
Asymp. Sig. (2-tailed)	.013

The C group has a higher mean rank (mean rank = 35.92) than the RbR group (mean rank = 25.08) suggesting that the products of C group are assessed to be more creative in Task 2.

Table 21. Ranks for Overall Creativity criterion for experiment groups C vs RbR.

Groups	N	Mean Rank	Sum of Ranks
Control	30	35.92	1077.50
RbR	30	23.23	752.50
Total	60		

4.1.2.2. Novelty

A Kruskal-Wallis H test showed that there was a statistically significant difference in novelty score between the different forms of reasoning, $\chi2(2) = 13.182$, $p = 0.001$, with a mean rank unity score of 57.97 for control group (C), 34.42 for associative reasoning group (AR) and 44.12 for rule-based reasoning group (RbR).

Table 22. Ranks for Novelty in Task 2 in Experiment I.

Groups	N (number of products)	Mean Rank
C	10	**57.97**
RbR	10	44.12
AR	10	34.42
Total	30	

Among pairwise comparisons, there were two statistically different results in novelty score. A Mann-Whitney U test indicated that there was a significant difference (U = 220.500, p = 0.000) between AR group that starts to design with a precedent compared to the C group that received no intervention.

Table 23. Mann-Whitney U test statistics for experiment groups C vs AR.

	Novelty
Mann-Whitney U	220.500
Wilcoxon W	685.500
Z	-3.503
Asymp. Sig. (2-tailed)	.000

The C group has a higher mean rank (mean rank = 38.15) than the AR group (mean rank = 22.85) suggesting that the products are assessed to be more novel in Task 2.

Table 24. Ranks for Novelty criterion for experiment groups C vs RbR.

Groups	N	Mean Rank	Sum of Ranks
Control	30	38.15	1144.50
AR	30	22.85	685.50
Total	60		

A Mann-Whitney U test indicated that there was a significant difference (U = 307.500, p = 0.027) between RbR group that were asked to start to design with a list of shape rules compared to the C group that received no intervention.

Table 25. Mann-Whitney U test statistics for experiment groups C vs RbR.

	Novelty
Mann-Whitney U	305.500

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Table 25 (cont.)

Wilcoxon W	770.500
Z	-3.503
Asymp. Sig. (2-tailed)	.027

The C group has a higher mean rank (mean rank = 35.32) than the RbR group (mean rank = 25.68) suggesting that the products of C group are assessed to be more novel in Task 2.

Table 26. Ranks for Novelty criterion for experiment groups C vs RbR.

Groups	N	Mean Rank	Sum of Ranks
Control	30	35.32	1059.50
RbR	30	25.68	770.50
Total	60		

4.1.2.3. Shape emergence

A Kruskal-Wallis H test showed that there was a statistically significant difference in unity score between the different forms of reasoning, $\chi2(2) = 12.611$, $p = 0.002$, with a mean rank unity score of 58.88 for control group, 38.55 for associative reasoning group (AR) and 39.07 for rule-based reasoning group (RbR).

Table 27. Ranks for Shape Emergence in Task 2 in Experiment I.

Groups	N (number of products)	Mean Rank
C	10	**58.88**
RbR	10	39.07
AR	10	38.55
Total	30	

Among pairwise comparisons, there were two statistically different results in shape emergence score. A Mann-Whitney U test indicated that there was a significant difference (U = 243.500, p = 0.002) between AR group that starts to design with a precedent compared to the C group that received no intervention.

Table 28. Mann-Whitney U test statistics for experiment groups C vs AR.

	Shape Emergence
Mann-Whitney U	243.500
Wilcoxon W	708.500
Z	-3.165
Asymp. Sig. (2-tailed)	.002

The C group has a higher mean rank (mean rank = 37.38) than the AR group (mean rank = 23.62) suggesting that the products are assessed as better in making new wholes in Task 2.

Table 29. Ranks for Shape Emergence criterion for experiment groups C vs AR.

Groups	N	Mean Rank	Sum of Ranks
Control	30	37.38	1121.50
AR	30	23.62	708.50
Total	60		

A Mann-Whitney U test indicated that there was a significant difference (U = 255.000, p = 0.003) between RbR group that were asked to start to design with a list of shape rules compared to the C group that received no intervention.

Table 30. Mann-Whitney U test statistics for experiment groups C vs RbR.

	Shape Emergence
Mann-Whitney U	255.000
Wilcoxon W	720.000
Z	-2.983
Asymp. Sig. (2-tailed)	.003

The C group has a higher mean rank (mean rank = 37.00) than the RbR group (mean rank = 24.00) suggesting that the products of C group are assessed to be better in terms of unity in Task 2.

Table 31. Ranks for Shape Emergence criterion for experiment groups C vs RbR.

Groups	N	Mean Rank	Sum of Ranks
Control	30	37.00	1110.00
RbR	30	24.00	720.00
Total	60		

4.1.2.4. Shape Recurrence

A Kruskal-Wallis H test showed that there was a statistically significant difference in unity score between the different forms of reasoning, $\chi 2(2) = 12.773$, $p = 0.002$, with a mean rank unity score of 58.78 for control group (C), 40.13 for associative reasoning group (AR) and 37.58 for rule-based reasoning group (RbR).

Table 32. Ranks for Shape Recurrence in Task 2 in Experiment I.

Groups	N (number of products)	Mean Rank
C	10	**58.78**
AR	10	40.13
RbR	10	37.58
Total	30	

Among pairwise comparisons, there were two statistically different results in shape recurrence score. A Mann-Whitney U test indicated that there was a significant difference ($U = 268.000$, $p = 0.005$) between AR group that starts to design with a precedent compared to the C group that received no intervention.

Table 33. Mann-Whitney U test statistics for experiment groups C vs AR.

	Shape Recurrence
Mann-Whitney U	268.000
Wilcoxon W	733.000
Z	-2.793
Asymp. Sig. (2-tailed)	.005

The C group has a higher mean rank (mean rank = 36.57) than the AR group (mean rank = 24.43) suggesting that the products are assessed as better in establishing links of similarity between the parts in Task 2.

Table 34. Ranks for Shape Recurrence in Task 2 in Experiment I.

Groups	N	Mean Rank	Sum of Ranks
Control	30	36.57	1097.00
AR	30	24.43	733.00
Total	60		

A Mann-Whitney U test indicated that there was a significant difference (U = 233.500, p = 0.001) between RbR group that were asked to start to design with a list of shape rules compared to the C group that received no intervention.

Table 35. Mann-Whitney U test statistics for experiment groups C vs RbR.

	Shape Recurrence
Mann-Whitney U	233.500
Wilcoxon W	698.500
Z	-3.342
Asymp. Sig. (2-tailed)	.001

The C group has a higher mean rank (mean rank = 37.72) than the RbR group (mean rank = 23.28) suggesting that the products of C group are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 36. Ranks for Shape Recurrence in Task 2 in Experiment I.

Groups	N	Mean Rank	Sum of Ranks
Control	30	37.72	1131.50
RbR	30	23.28	698.50
Total	60		

4.1.2.5. Shape variation

A Kruskal-Wallis H test showed that there was a statistically significant difference in shape variation score between the different forms of reasoning, $\chi2(2) = 9.684$, $p = 0.008$, with a mean rank unity score of 55.72 for control group, 45.07 for associative reasoning group (AR) and 35.72 for rule-based reasoning group (RbR).

Table 37. Ranks for Shape Variation in Task 2 in Experiment I.

Groups	N (number of products)	Mean Rank
C	10	**55.72**
AR	10	45.07
RbR	10	35.72
Total	30	

Among pairwise comparisons, there was one statistically different result in shape variation score. A Mann-Whitney U test indicated that there was a significant difference ($U = 257.500$, $p = 0.003$) between RbR group that were asked to start to design with a list of shape rules compared to the C group that received no intervention.

Table 38. Mann-Whitney U test statistics for experiment groups C vs RbR.

	Shape Variation
Mann-Whitney U	257.500
Wilcoxon W	722.500
Z	-2.968
Asymp. Sig. (2-tailed)	.003

The C group has a higher mean rank (mean rank = 36.92) than the RbR group (mean rank = 24.08) suggesting that the products of C group are assessed to be better in establishing links of variance between the parts in Task 2.

Table 39. Ranks for Shape Recurrence in Task 2 in Experiment I.

Groups	N	Mean Rank	Sum of Ranks
Control	30	36.92	1107.50
RbR	30	24.08	722.50
Total	60		

4.1.2.6. Unity

A Kruskal-Wallis H test showed that there was a statistically significant difference in unity score between the different forms of reasoning, $\chi2(2) = 16.704$, $p = 0.000$, with a mean rank unity score of 58.68 for control group (C), 32.23 for associative reasoning group (AR) and 45.58 for rule-based reasoning group (RbR).

Table 40. Ranks for Unity in Task 2 in Experiment I.

Groups	**N (number of products)**	**Mean Rank**
C	10	**58.68**
RbR	10	45.58
AR	10	32.23
Total	30	

Among pairwise comparisons, there were three statistically different results in unity score. A Mann-Whitney U test indicated that there was a significant difference (U = 190.500, p = 0.000) between AR group that starts to design with a precedent compared to the C group that received no intervention.

Table 41. Mann-Whitney U test statistics for experiment groups C vs AR.

	Unity
Mann-Whitney U	190.500
Wilcoxon W	655.500
Z	-3.995
Asymp. Sig. (2-tailed)	.000

The C group has a higher mean rank (mean rank = 39.15) than the AR group (mean rank = 21.85) suggesting that the products are assessed as better in achieving unity in Task 2.

Table 42. Ranks for Unity in Task 2 in Experiment I.

Groups	N	Mean Rank	Sum of Ranks
Control	30	39.15	1174.50
AR	30	21.85	655.50
Total	60		

A Mann-Whitney U test indicated that there was a significant difference (U = 314.000, p = 0.035) between RbR group that were asked to start to design with a list of shape rules compared to the C group that received no intervention.

Table 43. Mann-Whitney U test statistics for experiment groups C vs RbR.

	Unity
Mann-Whitney U	314.000

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Table 43 (cont.)

Wilcoxon W	779.000
Z	-2.104
Asymp. Sig. (2-tailed)	.035

The C group has a higher mean rank (mean rank = 35.03) than the RbR group (mean rank = 25.97) suggesting that the products of C group are assessed to be better in achieving unity in Task 2.

Table 44. Ranks for Unity in Task 2 in Experiment I.

Groups	N	Mean Rank	Sum of Ranks
Control	30	35.03	1051.00
RbR	30	25.97	779.00
Total	60		

A Mann-Whitney U test indicated that there was a significant difference (U = 311.500, p = 0.031) between AR group that starts to design with a precedent compared to the RbR group that were asked to start to design with a list of shape rules.

Table 45. Mann-Whitney U test statistics for experiment groups RbR vs AR.

	Unity
Mann-Whitney U	311.500
Wilcoxon W	776.500
Z	-2.151
Asymp. Sig. (2-tailed)	.031

The products in RbR group have a higher mean rank (mean rank = 35.12) than the products in AR group (mean rank = 25.88) suggesting that they are more successful in achieving a sense of unity in Task 2.

Table 46. Ranks for Unity in Task 2 in Experiment I.

Groups	N	Mean Rank	Sum of Ranks
AR	30	25.88	776.50
RbR	30	35.12	1053.50
Total	60		

4.1.2.7. Experiment I – Design Examples

In this section, three examples illustrative of participants' designs are provided to illustrate the collected data for the first experiment. These include one example for each experiment group for all tasks (Figure 10).

Control group (C) | Associative Reasoning Group (AR) | Rule-based reasoning Group (RbR)

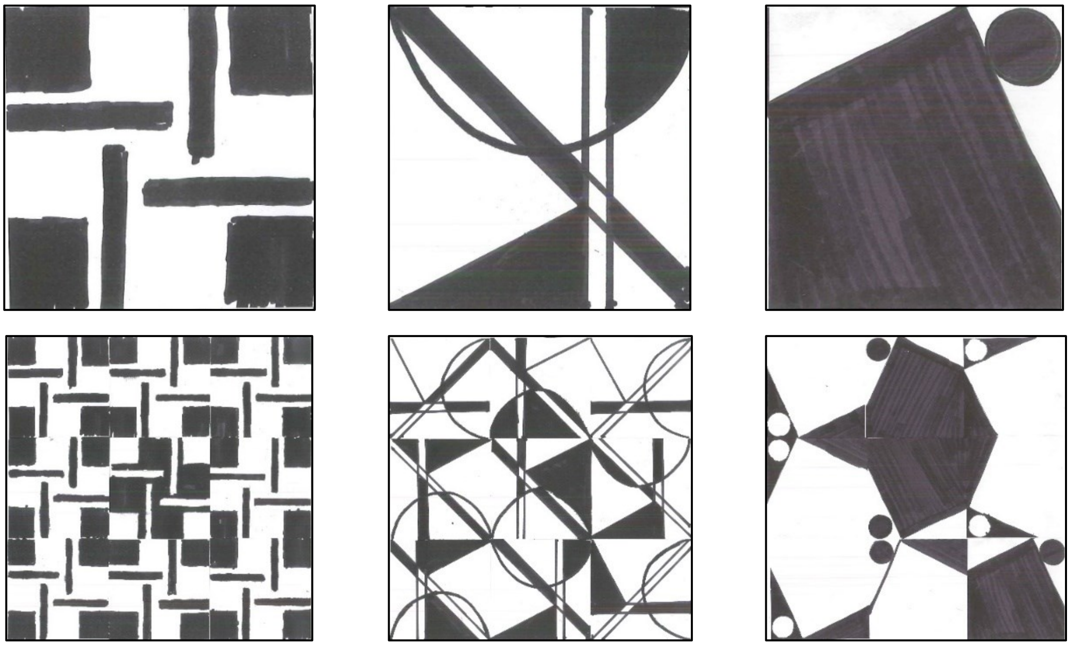

Figure 10. Design examples for Task 1 and Task 2 in Experiment I.

4.1.3. Experiment II – Task 1

Kruskall Wallis H test is applied on the measurement criteria to determine the statistically significant results for Experiment II Task 1, which asked students to undertake the a x a design unit problem in six different sequences. Chi-Square results indicate that four criteria among seven were significant: overall creativity (T1C1, $\chi2(2)$ = 12.408, p= 0.030), novelty (T1C2, $\chi2(2)$ = 19.418, p= 0.002), shape emergence (T1C3, $\chi2(2)$ = 12.184, p= 0.032), complexity (T1C7, $\chi2(2)$ = 11.205, p= 0.047), which partially confirms Hypothesis 2. The order in which the reasoning strategies are performed has an impact on the creative output of novice learner.

Table 47. Kruskal Wallis H test statistics for Task 1 in Experiment II.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Chi-Square	12.408	19.418	12.184	7.189	6.558	9.712	11.205
Df	5	5	5	5	5	5	5
Asym. Sig.	**.030**	**.002**	**.032**	.207	.256	.084	**.047**

4.1.3.1. Overall creativity

A Kruskal-Wallis H test showed that there was a statistically significant difference in overall creativity score between the different sequences, $\chi2(2) = 12.408$, $p = 0.030$, with a mean rank unity score of 90.67 for AR-RbR-C group, 83.26 AR-C-RbR group, 121.11 for C-AR-RbR group, 103.28 for RbR-AR-C group, 79.78 for RbR-C-AR group, 91.46 for C-RbR-AR group.

Table 48. Ranks for Overall Creativity in Task 1 in Experiment II.

Groups	**N (number of products)**	**Mean Rank**
AR-RbR-C	27	90.67
AR-C-RbR	27	83.26

(cont. on next page)

Table 48 (cont.)

C-AR-RbR	27	**121.11**
RbR-AR-C	45	103.28
RbR-C-AR	36	79.78
C-RbR-AR	27	91.46
Total	189	

Among pairwise comparisons, there were five statistically different results in overall creativity score. A Mann-Whitney U test indicated that there was a significant difference (U = 244.500, p = 0.029) between the AR-RbR-C sequence and the C-AR-RbR sequence.

Table 49. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-RbR-C.

	C-AR-RbR AR-RbR-C
Mann-Whitney U	244.500
Wilcoxon W	622.500
Z	-2.179
Asymp. Sig. (2-tailed)	.029

The C-AR-RbR sequence has a higher mean rank (mean rank = 31.94) than the AR-RbR-C sequence (mean rank = 23.06) suggesting that the products are assessed to be more creative in Task 1.

Table 50. Ranks for Overall Creativity in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	31.94	862.50
AR-RbR-C	27	23.06	622.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 232.500, p = 0.017) between the AR-C-RbR sequence and the C-AR-RbR sequence.

Table 51. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	232.500
Wilcoxon W	610.500
Z	-2.397
Asymp. Sig. (2-tailed)	.017

The C-AR-RbR sequence has a higher mean rank (mean rank = 32.39) than the AR-C-RbR sequence (mean rank = 22.61) suggesting that the products are assessed to be more creative in Task 1.

Table 52. Ranks for Overall Creativity in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	32.39	874.50
AR-C-RbR	27	23.06	610.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 295.500, p = 0.006) between the RbR-C-AR sequence and the C-AR-RbR sequence.

Table 53. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-C-AR.

	C-AR-RbR RbR-C-AR
Mann-Whitney U	295.500
Wilcoxon W	961.500
Z	-2.738
Asymp. Sig. (2-tailed)	.006

The C-AR-RbR sequence has a higher mean rank (mean rank = 39.06) than the RbR-C-AR sequence (mean rank = 26.71) suggesting that the products are assessed to be more creative in Task 1.

Table 54. Ranks for Overall Creativity in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	39.06	1054.50
RbR-C-AR	36	26.71	961.50
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 235.500, p = 0.017) between the C-RbR-AR sequence and the C-AR-RbR sequence.

Table 55. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. C-RbR-AR.

	C-AR-RbR C-RbR-AR
Mann-Whitney U	235.500
Wilcoxon W	613.500
Z	-2.378
Asymp. Sig. (2-tailed)	.017

The C-AR-RbR sequence has a higher mean rank (mean rank = 32.28) than the C-RbR-AR sequence (mean rank = 22.72) suggesting that the products are assessed to be more creative in Task 1.

Table 56. Ranks for Overall Creativity in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	32.28	871.50
C-RbR-AR	27	22.72	613.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 598.000, p = 0.036) between the RbR-AR-C sequence and the RbR-C-AR sequence.

Table 57. Mann-Whitney U test statistics for experiment groups RbR-AR-C vs. RbR-C-AR.

	RbR-AR-C RbR-C-AR
Mann-Whitney U	235.500
Wilcoxon W	613.500
Z	-2.378
Asymp. Sig. (2-tailed)	.017

The RbR-AR-C sequence has a higher mean rank (mean rank = 45.71) than the RbR-C-AR sequence (mean rank = 35.11) suggesting that the products are assessed to be more creative in Task 1.

Table 58. Ranks for Overall Creativity in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	45	45.71	2057.00
C-RbR-AR	36	35.11	1264.00
Total	81		

4.1.3.2. Novelty

A Kruskal-Wallis H test showed that there was a statistically significant difference in novelty score across the different sequences, $\chi2(2) = 19.418$, p = 0.002, with a mean rank novelty score of 111.56 for AR-RbR-C group, 80.43 for AR-C-RbR group, 119.11 for C-AR-RbR group, 103.24 for RbR-AR-C group, 72.06 for RbR-C-AR group, 85.76 for C-RbR-AR group.

Table 59. Ranks for Novelty in Task 1 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	111.56
AR-C-RbR	27	80.43
C-AR-RbR	27	**119.11**
RbR-AR-C	45	103.24
RbR-C-AR	36	72.06
C-RbR-AR	27	85.76
Total	189	

Among pairwise comparisons, there were six statistically different results in novelty score. A Mann-Whitney U test indicated that there was a significant difference ($U = 246.500$, $p = 0.034$) between the AR-RbR-C sequence and the AR-C-RbR sequence.

Table 60. Mann-Whitney U test statistics for experiment groups AR-RbR-C vs. AR-C-RbR.

	AR-RbR-C AR-C-RbR
Mann-Whitney U	246.500
Wilcoxon W	624.500
Z	-2.120
Asymp. Sig. (2-tailed)	.034

The AR-RbR-C sequence has a higher mean rank (mean rank = 31.87) than the AR-C-RbR sequence (mean rank = 23.13) suggesting that the products are assessed to be more novel in Task 1.

Table 61. Ranks for Novelty in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
AR-RbR-C	27	31.87	860.50
AR-C-RbR	27	23.13	624.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 282.000, p = 0.003) between the AR-RbR-C sequence and the RbR-C-AR sequence.

Table 62. Mann-Whitney U test statistics for experiment groups AR-RbR-C vs. RbR-C-AR.

	AR-RbR-C RbR-C-AR
Mann-Whitney U	282.000
Wilcoxon W	948.000
Z	-2.953
Asymp. Sig. (2-tailed)	.003

The AR-RbR-C sequence has a higher mean rank (mean rank = 39.56) than the RbR-C-AR sequence (mean rank = 26.33) suggesting that the products are assessed to be more novel in Task 1.

Table 63. Ranks for Novelty in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
AR-RbR-C	27	39.56	1068.00
RbR-C-AR	36	26.33	948.00
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 223.500, p = 0.010) between the AR-C-RbR sequence and the C-AR-RbR.

Table 64. Mann-Whitney U test statistics for experiment groups AR-RbR-C vs. RbR-C-AR.

	AR-C-RbR C-AR-RbR
Mann-Whitney U	223.500
Wilcoxon W	601.500
Z	-2.569
Asymp. Sig. (2-tailed)	.010

The C-AR-RbR sequence has a higher mean rank (mean rank = 32.72) than the AR-C-RbR sequence (mean rank = 22.28) suggesting that the products are assessed to be more novel in Task 1.

Table 65. Ranks for Novelty in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	32.72	883.50
AR-C-RbR	27	22.28	601.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 248.500, p = 0.001) between the RbR-C-AR sequence and the C-AR-RbR.

Table 66. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-C-AR.

	C-AR-RbR RbR-C-AR
Mann-Whitney U	248.500
Wilcoxon W	914.500
Z	-3.465
Asymp. Sig. (2-tailed)	.001

The C-AR-RbR sequence has a higher mean rank (mean rank = 40.80) than the RbR-C-AR sequence (mean rank = 25.40) suggesting that the products are assessed to be more novel in Task 1.

Table 67. Ranks for Novelty in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	40.80	1101.50
RbR-C-AR	36	22.28	914.50
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 229.000, p = 0.012) between the C-RbR-AR sequence and the C-AR-RbR.

Table 68. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. C-RbR-AR.

	C-AR-RbR C-RbR-AR
Mann-Whitney U	229.000
Wilcoxon W	607.000
Z	-2.498
Asymp. Sig. (2-tailed)	.012

The C-AR-RbR sequence has a higher mean rank (mean rank = 32.52) than the C-RbR-AR sequence (mean rank = 22.48) suggesting that the products are assessed to be more novel in Task 1.

Table 69. Ranks for Novelty in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	32.52	878.00
C-RbR-AR	36	22.48	607.00
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 541.000, p = 0.008) between the RbR-C-AR sequence and the RbR-AR-C.

Table 70. Mann-Whitney U test statistics for experiment groups RbR-AR-C vs. RbR-C-AR.

	RbR-AR-C RbR-C-AR
Mann-Whitney U	541.000
Wilcoxon W	1207.000
Z	-2.671
Asymp. Sig. (2-tailed)	.008

The RbR-AR-C sequence has a higher mean rank (mean rank = 46.98) than the RbR-C-AR sequence (mean rank = 33.53) suggesting that the products are assessed to be more novel in Task 1.

Table 71. Ranks for Novelty in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	45	46.98	2114.00
C-RbR-AR	36	33.53	1207.00
Total	81		

4.1.3.3. Shape emergence

A Kruskal-Wallis H test showed that there was a statistically significant difference in shape emergence score between the different sequences, $\chi2(2) = 12.184$, $p = 0.032$, with a mean rank shape emergence score of 94.11 for AR-RbR-C group, 72.54 for AR-C-RbR group, 120.43 for C-AR-RbR group, 94.40 for RbR-AR-C group, 90.15 for RbR-C-AR group, 100.39 for C-RbR-AR group.

Table 72. Ranks for Shape Emergence in Task 1 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	94.11
AR-C-RbR	27	72.54
C-AR-RbR	27	**120.43**
RbR-AR-C	45	94.40
RbR-C-AR	36	90.15
C-RbR-AR	27	100.39
Total	189	

Among pairwise comparisons, there were four statistically different results in shape emergence score. A Mann-Whitney U test indicated that there was a significant difference (U =195.500, p = 0.002) between the C-AR-RbR sequence and the AR-C-RbR sequence.

Table 73. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	195.500
Wilcoxon W	573.500
Z	-3.037
Asymp. Sig. (2-tailed)	.002

The C-AR-RbR sequence has a higher mean rank (mean rank = 33.76) than the AR-C-RbR sequence (mean rank = 21.24) suggesting that the products are assessed to be better in making new shapes or new parts in Task 1.

Table 74. Ranks for Shape Emergence in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	33.76	911.50
AR-C-RbR	27	21.24	573.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U =256.000, p = 0.047) between the C-RbR-AR sequence and the AR-C-RbR sequence.

Table 75. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. AR-C-RbR.

	C-RbR-AR AR-C-RbR
Mann-Whitney U	256.000
Wilcoxon W	634.000
Z	-1.982
Asymp. Sig. (2-tailed)	.047

The C-RbR-AR sequence has a higher mean rank (mean rank = 31.52) than the AR-C-RbR sequence (mean rank = 23.48) suggesting that the products are assessed to be better in making new shapes or new parts in Task 1.

Table 76. Ranks for Shape Emergence in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-RbR-AR	27	31.52	851.00
AR-C-RbR	27	23.48	634.00
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U =437.000, p = 0.038) between the C-AR-RbR sequence and the RbR-AR-C sequence.

Table 77. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-AR-C.

	C-AR-RbR RbR-AR-C
Mann-Whitney U	437.000
Wilcoxon W	1472.000
Z	-2.078
Asymp. Sig. (2-tailed)	.038

The C-AR-RbR sequence has a higher mean rank (mean rank = 42.81) than the RbR-AR-C sequence (mean rank = 32.71) suggesting that the products are assessed to be better in making new shapes or new parts in Task 1.

Table 78. Ranks for Shape Emergence in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	42.81	1156.00
RbR-AR-C	45	32.71	1472.00
Total	72		

A Mann-Whitney U test indicated that there was a significant difference (U =333.500, p = 0.027) between the C-AR-RbR sequence and the RbR-C-AR sequence.

Table 79. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-C-AR.

	C-AR-RbR RbR-C-AR
Mann-Whitney U	333.500
Wilcoxon W	999.500
Z	-2.209
Asymp. Sig. (2-tailed)	.027

The C-AR-RbR sequence has a higher mean rank (mean rank = 37.65) than RbR-C-AR sequence (mean rank = 27.76) suggesting that the products are assessed to be better in making new shapes or new parts in Task 1.

Table 80. Ranks for Shape Emergence in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	37.65	1016.50
RbR-C-AR	36	27.76	999.50
Total	63		

4.1.3.4. Complexity

A Kruskal-Wallis H test showed that there was a statistically significant difference in complexity score between the different sequences, $\chi 2(2) = 11.205$, p = 0.047, with a mean rank complexity score of 90.09 for AR-RbR-C group, 77.22 for AR-C-RbR group, 116.11 for C-AR-RbR group, 98.96 for RbR-AR-C group, 83.06 for RbR-C-AR group, 105.91 for C-RbR-AR group.

Table 81. Ranks for Complexity in Task 1 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	90.09
AR-C-RbR	27	77.22
C-AR-RbR	27	**116.11**
RbR-AR-C	45	98.96
RbR-C-AR	36	83.06
C-RbR-AR	27	105.91
Total	189	

Among pairwise comparisons, there were three statistically different results in complexity score. A Mann-Whitney U test indicated that there was a significant difference (U =211.500, p = 0.005) between the C-AR-RbR sequence and the AR-C-RbR sequence.

Table 82. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	211.500
Wilcoxon W	589.500
Z	-2.802
Asymp. Sig. (2-tailed)	.005

The C-AR-RbR sequence has a higher mean rank (mean rank = 33.17) than the AR-C-RbR sequence (mean rank = 21.83) suggesting that the products are assessed as having more complex relations between parts of the composition in Task 1.

Table 83. Ranks for Complexity in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	33.17	895.50
AR-C-RbR	27	21.83	589.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U =253.000, p = 0.042) between the C-RbR-AR sequence and the AR-C-RbR sequence.

Table 84. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. AR-C-RbR.

	C-RbR-AR AR-C-RbR
Mann-Whitney U	253.000
Wilcoxon W	631.000
Z	-2.032
Asymp. Sig. (2-tailed)	.042

The C-RbR-AR sequence has a higher mean rank (mean rank = 31.63) than the AR-C-RbR sequence (mean rank = 23.37) suggesting that the products are assessed as having more complex relations between parts of the composition in Task 1.

Table 85. Ranks for Complexity in Task 1 in Experiment II.

Groups	**N**	**Mean Rank**	**Sum of Ranks**
C-RbR-AR	27	31.63	854.00
AR-C-RbR	27	23.37	631.00
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U =314.500, p = 0.012) between the C-AR-RbR sequence and the RbR-C-AR sequence.

Table 86. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-C-AR.

	C-AR-RbR RbR-C-AR
Mann-Whitney U	314.500
Wilcoxon W	980.500
Z	-2.516
Asymp. Sig. (2-tailed)	.012

The C-AR-RbR sequence has a higher mean rank (mean rank = 38.35) than the RbR-C-AR sequence (mean rank = 27.24) suggesting that the products are assessed as having more complex relations between parts of the composition in Task 1.

Table 87. Ranks for Complexity in Task 1 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	38.35	1035.50
RbR-C-AR	36	27.24	980.50
Total	63		

4.1.4. Experiment II – Task 2

Kruskall Wallis H test is applied on the measurement criteria to determine the statistically significant results for Experiment 2 Task 2, which asked students to design a composition of 3 x a x a in three different sequences of reasoning strategy. Chi-Square results indicate that five criteria among seven were significant: overall creativity (T2C, $\chi2(2) = 18.240$, p= 0.003), shape recurrence (T2C3, $\chi2(2) = 13.318$, p= 0.021), shape variation (T2C4, $\chi2(2) = 16.275$, p= 0.006), unity (T2C5, $\chi2(2) = 17.332$, p= 0.004), complexity (T2C6, $\chi2(2) = 17.153$, p= 0.004), which partially confirms Hypothesis 2. The order in which the reasoning strategies are performed has an impact only on the creative output of novice learner.

Table 88. Kruskal Wallis H test statistics for Task 2 in Experiment II.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Chi-Square	18.240	10.727	5.943	13.318	16.275	17.332	17.153
Df	5	5	5	5	5	5	5
Asym. Sig.	**.003**	.057	.312	**.021**	**.006**	**.004**	**.004**

4.1.4.1. Overall creativity

A Kruskal-Wallis H test showed that there was a statistically significant difference in overall creativity score between the different sequences, $\chi2(2) = 18.240$, $p = 0.003$, with a mean rank overall creativity score of 86.28 for AR-RbR-C group, 63.72 for AR-C-RbR group, 119.56 for C-AR-RbR group, 99.68 for RbR-AR-C group, 91.69 for RbR-C-AR group, 107.06 for C-RbR-AR group.

Table 89. Ranks for Overall Creativity in Task 2 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	86.28
AR-C-RbR	27	63.72
C-AR-RbR	27	**119.56**
RbR-AR-C	45	99.68
RbR-C-AR	36	91.69
C-RbR-AR	27	107.06
Total	189	

Among pairwise comparisons, there were six statistically different results in overall creativity score. A Mann-Whitney U test indicated that there was a significant difference ($U = 233.000$, $p = 0.017$) between the AR-RbR-C sequence and the C-AR-RbR sequence.

Table 90. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-RbR-C.

	C-AR-RbR AR-RbR-C
Mann-Whitney U	233.000
Wilcoxon W	611.000
Z	-2.381
Asymp. Sig. (2-tailed)	.017

The C-AR-RbR sequence has a higher mean rank (mean rank = 32.37) than the AR-RbR-C sequence (mean rank = 22.63) suggesting that the products are assessed to be more creative in Task 2.

Table 91. Ranks for Overall Creativity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	32.37	874.00
AR-RbR-C	27	22.63	611.00
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 164.500, p = 0.000) between the AR-C-RbR sequence and the C-AR-RbR sequence.

Table 92. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	164.500
Wilcoxon W	542.500
Z	-3.608
Asymp. Sig. (2-tailed)	.000

The C-AR-RbR sequence has a higher mean rank (mean rank = 34.91) than the AR-C-RbR sequence (mean rank = 20.09) suggesting that the products are assessed to be more creative in Task 2.

Table 93. Ranks for Overall Creativity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	34.91	942.50
AR-C-RbR	27	20.09	542.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 361.500, p = 0.003) between the AR-C-RbR sequence and the RbR-AR-C sequence.

Table 94. Mann-Whitney U test statistics for experiment groups RbR-AR-C vs. AR-C-RbR.

	RbR-AR-C AR-C-RbR
Mann-Whitney U	361.500
Wilcoxon W	739.500
Z	-3.012
Asymp. Sig. (2-tailed)	.003

The RbR-AR-C sequence has a higher mean rank (mean rank = 41.97) than the AR-C-RbR sequence (mean rank = 27.39) suggesting that the products are assessed to be more creative in Task 2.

Table 95. Ranks for Overall Creativity in Task 2 in Experiment II.

Groups	**N**	**Mean Rank**	**Sum of Ranks**
RbR-AR-C	45	41.97	1888.50
AR-C-RbR	27	27.39	739.50
Total	72		

A Mann-Whitney U test indicated that there was a significant difference (U = 341.500, p = 0.033) between the AR-C-RbR sequence and the RbR-C-AR sequence.

Table 96. Mann-Whitney U test statistics for experiment groups RbR-C-AR vs. AR-C-RbR.

	RbR-C-AR AR-C-RbR
Mann-Whitney U	341.500
Wilcoxon W	719.500
Z	-2.128
Asymp. Sig. (2-tailed)	.033

The RbR-C-AR sequence has a higher mean rank (mean rank = 36.01) than the AR-C-RbR sequence (mean rank = 26.65) suggesting that the products are assessed to be more creative in Task 2.

Table 97. Ranks for Overall Creativity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
RbR-C-AR	36	36.01	1296.50
AR-C-RbR	27	26.65	719.50
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 203.000, p = 0.003) between the AR-C-RbR sequence and the C-RbR-AR sequence.

Table 98. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. AR-C-RbR.

	C-RbR-AR AR-C-RbR
Mann-Whitney U	203.000
Wilcoxon W	581.000
Z	-2.941
Asymp. Sig. (2-tailed)	.003

The C-RbR-AR sequence has a higher mean rank (mean rank = 33.48) than the AR-C-RbR sequence (mean rank = 21.52) suggesting that the products are assessed to be more creative in Task 2.

Table 99. Ranks for Overall Creativity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-RbR-AR	27	33.48	904.00
AR-C-RbR	27	21.52	581.00
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 348.000, p = 0.046) between the RbR-C-AR sequence and the C-AR-RbR sequence.

Table 100. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-C-AR.

	C-AR-RbR RbR-C-AR
Mann-Whitney U	348.000
Wilcoxon W	1014.000
Z	-1.992
Asymp. Sig. (2-tailed)	.046

The C-AR-RbR sequence has a higher mean rank (mean rank = 37.11) than the RbR-C-AR sequence (mean rank = 28.17) suggesting that the products are assessed to be more creative in Task 2.

Table 101. Ranks for Overall Creativity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	37.11	1002.00
RbR-C-AR	36	28.17	1014.00
Total	63		

4.1.4.2. Shape recurrence

A Kruskal-Wallis H test showed that there was a statistically significant difference in shape recurrence score between the different sequences, $\chi2(2) = 13.318$, p = 0.021, with a mean rank shape recurrence score of 96.63 for AR-RbR-C group, 73.24 for AR-C-RbR group, 111.93 for C-AR-RbR group, 94.51 for RbR-AR-C group, 83.01 for RbR-C-AR group, 115.00 for C-RbR-AR group.

Table 102. Ranks for Shape Recurrence in Task 2 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	96.63
AR-C-RbR	27	73.24
C-AR-RbR	27	111.93
RbR-AR-C	45	94.51
RbR-C-AR	36	83.01
C-RbR-AR	27	**115.00**
Total	189	

Among pairwise comparisons, there were four statistically different results in shape recurrence score. A Mann-Whitney U test indicated that there was a significant difference (U = 217.500, p = 0.008) between the AR-C-RbR sequence and the C-AR-RbR sequence.

Table 103. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	217.500
Wilcoxon W	595.500
Z	-2.649
Asymp. Sig. (2-tailed)	.008

The C-AR-RbR sequence has a higher mean rank (mean rank = 32.94) than the AR-C-RbR sequence (mean rank = 22.06) suggesting that the products of the C-AR-RbR sequence are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 104. Ranks for Shape Recurrence in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	32.94	889.50

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Table 104 (cont.)

AR-C-RbR	27	22.06	595.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 213.000, p = 0.007) between the AR-C-RbR sequence and the C-RbR-AR sequence.

Table 105. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. AR-C-RbR.

	C-RbR-AR AR-C-RbR
Mann-Whitney U	213.000
Wilcoxon W	591.000
Z	-2.714
Asymp. Sig. (2-tailed)	.007

The C-RbR-AR sequence has a higher mean rank (mean rank = 33.11) than the AR-C-RbR sequence (mean rank = 21.89) suggesting that the products of C-RbR-AR sequence are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 106. Ranks for Shape Recurrence in Task 2 in Experiment II.

Groups	**N**	**Mean Rank**	**Sum of Ranks**
C-RbR-AR	27	33.11	894.00
AR-C-RbR	27	21.89	591.00
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 336.000, p = 0.029) between the RbR-C-AR sequence and the C-AR-RbR sequence.

Table 107. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-C-AR.

	C-AR-RbR RbR-C-AR
Mann-Whitney U	336.000
Wilcoxon W	1002.000
Z	-2.181
Asymp. Sig. (2-tailed)	.029

The C-AR-RbR sequence has a higher mean rank (mean rank = 37.56) than the RbR-C-AR sequence (mean rank = 27.83) suggesting that the products of C-AR-RbR sequence are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 108. Ranks for Shape Recurrence in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	37.56	1014.00
RbR-C-AR	36	27.83	1002.00
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 326.000, p = 0.021) between the RbR-C-AR sequence and the C-RbR-AR sequence.

Table 109. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. RbR-C-AR.

	C-RbR-AR RbR-C-AR
Mann-Whitney U	326.000
Wilcoxon W	992.000
Z	-2.309
Asymp. Sig. (2-tailed)	.021

The C-RbR-AR sequence has a higher mean rank (mean rank = 37.93) than the RbR-C-AR sequence (mean rank = 27.56) suggesting that the products of C-RbR-AR sequence are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 110. Ranks for Shape Recurrence in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-RbR-AR	27	37.93	1024.00
RbR-C-AR	36	27.56	992.00
Total	63		

4.1.4.3. Shape variation

A Kruskal-Wallis H test showed that there was a statistically significant difference in shape variation score between the different sequences, $\chi2(2) = 16.275$, $p = 0.006$, with a mean rank shape variation score of 108.56 for AR-RbR-C group, 60.85 for AR-C-RbR group, 102.19 for C-AR-RbR group, 102.89 for RbR-AR-C group, 88.49 for RbR-C-AR group, 103.94 for C-RbR-AR group.

Table 111. Ranks for Shape Variation in Task 2 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	**108.56**
AR-C-RbR	27	60.85
C-AR-RbR	27	102.19
RbR-AR-C	45	102.89
RbR-C-AR	36	88.49
C-RbR-AR	27	103.94
Total	189	

Among pairwise comparisons, there were five statistically different results in shape variation score. A Mann-Whitney U test indicated that there was a significant difference (U = 195.500, p = 0.002) between the AR-RbR-C sequence and the AR-C-RbR sequence.

Table 112. Mann-Whitney U test statistics for experiment groups AR-RbR-C vs. AR-C-RbR.

	AR-RbR-C AR-C-RbR
Mann-Whitney U	195.500
Wilcoxon W	573.500
Z	-3.054
Asymp. Sig. (2-tailed)	.002

The AR-RbR-C sequence has a higher mean rank (mean rank = 33.76) than the AR-C-RbR sequence (mean rank = 21.24) suggesting that the products of the AR-RbR-C sequence are assessed to be better in establishing links of variance between the parts in Task 2.

Table 113. Ranks for Shape Variation in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
AR-RbR-C	27	33.76	911.50
AR-C-RbR	27	21.24	573.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 200.500, p = 0.003) between the C-AR-RbR sequence and the AR-C-RbR sequence.

Table 114. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	200.500

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Table 114 (cont.

Wilcoxon W	578.500
Z	-2.989
Asymp. Sig. (2-tailed)	.003

The C-AR-RbR sequence has a higher mean rank (mean rank = 33.57) than the AR-C-RbR sequence (mean rank = 21.43) suggesting that the products of the C-AR-RbR sequence are assessed to be better in establishing links of variance between the parts in Task 2.

Table 115. Ranks for Shape Variation in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	33.57	906.50
AR-C-RbR	27	21.43	578.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 337.500, p = 0.001) between the RbR-AR-C sequence and the AR-C-RbR sequence.

Table 116. Mann-Whitney U test statistics for experiment groups RbR-AR-C vs. AR-C-RbR.

	RbR-AR-C AR-C-RbR
Mann-Whitney U	337.500
Wilcoxon W	715.500
Z	-3.287
Asymp. Sig. (2-tailed)	.001

The RbR-AR-C sequence has a higher mean rank (mean rank = 42.50) than the AR-C-RbR sequence (mean rank = 26.50) suggesting that the products of the RbR-AR-C sequence are assessed to be better in establishing links of variance between the parts in Task 2.

Table 117. Ranks for Shape Variation in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
RbR-AR-C	45	42.50	1912.50
AR-C-RbR	27	26.50	715.50
Total	72		

A Mann-Whitney U test indicated that there was a significant difference (U = 337.500, p = 0.029) between the RbR-C-AR sequence and the AR-C-RbR sequence.

Table 118. Mann-Whitney U test statistics for experiment groups RbR-C-AR vs. AR-C-RbR.

	RbR-C-AR AR-C-RbR
Mann-Whitney U	337.500
Wilcoxon W	715.500
Z	-2.177
Asymp. Sig. (2-tailed)	.029

The RbR-C-AR sequence has a higher mean rank (mean rank = 36.13) than the AR-C-RbR sequence (mean rank = 26.50) suggesting that the products of the RbR-C-AR sequence are assessed to be better in establishing links of variance between the parts in Task 2.

Table 119. Ranks for Shape Variation in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
RbR-C-AR	36	36.13	1300.50
AR-C-RbR	27	26.50	715.50
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 194.000, p = 0.002) between the C-RbR-AR sequence and the AR-C-RbR sequence.

Table 120. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. AR-C-RbR.

	C-RbR-AR AR-C-RbR
Mann-Whitney U	194.000
Wilcoxon W	572.000
Z	-3.098
Asymp. Sig. (2-tailed)	.002

The C-RbR-AR sequence has a higher mean rank (mean rank = 33.81) than the AR-C-RbR sequence (mean rank = 21.19) suggesting that the products of the C-RbR-AR sequence are assessed to be better in establishing links of variance between the parts in Task 2.

Table 121. Ranks for Shape Variation in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-RbR-AR	27	33.81	913.00
AR-C-RbR	27	21.19	572.00
Total	54		

4.1.4.4. Unity

A Kruskal-Wallis H test showed that there was a statistically significant difference in unity score between the different sequences, $\chi 2(2) = 17.332$, $p = 0.004$, with a mean rank unity score of 87.56 for AR-RbR-C group, 66.09 for AR-C-RbR group, 118.06 for C-AR-RbR group, 100.81 for RbR-AR-C group, 86.99 for RbR-C-AR group, 109.30 for C-RbR-AR group.

Table 122. Ranks for Unity in Task 2 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	87.56

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Table 122 (cont.)

AR-C-RbR	27	66.09
C-AR-RbR	27	**118.06**
RbR-AR-C	45	100.81
RbR-C-AR	36	86.99
C-RbR-AR	27	109.30
Total	189	

Among pairwise comparisons, there were four statistically different results in unity score. A Mann-Whitney U test indicated that there was a significant difference (U = 172.500, p = 0.001) between the C-AR-RbR sequence and the AR-C-RbR sequence.

Table 123. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	172.500
Wilcoxon W	550.500
Z	-3.457
Asymp. Sig. (2-tailed)	.001

The C-AR-RbR sequence has a higher mean rank (mean rank = 34.61) than the AR-C-RbR sequence (mean rank = 20.39) suggesting that the products of the C-AR-RbR sequence are more successful in achieving a sense of unity in Task 2.

Table 124. Ranks for Unity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	34.61	934.50
AR-C-RbR	27	20.39	550.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 384.000, p = 0.007) between the RbR-AR-C sequence and the AR-C-RbR sequence.

Table 125. Mann-Whitney U test statistics for experiment groups RbR-AR-C vs. AR-C-RbR.

	RbR-AR-C AR-C-RbR
Mann-Whitney U	384.000
Wilcoxon W	762.000
Z	-2.721
Asymp. Sig. (2-tailed)	.007

The RbR-AR-C sequence has a higher mean rank (mean rank = 41.47) than the AR-C-RbR sequence (mean rank = 28.22) suggesting that the products of the RbR-AR-C sequence are more successful in achieving a sense of unity in Task 2.

Table 126. Ranks for Unity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
RbR-AR-C	45	41.47	1866.00
AR-C-RbR	27	28.22	762.00
Total	72		

A Mann-Whitney U test indicated that there was a significant difference (U = 192.500, p = 0.002) between the C-RbR-AR sequence and the AR-C-RbR sequence.

Table 127. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. AR-C-RbR.

	C-RbR-AR AR-C-RbR
Mann-Whitney U	192.500
Wilcoxon W	570.500

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Table 127 (cont.)

Z	-3.119
Asymp. Sig. (2-tailed)	.002

The C-RbR-AR sequence has a higher mean rank (mean rank = 33.87) than the AR-C-RbR sequence (mean rank = 21.13) suggesting that the products of the C-RbR-AR sequence are more successful in achieving a sense of unity in Task 2.

Table 128. Ranks for Unity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-RbR-AR	27	33.87	914.50
AR-C-RbR	27	21.13	570.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 333.000, p = 0.028) between the C-AR-RbR sequence and the RbR-C-AR sequence.

Table 129. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. RbR-C-AR.

	C-AR-RbR RbR-C-AR
Mann-Whitney U	333.000
Wilcoxon W	999.000
Z	-2.204
Asymp. Sig. (2-tailed)	.028

The C-AR-RbR sequence has a higher mean rank (mean rank = 37.67) than the RbR-C-AR sequence (mean rank = 27.75) suggesting that the products of the C-AR-RbR sequence are more successful in achieving a sense of unity in Task 2.

Table 130. Ranks for Unity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	37.67	1017.00
RbR-C-AR	36	27.75	999.00
Total	63		

4.1.4.5. Complexity

A Kruskal-Wallis H test showed that there was a statistically significant difference in complexity score between the different sequences, $\chi2(2) = 17.153$, $p = 0.004$, with a mean rank complexity score of 87.65 for AR-RbR-C group, 62.85 for AR-C-RbR group, 110.26 for C-AR-RbR group, 103.60 for RbR-AR-C group, 90.17 for RbR-C-AR group, 111.35 for C-RbR-AR group.

Table 131. Ranks for Complexity in Task 2 in Experiment II.

Groups	N (number of products)	Mean Rank
AR-RbR-C	27	87.65
AR-C-RbR	27	62.85
C-AR-RbR	27	110.26
RbR-AR-C	45	103.60
RbR-C-AR	36	90.17
C-RbR-AR	27	**111.35**
Total	189	

Among pairwise comparisons, there were four statistically different results in complexity score. A Mann-Whitney U test indicated that there was a significant difference ($U = 188.500$, $p = 0.001$) between the C-AR-RbR sequence and the AR-C-RbR sequence.

Table 132. Mann-Whitney U test statistics for experiment groups C-AR-RbR vs. AR-C-RbR.

	C-AR-RbR AR-C-RbR
Mann-Whitney U	188.500
Wilcoxon W	566.500
Z	-3.211
Asymp. Sig. (2-tailed)	.001

The C-AR-RbR sequence has a higher mean rank (mean rank = 34.02) than the AR-C-RbR sequence (mean rank = 20.98) suggesting that the products of the C-AR-RbR sequence are assessed as having more complex relations between parts of the composition in Task 2.

Table 133. Ranks for Complexity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
C-AR-RbR	27	34.02	918.50
AR-C-RbR	27	20.98	566.50
Total	54		

A Mann-Whitney U test indicated that there was a significant difference (U = 346.500, p = 0.001) between the RbR-AR-C sequence and the AR-C-RbR sequence.

Table 134. Mann-Whitney U test statistics for experiment groups RbR-AR-C vs. AR-C-RbR.

	RbR-AR-C AR-C-RbR
Mann-Whitney U	346.500
Wilcoxon W	724.500
Z	-3.194
Asymp. Sig. (2-tailed)	.001

The RbR-AR-C sequence has a higher mean rank (mean rank = 42.30) than the AR-C-RbR sequence (mean rank = 26.83) suggesting that the products of the RbR-AR-C sequence are assessed as having more complex relations between parts of the composition in Task 2.

Table 135. Ranks for Complexity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
RbR-AR-C	45	42.30	1903.50
AR-C-RbR	27	26.83	724.50
Total	72		

A Mann-Whitney U test indicated that there was a significant difference (U = 340.000, p = 0.029) between the RbR-C-AR sequence and the AR-C-RbR sequence.

Table 136. Mann-Whitney U test statistics for experiment groups RbR-C-AR vs. AR-C-RbR.

	RbR-C-AR AR-C-RbR
Mann-Whitney U	340.000
Wilcoxon W	718.000
Z	-2.177
Asymp. Sig. (2-tailed)	.029

The RbR-C-AR sequence has a higher mean rank (mean rank = 36.06) than the AR-C-RbR sequence (mean rank = 26.59) suggesting that the products of the RbR-C-AR sequence are assessed as having more complex relations between parts of the composition in Task 2.

Table 137. Ranks for Complexity in Task 2 in Experiment II.

Groups	N	Mean Rank	Sum of Ranks
RbR-C-AR	36	36.06	1298.00

(cont. on next page)

Table 137 (cont.)

AR-C-RbR	27	26.59	718.00
Total	63		

A Mann-Whitney U test indicated that there was a significant difference (U = 178.000, p = 0.001) between the C-RbR-AR sequence and the AR-C-RbR sequence.

Table 138. Mann-Whitney U test statistics for experiment groups C-RbR-AR vs. AR-C-RbR.

	C-RbR-AR AR-C-RbR
Mann-Whitney U	178.000
Wilcoxon W	556.000
Z	-3.399
Asymp. Sig. (2-tailed)	.001

The C-RbR-AR sequence has a higher mean rank (mean rank = 34.41) than the AR-C-RbR sequence (mean rank = 20.59) suggesting that the products of the C-RbR-AR sequence are assessed as having more complex relations between parts of the composition in Task 2.

Table 139. Ranks for Complexity in Task 2 in Experiment II.

Groups	**N**	**Mean Rank**	**Sum of Ranks**
C-RbR-AR	27	34.41	929.00
AR-C-RbR	27	20.59	556.00
Total	63		

4.1.5. Experiment II - Order effects

The ratings of each criterion in each condition within the sequences are examined. An increase is considered as a positive impact of the order of reasoning strategies that the participants adopted.

4.1.6. Experiment II – Task 1

The following figures shows the order effect of reasoning strategies in Task 1 for each criterion through the sequences.

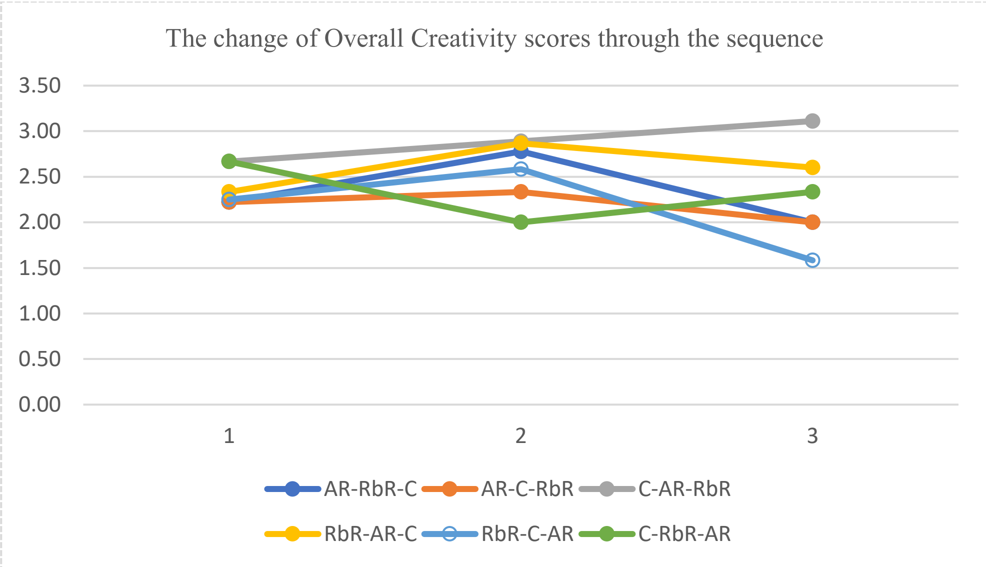

Figure 11. The change of Overall Creativity scores of Task 1 through the sequences.

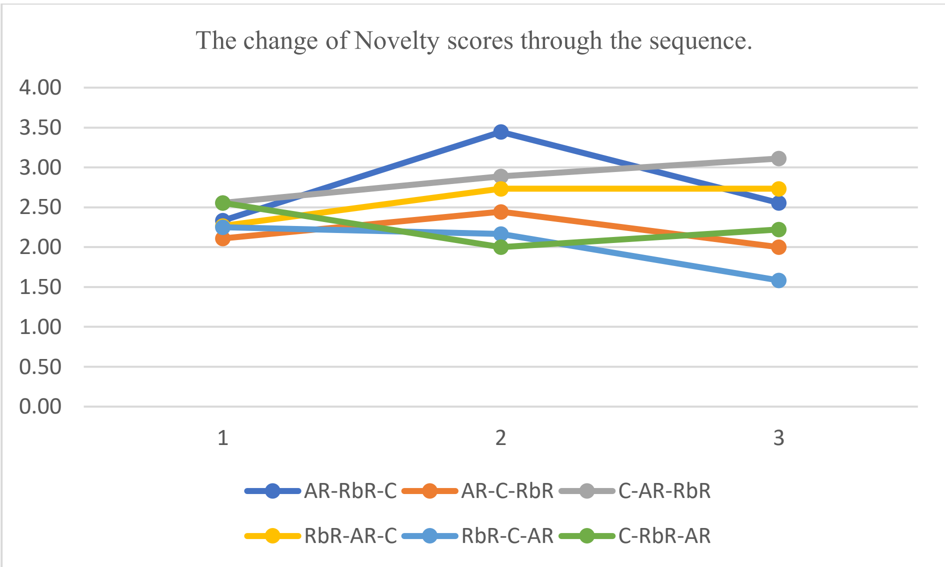

Figure 12. The change of Novelty scores of Task 1 through the sequences.

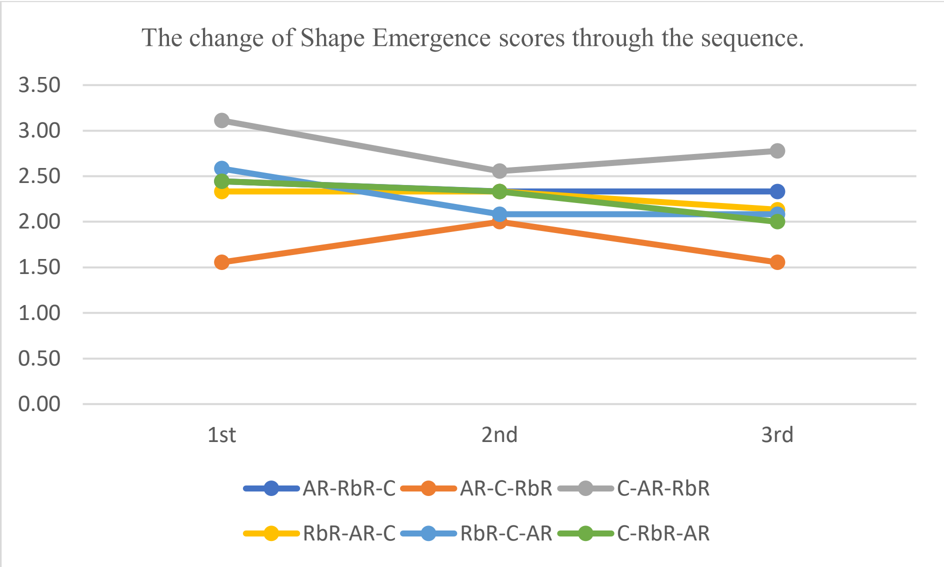

Figure 13. The change of Shape Emergence scores of Task 1through the sequences.

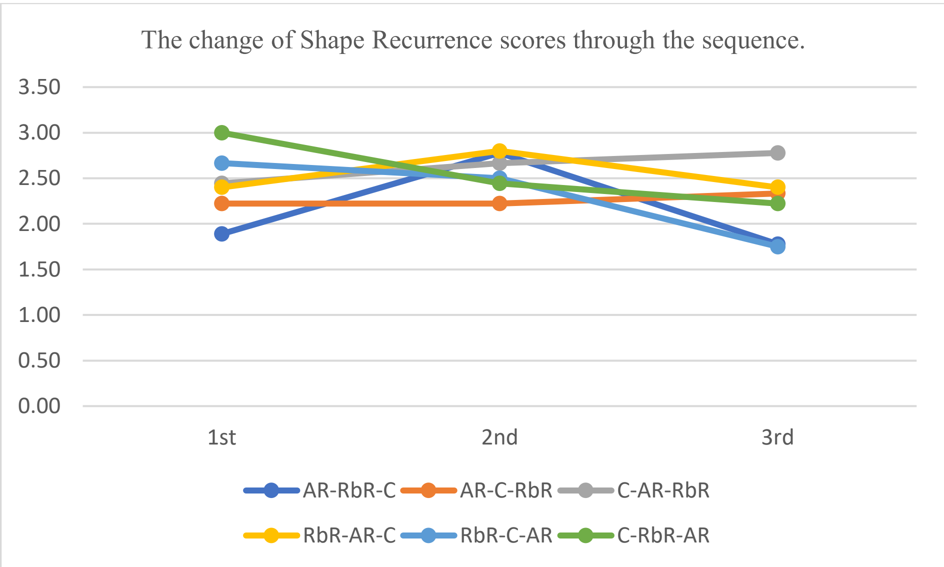

Figure 14. The change of Shape Recurrence scores of Task 1 through the sequences.

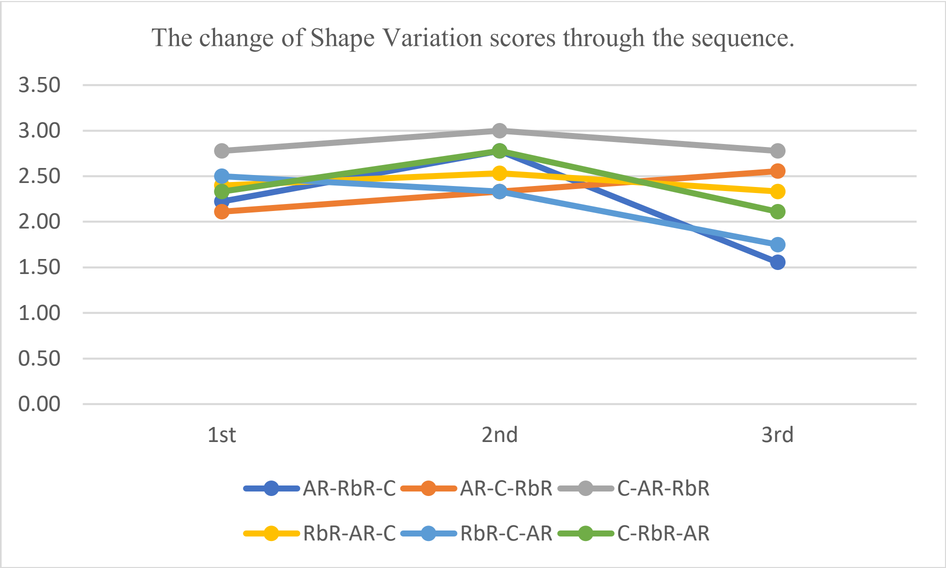

Figure 15. The change of Shape Variation scores of Task 1 through the sequences.

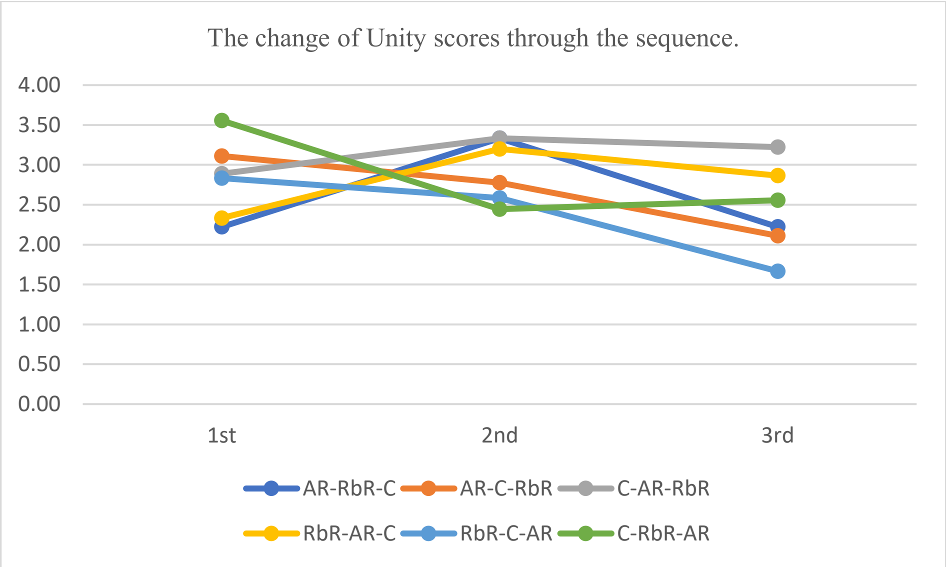

Figure 16. The change of Unity scores of Task 1 through the sequences.

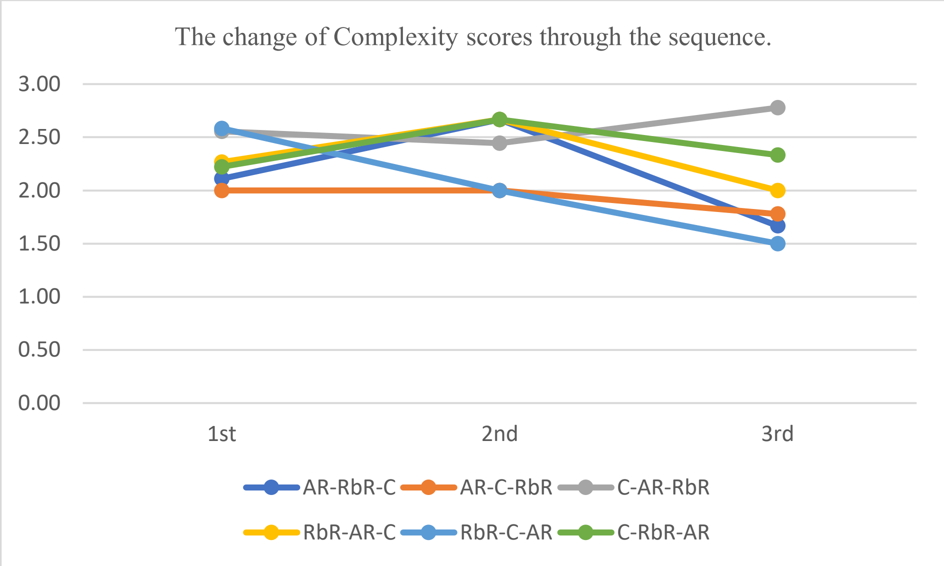

Figure 17. The change of Complexity scores of Task 1 through the sequences.

It is observed that there is a steady improvement for Overall Creativity, Novelty and Shape Recurrence scores for Task 1 in the C-AR-RbR sequence (see Figure 11, Figure 12 and Figure 14).

4.1.7. Experiment II – Task 2

The following figures shows the order effect of reasoning strategies in Task 2 for each criterion through the sequences.

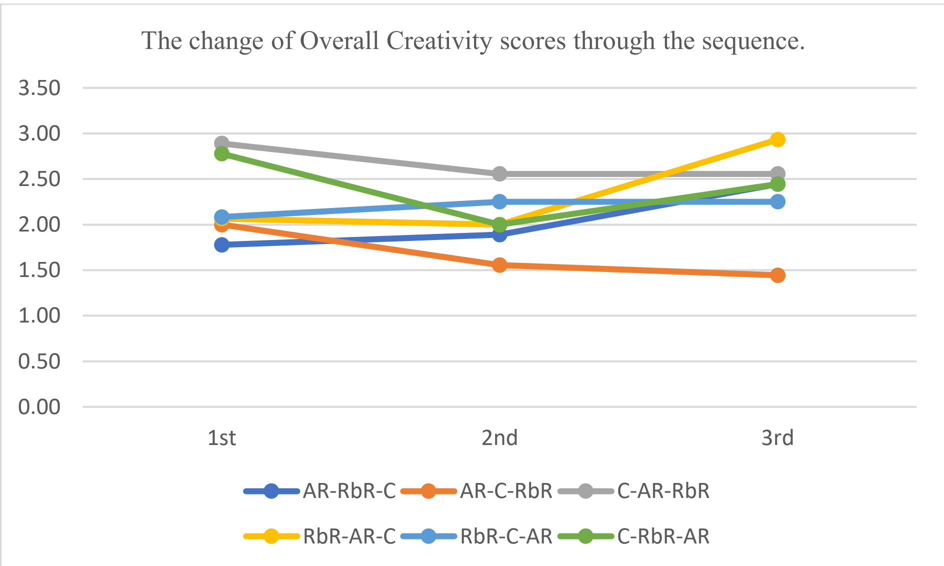

Figure 18. The change of Overall Creativity scores of Task 2 through the sequences.

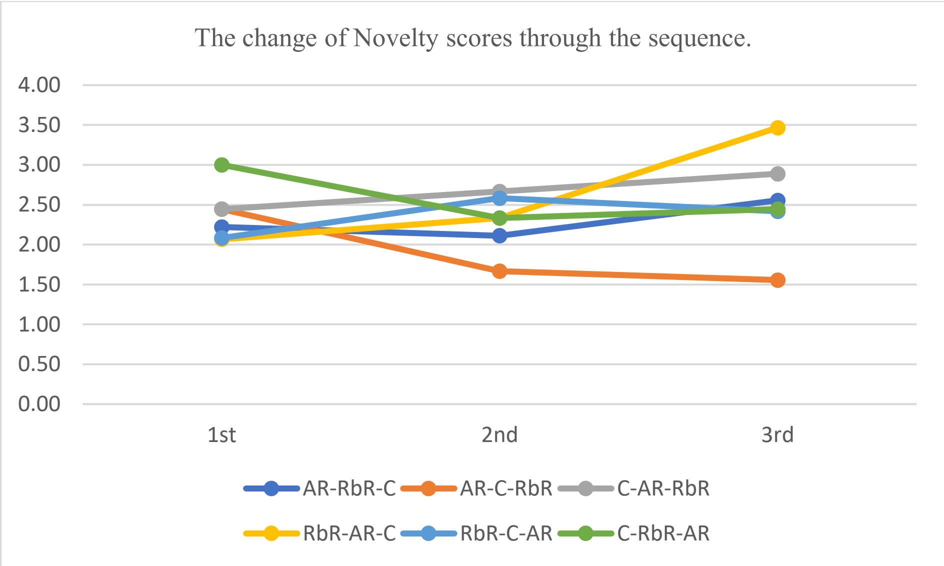

Figure 19. The change of Novelty scores of Task 2 through the sequences.

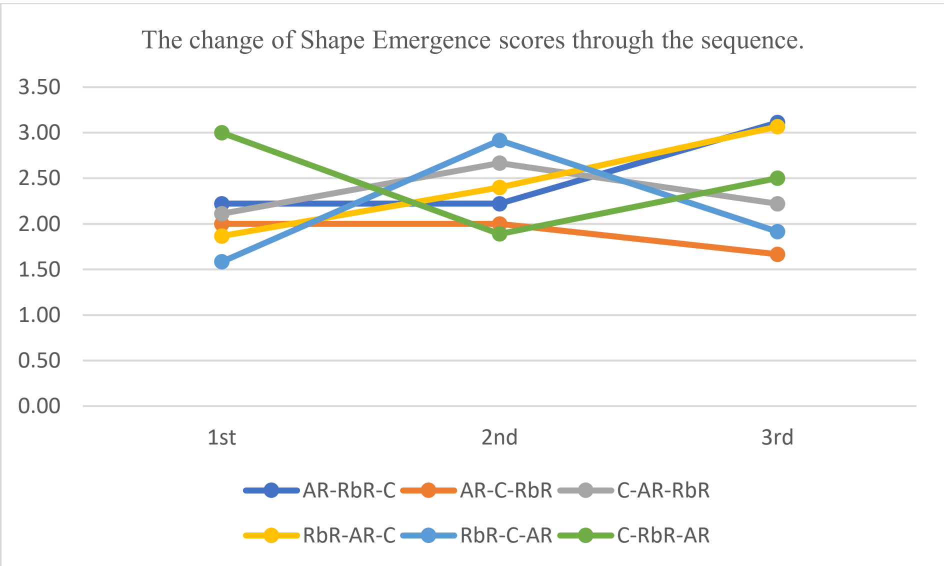

Figure 20. The change of Shape Emergence scores of Task 2 through the sequences.

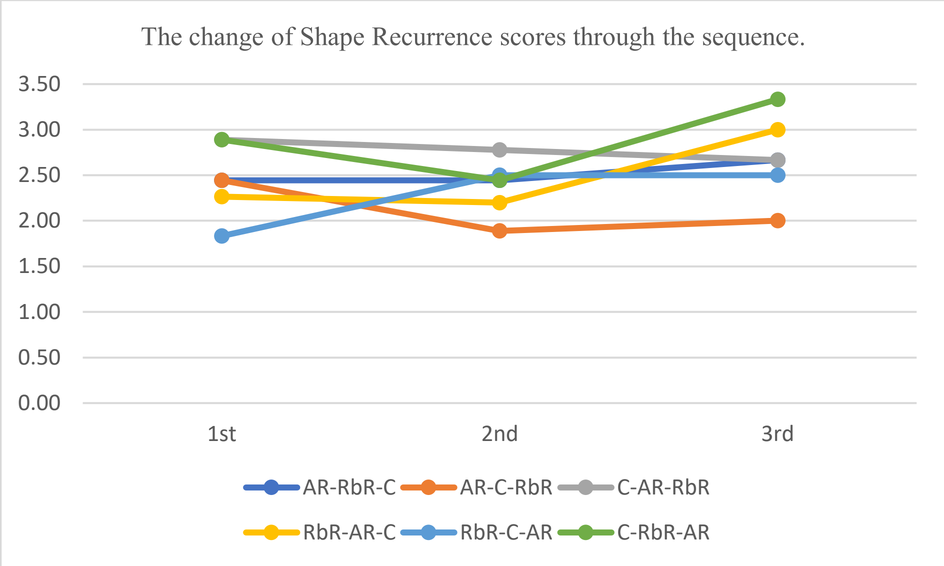

Figure 21. The change of Shape Recurrence scores of Task 2 through the sequences.

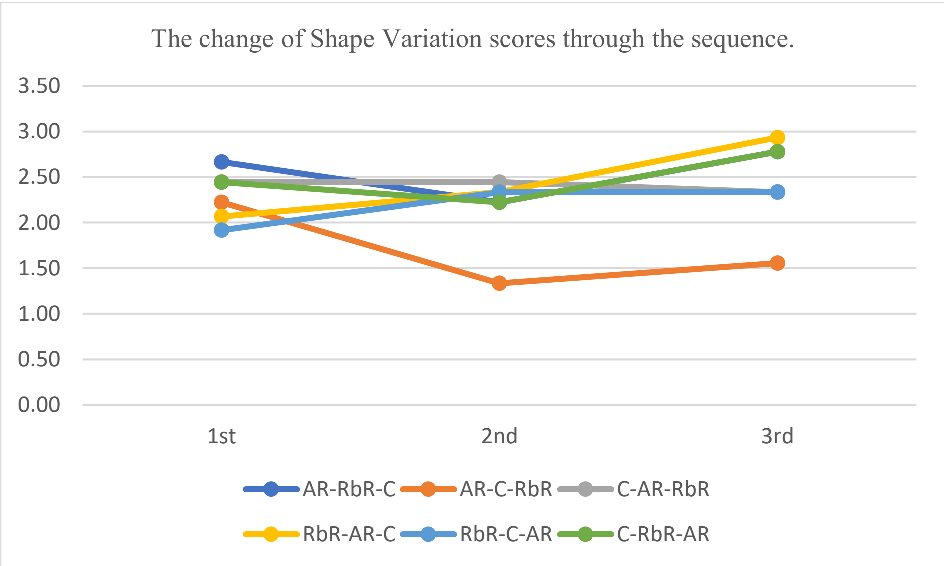

Figure 22. The change of Shape Variation scores of Task 2 through the sequences.

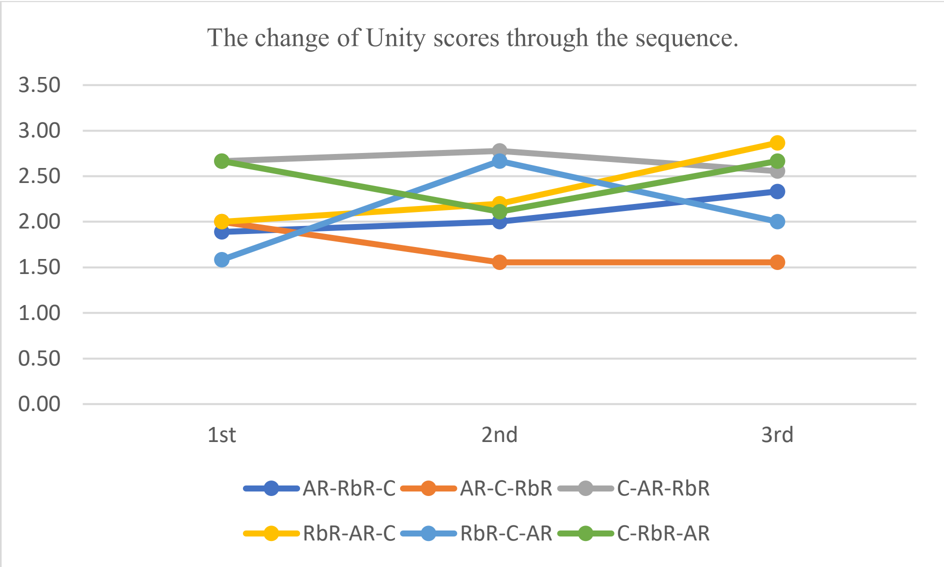

Figure 23. The change of Unity scores of Task 2 through the sequences.

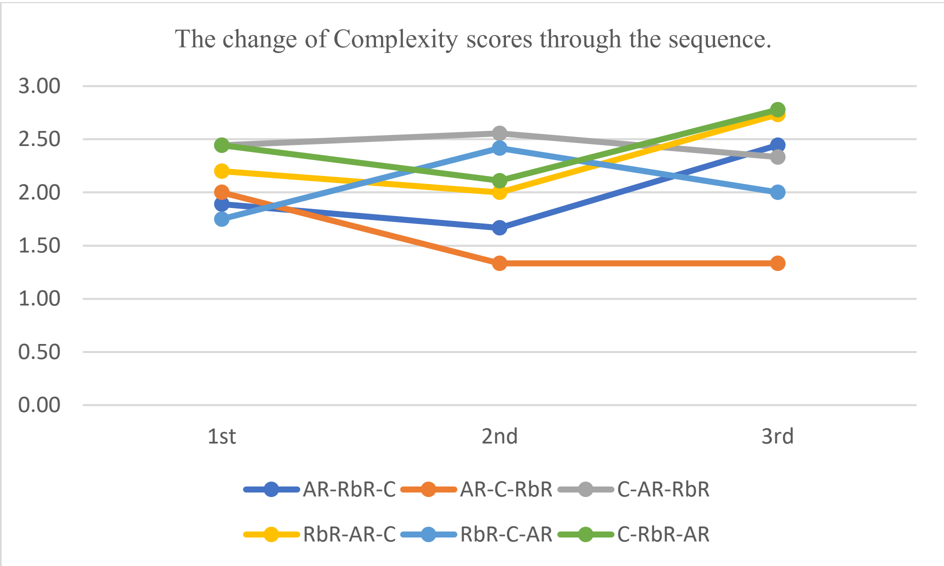

Figure 24. The change of Unity scores of Task 2 through the sequences.

It is observed that there is an increase in the novelty scores both in C-AR-RbR and RbR-AR-C sequences (see Figure 19). There is a steady improvement for shape emergence, shape variation and unity scores for Task 2 in the RbR-AR-C sequence (see Figure 20, Figure 2 , Figure 23 respectively).

4.1.7.1. Experiment II – Design Examples

In this section, an example from one participants' design is provided to illustrate the collected data for the second experiment. It includes one example for Task 1 and Task 2 for the AR-RbR-C sequence (see Figure 25).

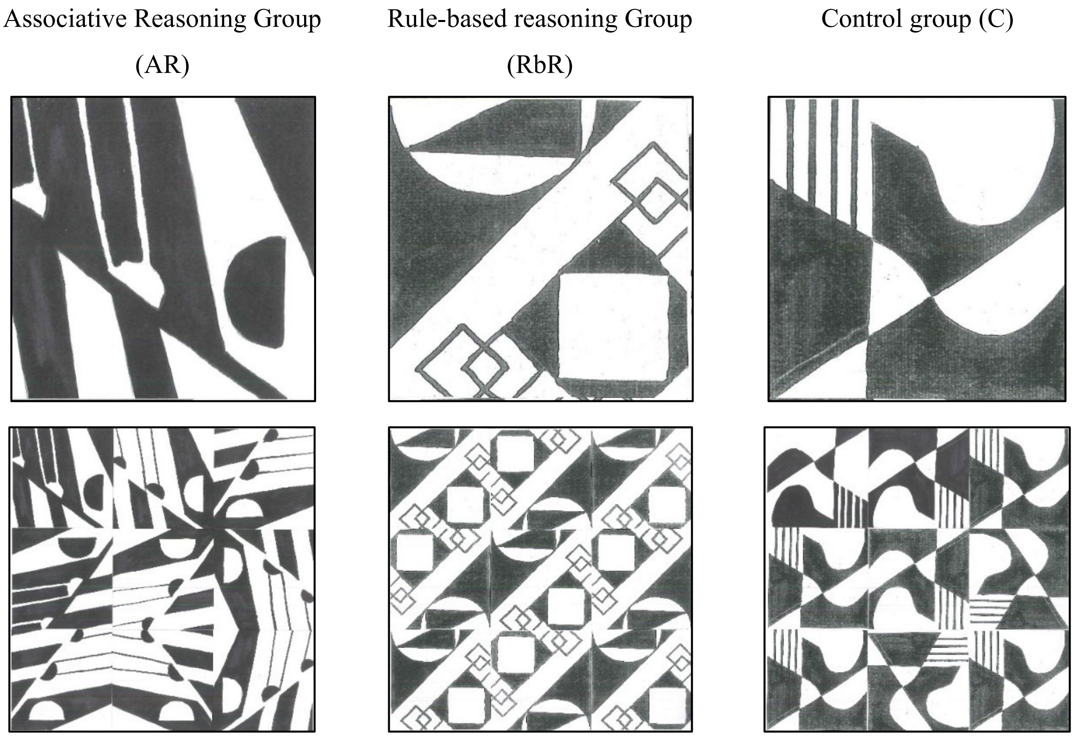

Figure 25. Design examples for Task 1 and Task 2 in Experiment II for the AR-RbR-C sequence.

4.1.8. Experiment III – Task 1

Mann Whitney U tests showed that there was no statistically significant difference in all seven assessment items for Experiment III Task 1, which asked students to design a x a base unit after a specific lecture dedicated to introduce a particular form of reasoning in design, between the associative reasoning group (I-AR) and rule-based reasoning group (I-RbR), which does not confirm Hypothesis 3.

Table 140. Mann Whitney U test statistics for Task 1 in Experiment III between I-AR and I-RbR.

	Overall creativity	Novelty	Shape Emergence	Shape recurrence	Shape variation	Unity	Complexity
Mann-Whitney U	370.500	455.500	474.500	472.500	437.000	367.500	469.000
Wilcoxon W	931.500	1016.500	939.500	1033.500	902.000	928.500	934.000
Z	-1.805	-.573	-.300	-.333	-.871	-1.829	-.384
Asym. Sig. (2-tailed)	.071	.567	.764	.739	.384	.067	.701

4.1.9. Experiment III – Task 2

Mann-Whitney U test is applied on the measurement criteria to determine the statistically significant results for Experiment III Task 2, which asked students to design a 3 x a x a composition after a lecture dedicated to the specified reasoning strategy and Experiment III Task 1. The results indicate that seven criteria among seven were significant: overall creativity (Overall Creativity, U = 183.500, p = 0.000), novelty (T2C2, U = 234.500, p = 0.000), shape emergence (T2C3, U = 217.500, p = 0.000), shape recurrence (T2C4, U = 214.000, p = 0.000), shape variation (T2C5, U = 252.000, p = 0.001), unity (T2C6, U = 204.500, p = 0.000), complexity (T2C7, U = 332.500, p = 0.020). The AR group scores for each criterion is significantly higher than the scores of RbR scores, which partially confirms Hypothesis 3. Instructions to use particular reasoning strategies will have a positive impact only on the creative outputs of students.

Table 141. Mann Whitney U test statistics for Task 1 in Experiment III between I-AR and I-RbR.

	Overall creativity	Novelty	Shape Emergence	Shape recurrence	Shape variation	Unity	Complexity
Mann-Whitney U	183.500	234.500	217.500	214.000	252.000	204.500	332.500
Wilcoxon W	744.500	795.500	778.500	775.000	813.000	765.500	893.500
Z	-4.422	-3.709	-3.949	-3.999	-3.446	-4.126	-2.321

(cont. on next page)

Table 141 (cont.)

Asym. Sig. (2-tailed)	**.000**	**.000**	**.000**	**.000**	**.001**	**.000**	**.020**

4.1.9.1. Overall creativity

A Mann-Whitney U test indicated that there was a significant difference (U = 183.500, p = 0.000) between I-AR group and I-RbR group. I-AR group has a higher mean rank (mean rank = 42.38) than I-RbR group (mean rank = 22.56) suggesting that the products are assessed to be more creative in Task 2.

Table 142. Ranks for Overall Creativity between experiment groups I-AR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	42.38	1271.50
I-RbR	33	22.56	744.50
Total	63		

4.1.9.2. Novelty

A Mann-Whitney U test indicated that there was a significant difference (U = 234.500, p = 0.000) between I-AR group and I-RbR group. I-AR group has a higher mean rank (mean rank = 40.68) than I-RbR group (mean rank = 24.11) suggesting that the products are assessed to be more novel in Task 2.

Table 143. Ranks for Novelty between experiment groups I-AR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	40.68	1220.50
I-RbR	33	24.11	795.50
Total	63		

4.1.9.3. Shape emergence

A Mann-Whitney U test indicated that there was a significant difference (U = 217.500, p = 0.000) between I-AR group and I-RbR group. I-AR group has a higher mean rank (mean rank = 41.25) than I-RbR group (mean rank = 23.59) suggesting that the products of I-AR group are assessed as better in making new shapes in Task 2.

Table 144. Ranks for Shape Emergence between experiment groups I-AR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	41.25	1237.50
I-RbR	33	23.59	778.50
Total	63		

4.1.9.4. Shape recurrence

A Mann-Whitney U test indicated that there was a significant difference (U = 214.000, p = 0.000) between I-AR group and I-RbR group. I-AR group has a higher mean rank (mean rank = 41.37) than I-RbR group (mean rank = 23.48) suggesting the products of I-AR group are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 145. Ranks for Shape Recurrence between experiment groups I-AR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	41.37	1241.00
I-RbR	33	23.48	775.00
Total	63		

4.1.9.5. Shape variation

A Mann-Whitney U test indicated that there was a significant difference (U = 252.000, p = 0.001) between I-AR group and I-RbR group. I-AR group has a higher mean rank (mean rank = 40.10) than I-RbR group (mean rank = 24.64) suggesting the products of I-AR group are assessed to be better in establishing links of variance between the parts in Task 2.

Table 146. Ranks for Shape Variation between experiment groups I-AR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	40.10	1203.00
I-RbR	33	24.64	813.00
Total	63		

4.1.9.6. Unity

A Mann-Whitney U test indicated that there was a significant difference (U = 204.500, p = 0.001) between I-AR group and I-RbR group. I-AR group has a higher mean rank (mean rank = 41.68) than the I-RbR group (mean rank = 23.20) suggesting the products of I-AR group are assessed as better in achieving unity in Task 2.

Table 147. Ranks for Unity between experiment groups I-AR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	41.68	1250.50
I-RbR	33	23.20	765.50
Total	63		

4.1.9.7. Complexity

A Mann-Whitney U test indicated that there was a significant difference (U = 332.500, p = 0.020) between I-AR group and I-RbR group. I-AR group has a higher mean rank (mean rank = 37.42) than I-RbR group (mean rank = 27.08) suggesting the products of I-AR group are assessed as having more complex relations between parts of the composition in Task 2.

Table 148. Ranks for Complexity between experiment groups I-AR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	37.42	1122.50
I-RbR	33	27.08	893.50
Total	63		

4.1.9.8. Experiment III – Design Examples

In this section, three examples from participants' designs are provided to illustrate the collected data for the third experiment. These include one example for each experiment group for all tasks.

Associative Reasoning Group (I-AR) | Rule-based reasoning Group (I-RbR)

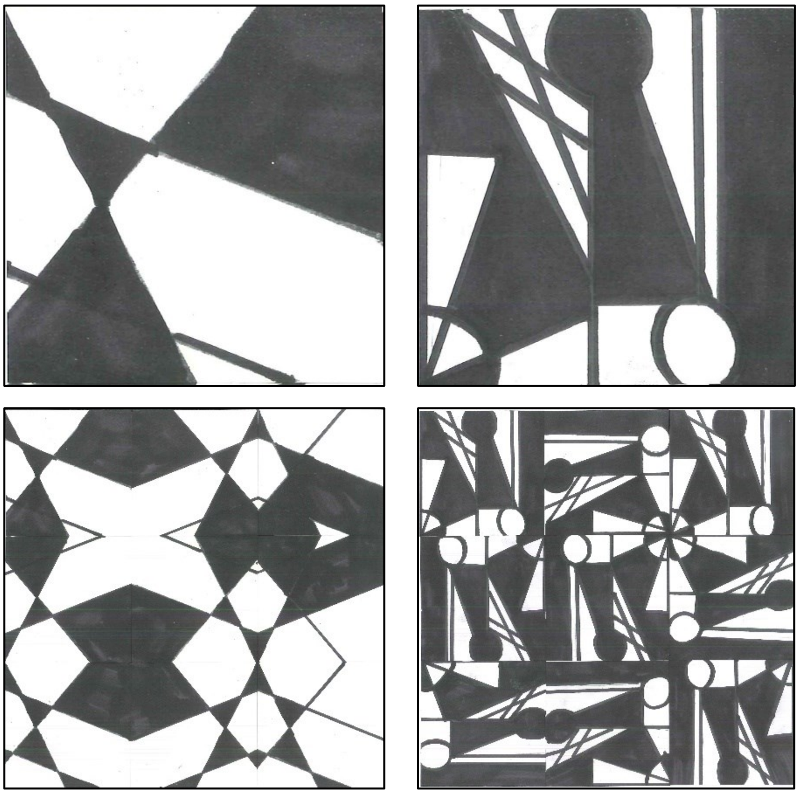

Figure 26. Design examples for Task 1 and Task 2 in Experiment III.

4.1.10. Experiment I and III – Task 1

In this analysis, data from Experiment I Task 1 and Task 2 were compared to data from Experiment III Task 1 and Task 2 to determine whether the specific lectures regarding the reasoning strategies students were asked to use had any impact on students' performances in comparison to those students who did not receive any lectures and any specific directions to use one of the two reasoning strategies.

First, comparisons between the scores of Task 1 in Experiment I and III are given. Mann Whitney U tests showed that there was no statistically significant difference in all seven assessment items for Task 1 for the comparison between AR group and AR group that received explicit instruction (I-AR), which does not confirm Hypothesis 3. The lecture before the task has no significant impact on the I-AR group's creative performance contrary to the prediction that the lecture would have a positive impact on students.

Table 149. Mann-Whitney U Test Statistics for AR vs I-AR for Task 1.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Mann-Whitney U	397.500	431.000	393.000	446.000	358.000	357.500	409.000
Wilcoxon W	862.500	896.000	858.000	911.000	823.000	822.500	874.000
Z	-0.813	-0.295	-0.898	-0.064	-1.457	-1.423	-0.651
Asym. Sig. (2-tailed)	0.416	0.768	0.369	0.949	0.145	0.155	0.515

Mann Whitney U tests showed that three criteria among seven were significant in all seven assessment items for Task 1 for the comparison between RbR group and RbR group that received explicit instruction (I-RbR): overall creativity (T2C1, $U = 322.500$, $p = 0.018$), novelty (T2C2, $U = 359.000$, $p = 0.050$, unity (T2C6, $U = 294.500$, $p = 0.004$), which does not confirm Hypothesis 3. The lecture before the task has a negative impact on the I-RbR group's creative performance although it was expected that the lecture would have a positive impact.

Table 150. Mann-Whitney U Test Statistics for RbR vs I-RbR for Task 1.

	Overall creativity	Novelty	Shape Emergence	Shape recurrence	Shape variation	Unity	Complexity
Mann-Whitney U	322.500	359.000	446.000	362.500	412.000	294.500	378.500
Wilcoxon W	893.500	920.500	1007.000	923.500	973.000	855.000	939.500
Z	-2.357	-1.961	-0.721	-1.924	-1.23	-2.887	-1.691
Asym. Sig. (2-tailed)	**0.018**	**0.050**	0.471	0.054	0.219	**0.004**	0.091

4.1.10.1. Overall creativity

A Mann-Whitney U test indicated that there was a significant difference (U = 322.500, p = 0.018) between RbR group and RbR group that received explicit instruction (I-RbR). The RbR group has a higher mean rank (mean rank = 37.42) than the I-RbR group (mean rank = 27.08) suggesting that the products of RbR group are assessed to be more creative in Task 2.

Table 151. Ranks for Overall Creativity between experiment groups RbR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
RbR	30	37.42	1122.50
I-RbR	33	27.08	893.50
Total	63		

4.1.10.2. Novelty

A Mann-Whitney U test indicated that there was a significant difference (U = 359.000, p = 0.050) between RbR group and RbR group that received explicit instruction (I-RbR). The RbR group has a higher mean rank (mean rank = 36.52) than the I-RbR group (mean rank = 27.89) suggesting that the products of RbR group are assessed to be more novel in Task 2.

Table 152. Ranks for Novelty between experiment groups RbR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
RbR	30	36.52	1095.50
I-RbR	33	27.89	920.50
Total	63		

4.1.10.3. Unity

A Mann-Whitney U test indicated that there was a significant difference (U = 294.500, p = 0.004) between RbR group and RbR group that received explicit instruction (I-RbR). The RbR group has a higher mean rank (mean rank = 38.68) than the I-RbR group (mean rank = 25.92) suggesting that the products of RbR are assessed as better in achieving unity in Task 2.

Table 153. Ranks for Unity between experiment groups RbR and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
RbR	30	38.68	1160.50
I-RbR	33	25.92	855.50
Total	63		

Mann Whitney U tests showed that there was no statistically significant difference in all seven assessment items for Task 1 for the comparison between C group and AR group that received explicit instruction (I-AR), which does not confirm Hypothesis 3.

Table 154. Mann-Whitney U Test Statistics for C vs I-AR for Task 1.

	Overall creativity	Novelty	Shape Emergence	Shape recurrence	Shape variation	Unity	Complexity
Mann-Whitney U	448.500	397.500	447.000	391.000	330.500	402.500	360.500
Wilcoxon W	913.500	862.500	912.000	856.000	795.500	867.500	825.500
Z	-.023	-.813	-.047	-.949	-1.906	-.730	-1.408

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Table 154 (cont.)

Asym. Sig. (2-tailed)	.981	.416	.962	.343	.057	.465	.159

Mann Whitney U tests showed that one criterion among seven were significant in all seven assessment items for Task 1 for the comparison between C group and RbR group that received explicit instruction (I-RbR): unity (T2C6, U = 326.000, p = 0.016), which does not confirm Hypothesis 3. The lecture before the task has a negative impact on the I-RbR group's creative performance although it was predicted that the lecture would have a positive impact.

Table 155. Mann-Whitney U Test Statistics for C vs I-RbR for Task 1.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Mann-Whitney U	372.000	472.000	478.500	414.500	413.000	326.000	425.000
Wilcoxon W	933.000	937.000	943.500	975.500	974.000	887.000	986.000
Z	-1.788	-.332	-.240	-1.173	-1.240	-2.406	-1.017
Asym. Sig. (2-tailed)	.074	.740	.810	.241	.215	**.016**	.309

4.1.10.4. Unity

A Mann-Whitney U test indicated that there was a significant difference (U = 326.000, p = 0.016) between C group and RbR group that received explicit instruction (I-RbR). The C group has a higher mean rank (mean rank = 37.63) than the I-RbR group (mean rank = 26.88) suggesting that the products of C are assessed as better in achieving unity in Task 2.

Table 156. Ranks for Unity between experiment groups C and I-RbR.

Groups	**N**	**Mean Rank**	**Sum of Ranks**
C	30	37.63	1129.00

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Table 156 (cont.)

I-RbR	33	26.88	887.00
Total	63		

4.1.11. Experiment I and III – Task 2

In this section, comparisons between the scores of Task 1 in Experiment I and III are given. Mann-Whitney U test was applied on the measurement criteria to determine the statistically significant results for the comparison between AR group and AR group that received explicit instruction (I-AR). The results indicate that seven criteria among seven were significant: overall creativity (T2C1, U = 192.500, p = 0.000), novelty (T2C2, U = 194.500, p = 0.000), shape emergence (T2C3, U = 223.500, p = 0.001), shape recurrence (T2C4, U = 220.000, p = 0.000), shape variation (T2C5, U = 271.000, p = 0.005), unity (T2C6, U = 149.000, p = 0.000), complexity (T2C7, U = 284.000, p = 0.009), which partially confirms Hypothesis 3. The lecture before the task has a positive impact only on the creative outputs of students.

Table 157. Mann-Whitney U Test Statistics for AR vs I-AR for Task 2.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Mann-Whitney U	192.500	194.500	223.500	220.000	271.000	149.000	284.000
Wilcoxon W	657.500	659.500	688.500	685.000	736.000	614.000	749.000
Z	-3.946	-3.907	-3.455	-3.533	-2.779	-4.613	-2.607
Asym. Sig. (2-tailed)	**.000**	**.000**	**.001**	**.000**	**.005**	**.000**	**.009**

4.1.11.1. Overall creativity

A Mann-Whitney U test indicated that there was a significant difference (U = 192.500, p = 0.000) between AR group and AR group that received explicit instruction (I-AR). The I-AR group has a higher mean rank (mean rank = 39.08) than the AR group (mean rank = 21.92) suggesting that the products of I-AR group are assessed to be more creative in Task 2.

Table 158. Ranks for Overall Creativity between experiment groups AR and I-AR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	39.08	1172.50
AR	30	21.92	657.50
Total	60		

4.1.11.2. Novelty

A Mann-Whitney U test indicated that there was a significant difference (U = 194.500, p = 0.000) between AR group and I-AR group. I-AR group has a higher mean rank (mean rank = 39.02) than the AR group (mean rank = 21.98) suggesting that the products of I-AR group are assessed to be more novel in Task 2.

Table 159. Ranks for Novelty between experiment groups AR and I-AR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	39.02	1170.50
AR	30	21.98	659.50
Total	60		

4.1.11.3. Shape emergence

A Mann-Whitney U test indicated that there was a significant difference (U = 223.500, p = 0.001) between AR group and I-AR group. I-AR group has a higher mean rank (mean rank = 38.05) than the AR group (mean rank = 22.95) suggesting that the products of I-AR group are assessed as better in making new wholes in Task 2.

Table 160. Ranks for Shape Emergence between experiment groups AR and I-AR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	38.05	1141.50
AR	30	22.95	688.50
Total	60		

4.1.11.4. Shape recurrence

A Mann-Whitney U test indicated that there was a significant difference (U = 220.000, p = 0.000) between AR group and I-AR group. I-AR group has a higher mean rank (mean rank = 38.17) than the AR group (mean rank = 22.83) suggesting that the products of I-AR group are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 161. Ranks for Shape Recurrence between experiment groups AR and I-AR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	38.17	1145.00
AR	30	22.83	685.00
Total	60		

4.1.11.5. Shape variation

A Mann-Whitney U test indicated that there was a significant difference (U = 271.000, p = 0.005) between AR group and I-AR group. I-AR group has a higher mean rank (mean rank = 36.47) than the AR group (mean rank = 24.53) suggesting that the products of I-AR group are assessed to be better in establishing links of variance between the parts in Task 2.

Table 162. Ranks for Shape Variation between experiment groups AR and I-AR.

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	36.47	1094.00
AR	30	24.53	736.00
Total	60		

4.1.11.6. Unity

A Mann-Whitney U test indicated that there was a significant difference (U = 149.000, p = 0.000) between AR group and I-AR group. I-AR group has a higher mean rank (mean rank = 40.53) than the AR group (mean rank = 20.47) suggesting that the products of I-AR group are assessed as better in achieving unity in Task 2.

Table 163. Ranks for Shape Variation between experiment groups AR and I-AR

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	40.53	1216.00
AR	30	20.47	614.00
Total	60		

4.1.11.7. Complexity

A Mann-Whitney U test indicated that there was a significant difference (U = 284.000, p = 0.009) between AR group and I-AR group. I-AR group has a higher mean rank (mean rank = 36.03) than AR group (mean rank = 24.97) suggesting that the products of I-AR group are assessed as having more complex relations between parts of the composition in Task 2.

Table 164. Ranks for Shape Variation between experiment groups AR and I-AR

Groups	N	Mean Rank	Sum of Ranks
I-AR	30	36.03	1081.00
AR	30	24.97	749.00
Total	60		

Mann Whitney U tests showed that there was no statistically significant difference for the comparison between RbR group and I-RbR group in all seven assessment items for Task 2 which does not confirm Hypothesis 3. The lecture before the task has no significant impact on the I-RbR group's creative performance when it was expected that the lecture would have a positive impact.

Table 165. Mann-Whitney U Test Statistics for RbR vs I-RbR for Task 2.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Mann-Whitney U	386.000	410.000	437.500	461.500	489.500	362.000	491.500
Wilcoxon W	947.000	971.000	998.500	1022.500	1050.500	923.000	956.500
Z	-1.562	-1.217	-.828	-.482	-.080	-1.910	-.051
Asym. Sig. (2-tailed)	.118	.223	.407	.630	.936	.056	.960

Mann Whitney U tests showed that there was no statistically significant difference in all seven assessment items for Task 2 for the comparison between C group and AR group that received explicit instruction (I-AR), which does not confirm Hypothesis 3.

Table 166. Mann-Whitney U Test Statistics for C vs I-AR for Task 2.

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Mann-Whitney U	413.500	422.500	407.000	397.000	371.500	403.000	414.000
Wilcoxon W	878.500	887.500	872.000	862.000	836.500	868.000	879.000
Z	-.569	-.430	-.668	-.829	-1.229	-.729	-.560
Asym. Sig. (2-tailed)	.570	.668	.504	.407	.219	.466	.576

Mann-Whitney U test was applied on the measurement criteria to determine the statistically significant results for the comparison between C group and RbR group that received explicit instruction (I-RbR). The results indicate that six criteria among seven were significant: overall creativity (T2C1, U = 224.500, p = 0.000), novelty (T2C2, U = 265.000, p = 0.001), shape emergence (T2C3, U = 238.000, p = 0.000), shape recurrence (T2C4, U = 260.500, p = 0.001), shape variation (T2C5, U = 302.500, p = 0.006), unity

(T2C6, U = 237.500, p = 0.000), which does not confirm Hypothesis 3. The lecture before the task has a negative impact on the creative outputs of students.

Table 167. Mann-Whitney U Test Statistics for C vs I-RbR for Task 2.

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Table 167 (cont.)

	Overall creativity	**Novelty**	**Shape Emergence**	**Shape recurrence**	**Shape variation**	**Unity**	**Complexity**
Mann-Whitney U	224.500	265.000	238.000	260.500	302.500	237.500	374.000
Wilcoxon W	785.500	826.000	799.000	821.500	863.500	798.500	935.000
Z	-3.848	-3.273	-3.668	-3.335	-2.747	-3.653	-1.728
Asym. Sig. (2-tailed)	**.000**	**.001**	**.000**	**.001**	**.006**	**.000**	.084

4.1.11.8. Overall creativity

A Mann-Whitney U test indicated that there was a significant difference (U = 224.500, p = 0.000) between C group and RbR group that received explicit instruction (I-RbR). RbR group has a higher mean rank (mean rank = 41.02) than I-RbR group (mean rank = 23.80) suggesting that the products of C group are assessed to be more creative in Task 2.

Table 168. Ranks for Overall Creativity between experiment groups C and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
C	30	41.02	1230.50
I-RbR	33	23.80	785.50
Total	63		

4.1.11.9. Novelty

A Mann-Whitney U test indicated that there was a significant difference (U = 265.000, p = 0.001) between C group and RbR group that received explicit instruction (I-

RbR). RbR group has a higher mean rank (mean rank = 39.67) than I-RbR group (mean rank = 25.03) suggesting that the products of C group are assessed to be more novel in Task 2.

Table 169. Ranks for Novelty between experiment groups C and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
C	30	39.67	1190.00
I-RbR	33	25.03	826.00
Total	63		

4.1.11.10. Shape emergence

A Mann-Whitney U test indicated that there was a significant difference (U = 238.000, p = 0.000) between C group and I-RbR group. C group has a higher mean rank (mean rank = 40.57) than I-RbR group (mean rank = 24.21) suggesting that the products of C group are assessed as better in making new wholes in Task 2.

Table 170. Ranks for Shape Emergence between experiment groups C and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
C	30	40.57	1217.00
I-RbR	33	24.21	799.00
Total	63		

4.1.11.11. Shape recurrence

A Mann-Whitney U test indicated that there was a significant difference (U = 260.500, p = 0.001) between C group and I-RbR group. C group has a higher mean rank (mean rank = 39.82) than I-RbR group (mean rank = 24.89) suggesting that the products of C group are assessed to be better in establishing links of similarity between the parts in Task 2.

Table 171. Ranks for Shape Recurrence between experiment groups C and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
C	30	39.82	1194.50
I-RbR	33	24.89	821.50
Total	63		

4.1.11.12. Shape variation

A Mann-Whitney U test indicated that there was a significant difference (U = 302.500, p = 0.006) between C group and I-RbR group. C group has a higher mean rank (mean rank = 38.42) than I-RbR group (mean rank = 26.17) suggesting that the products of C group are assessed to be better in establishing links of variance between the parts in Task 2.

Table 172. Ranks for Shape Variation between experiment groups C and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
C	30	38.42	1152.50
I-RbR	33	26.17	863.50
Total	63		

4.1.11.13. Unity

A Mann-Whitney U test indicated that there was a significant difference (U = 237.500, p = 0.000) between C group and RbR group that received explicit instruction (I-RbR). C group has a higher mean rank (mean rank = 40.58) than I-RbR group (mean rank = 24.20) suggesting that the products of C are assessed as better in achieving unity in Task 2.

Table 173. Ranks for Unity between experiment groups C and I-RbR.

Groups	N	Mean Rank	Sum of Ranks
C	30	40.58	1217.50

(cont. on next page)

Table 173 (cont.)

I-RbR	33	24.20	798.50
Total	63		

4.2. Process Oriented Evaluation

This section presents the results for fluency and flexibility counts for Task 1 and Task 2 in each experiment based on the collected sketches from the participants.

4.2.1. Experiment I – Task 1

4.2.1.1. Fluency

A Kruskal-Wallis H test showed that there was a statistically significant difference in fluency score between the different forms of reasoning, $\chi2(2) = 5.783$, $p = 0.055$, with a mean rank fluency score of 10.30 for control group, 18.40 for associative reasoning group (AR) and 17.80 for rule-based reasoning group (RbR), which confirms Hypothesis I. Using an associative strategy has an impact on the creative process. It makes the process more divergent.

Table 174. Ranks for Fluency in Task 1 in Experiment I.

Groups	N (number of products)	Mean Rank
AR	10	**18.40**
RbR	10	17.80
C	10	10.30
Total	30	

Among pairwise comparisons, there were two statistically different results in fluency score. A Mann-Whitney U test indicated that there was a significant difference ($U = 23.500$, $p = 0.031$) between AR group that starts to design with a precedent compared to C group that received no intervention.

Table 175. Mann-Whitney U test statistics for experiment groups C vs AR.

	Fluency
Mann-Whitney U	23.500
Wilcoxon W	78.500
Z	-2.153
Asymp. Sig. (2-tailed)	.031

The products in AR group has a higher mean rank (mean rank = 13.15) than the products in C group (mean rank = 7.85) suggesting that starting to design with a precedent increases fluency in Task 1.

Table 176. Ranks for Fluency for experiment groups C vs AR.

Groups	N	Mean Rank	Sum of Ranks
AR	10	13.15	131.50
C	10	7.85	78.50
Total	20		

A Mann-Whitney U test indicated that there was a significant difference (U = 24.500, p = 0.038) between C group that received no intervention compared to RbR group that were asked to start to design with a list of shape rules.

Table 177. Mann-Whitney U test statistics for experiment groups C vs AR.

	Fluency
Mann-Whitney U	24.500
Wilcoxon W	79.500
Z	-2.072
Asymp. Sig. (2-tailed)	.038

The RbR group has a higher mean rank (mean rank = 13.05) than C group (mean rank = 7.95) suggesting that starting to design with given shape rules increases fluency in Task 1.

Table 178. Ranks for Fluency for experiment groups C vs RbR.

Groups	N	Mean Rank	Sum of Ranks
RbR	10	13.05	130.50
C	10	7.95	79.50
Total	20		

4.2.1.2. Flexibility

A Kruskal-Wallis H test showed that there was a statistically significant difference in flexibility score between the different forms of reasoning, $\chi2(2) = 5.906$, $p = 0.052$, with a mean rank flexibility score of 10.65 for control group, 17.00 for associative reasoning group (AR) and 18.85 for rule-based reasoning group (RbR), which confirms Hypothesis I. Using a rule-based strategy has an impact on the creative process. It makes the process more divergent.

Table 179. Ranks for Flexibility in Task 1 in Experiment I.

Groups	N (number of products)	Mean Rank
RbR	10	**18.85**
AR	10	17.00
C	10	10.65
Total	30	

Among pairwise comparisons, there was one statistically different result in flexibility score. A Mann-Whitney U test indicated that there was a significant difference ($U = 21.500$, $p = 0.014$) between C group that received no intervention compared to RbR group that were asked to start to design with a list of shape rules.

Table 180. Mann-Whitney U test statistics for experiment groups C vs RbR.

	Flexibility
Mann-Whitney U	21.500
Wilcoxon W	76.500
Z	-2.448
Asymp. Sig. (2-tailed)	.014

RbR group has a higher mean rank (mean rank = 13.35) than C group (mean rank = 7.65) suggesting that starting to design with given shape rules increases flexibility in Task 1.

Table 181. Ranks for Flexibility in Task 1 in Experiment I.

Groups	N	Mean Rank	Sum of Ranks
RbR	10	13.35	133.50
C	10	7.65	76.50
Total	20		

4.2.2. Experiment II – Task 1

Kruskal Wallis H tests showed that there was no statistically significant difference in both fluency and flexibility criteria for Task 1, which partially rejects Hypothesis I. The order in which the reasoning strategies are performed has no significant impact on the creative process of novice learner.

Table 182. Kruskal Wallis H Test Statistics for Fluency and Flexibility in Task 1 in Experiment II.

	Fluency	Flexibility
Chi-Square	2.931	2.931
Df	5	2
Asym. Sig.	.711	.711

4.2.3. Experiment II – Task 2

Kruskal Wallis H tests showed that there was no statistically significant difference in both fluency and flexibility criteria for Task 2, which partially rejects Hypothesis I. The order in which the reasoning strategies are performed has no significant impact on the creative process of novice learner.

Table 183. Kruskal Wallis H Test Statistics for Fluency and Flexibility in Task 2 in Experiment II.

	Fluency	Flexibility
Chi-Square	.000	0.000
Df	5	5
Asym. Sig.	1.000	1.000

4.2.4. Experiment III – Task 1

Mann-Whitney U tests showed that there was no statistically significant difference in both fluency and flexibility criteria for Task 1, which partially rejects Hypothesis 3. Instructions to use particular reasoning strategies will have no significant impact on the creative process of students.

Table 184. Mann-Whitney U Test Statistics for I-AR vs I-RbR for Task 1.

	Fluency	Flexibility
Mann-Whitney U	53.500	50.000
Wilcoxon W	119.500	105.000
Z	-.132	-.472
Asymp. Sig. (2-tailed)	.895	.637

4.2.5. Experiment III – Task 2

Mann-Whitney U tests showed that there was no statistically significant difference in both fluency and flexibility criteria for Task 2, which partially rejects Hypothesis 3. Instructions to use particular reasoning strategies will have no significant impact on the creative process of students.

Table 185. Mann-Whitney U Test Statistics for I-AR vs I-RbR for Task 2.

	Fluency	Flexibility
Mann-Whitney U	55.000	55.000
Wilcoxon W	121.000	121.000
Z	.000	.000
Asymp. Sig. (2-tailed)	1.000	1.000

4.2.6. Experiment I and III – Task 1

Mann-Whitney U tests showed that there was no statistically significant difference for both fluency and flexibility criteria for Task 1 results across groups, which partially rejects Hypothesis 3. Instructions to use particular reasoning strategies will have no significant impact on the creative process of students.

Table 186. Mann-Whitney U Test Statistics for AR vs I-AR for Task 1.

	Fluency	Flexibility
Mann-Whitney U	35.000	35.500
Wilcoxon W	90.000	90.500
Z	-1.215	-1.287
Asymp. Sig. (2-tailed)	.224	.198

Table 187. Mann-Whitney U Test Statistics for RbR vs I-RbR for Task 1.

	Fluency	Flexibility
Mann-Whitney U	38.000	39.000
Wilcoxon W	104.000	105.000
Z	-1.295	-1.223
Asymp. Sig. (2-tailed)	.195	.221

4.2.7. Experiment I and III – Task 2

Mann-Whitney U tests showed that there was no statistically significant difference for both fluency and flexibility criteria for Task 2 results across groups, which partially rejects Hypothesis 3. Instructions to use particular reasoning strategies will have no significant impact on the creative process of students.

Table 188. Mann-Whitney U Test Statistics for AR vs I-AR for Task 2.

	Fluency	**Flexibility**
Mann-Whitney U	45.000	45.000
Wilcoxon W	100.000	100.000
Z	-1.000	-1.000
Asymp. Sig. (2-tailed)	.317	.317

Table 189. Mann-Whitney U Test Statistics for RbR vs I-RbR for Task 2.

	Fluency	**Flexibility**
Mann-Whitney U	55.000	55.000
Wilcoxon W	121.000	121.000
Z	.000	.000
Asymp. Sig. (2-tailed)	.1000	.1000

CHAPTER 5

DISCUSSION

This section presents the interpretation of the statistical analysis of the three experiments and the content analysis of the students' retrospective reports in the light of dual process accounts on reasoning, creativity and learning.

The discussion follows the order of the experiments reported previously. First, the effect of directing students to use a particular form of reasoning on their creative performance is discussed in the light of dual process accounts on reasoning and dual process models of creativity. Second, the effect of directing students to use two forms of reasoning in particular orders on their creative performance is discussed in the search for a sequential program that can be helpful to introduce these two forms of reasoning in design education. Third, the effect of explicit instruction on the two forms of reasoning on students' creative performance is discussed.

5.1. Forms of reasoning and their effect on creative performance

The objective of Experiment 1 was to observe how an instruction to use a particular reasoning strategy affects first year students' creative performance. A nine-square grid exercise is used in the experiments. The structure of the exercise used in the experiments is important because it implies a certain route map for the design process. This route map has parallels with Jane Darke's map of the design process she described after several interviews with some well-known British architects. Instead of analysis and synthesis, her map reads generator-conjecture-analysis which had some parallels with a proposition by Hillier et al. (1972).

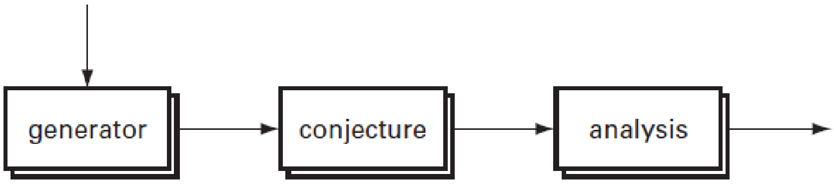

Figure 27. Jane Darke's map of the design process (Source: Lawson (2004, p. 46).

In the light of this map, as the instruction to use either a rule set or a precedent in the experiment manipulates the "primary generator" (Lawson, 2004), which helps the designer to develop a design proposal (Task 1), and then examine it to see what else one can discover about the problem itself through generation, exploration, and analysis (Task 2). Considering the nine-square grid exercise in the experiment, a student is expected to generate possible design solutions and then narrow down these possible solutions according to a design schema given in Task 2.

Task 1 requires students to configure a two-dimensional design. The results indicate that instruction to use a particular reasoning strategy has a minimal impact on students' performance and has a statistically significant effect only on the criterion of unity. Overall, the instruction to use either an associative reasoning strategy by way of consulting a precedent or to use a series of shape rules does not improve the creative performance of students, expect the unity dimension, when their results are compared to students who were told to just design freely. This supports the view that letting student explore a design task on their own has advantage over the other two interventions.

Unity in a design product is one of the fundamental qualities to achieve. In the beginning years of design education, it is also considered as one of the fundamental concepts to be learned regarding to the assembly of design elements. Results of the Task 1 in Experiment 1 where two different interventions' effect were compared to a control group indicates that using shape rules has the highest effect on participants' achieving unity. Since unity of a composition is described as the way individual elements used in the design relate to each other and to the total design (Demirkan and Afacan, 2012), using shape rules seems to help first year students achieve better part to part and part to whole relations.

The performance of AR participants is significantly lower compared to the other two groups in achieving a unity in their initial a x a compositions. The control group's performance is also significantly higher compared to the AR group. This result suggests that starting with a two-dimensional whole does not increase students' creative performance in a significant way.

Considering the description of unity in relation to the results, two inferences can be drawn from the results. First, rather than giving a finished product as a precedent, giving simple shapes and relations among them to students provide better performance in achieving unity. Second, shape rules indicate design elements to work with and actions for what to do with them by already established certain relations between shapes, however a precedent to work with only gives a unified whole where shapes and the relation among them are hidden from the eye which requires a student to be experienced in analysis and abstraction to search for possible shapes and relations.

Task 2 is a continuation of Task 1 where the a x a design unit produced in Task 1 is taken as the basis of a new 3 x a x a composition. Task 2 requires students to put together nine of the units of Task 1. Task 2 is the phase where the initial square composition needs to be adapted to a new framework through a limited set of possible transformations. Task 2 compared to Task 1 leads the problem solver to a process where one explores alternatives of an initial idea through transforming it with a set of predetermined operations. Such transformation of a selected idea can be considered as vertical transformations, as coined by Goel (1995), which also shows similarity with convergent thinking.

The product-oriented evaluation of Task 2 indicates that instruction to use a particular reasoning strategy has a statistically significant result. When Task 2 is considered as a continuation of Task 1, the analysis of six out of seven criteria shows that instruction to use a particular reasoning strategy has a detrimental effect on product creativity, which suggest that the evaluation process they go through during Task 2 is negatively impacted by the specific instructions students are asked to follow. The first hypothesis therefore was not confirmed. In other words, leaving students on their own has the highest positive effect on student's performance in all criteria scores, including overall creativity score, except the complexity criterion.

Dual process accounts on reasoning, creativity, and learning can provide explanations on the interference of instruction to use a particular reasoning strategy. The nature of two successive tasks implies a deliberate separation between "idea-producing thinking processes" and "idea-selection thinking processes". The serial models of creativity can be useful to discuss these results because of the structure of exercise and the nature of each task.

A deliberate separation of idea-producing thinking processes from idea-selection thinking processes is often touched upon in the literature on process of creative thinking and problem solving. For example, Guilford (1967) differentiated between idea-producing abilities (divergent production) and idea-judging abilities (evaluation) in his structure of intellect model. Basadur (1995) mentions the emergence of two schools of thought within this perspective. One school suggests that the use of judgmental, convergent thinking processes can happen during idea production. In the other one, it is suggested that only divergent thinking is used during idea production "to generate options without judgment or rules of logic" (Basadur, 1995, p.64). Basadur et. al. (1982) call this process of suspending judgment to separate divergent thinking from subsequent convergent thinking as ideation-evaluation. Ideation-evaluation is necessary for every stage during problem solving. Many models suggested for creative problem solving depicts of various serial stages where there are ideation-evaluation cycles in each stage. When Task 1 and Task 2 can be mapped onto process of ideation and evaluation respectively, these serial models of creativity have some relevance for explaining significant difference in product oriented and process-oriented evaluations of creativity between groups.

The Genoplore model by Finke, Ward and Smith (1992) proposes a model of creativity which consists of two processing stages: a *generative* phase, in which mental representations called "preinventive structures" are constructed, followed by an *exploratory* phase, in which these structures are explored for possible interpretations. Considering Genoplore model by Finke et al. (1992), Task 1 can be interpreted as an idea generation stage. In this line of thought, Task 2 becomes the idea exploration stage. The operations in the idea generation stage (Task 1) may involve both associative and rule-based processes which includes formation of associations as well as analytic processes which can be helpful to form new ideas and insights (Finke et al. 1992; Sowden et al. 2015). Task 2 requires participants to identify the attributes of the products of Task 1 and to evaluate their potential function in the new context. Task 2 seems to be a phase where only convergent thinking is involved however, due to the nature of the task, the operations in this exploration phase may require not only rule-based processes but also associative processes. This suggests that Task 1 can be described a phase when both divergent and convergent processes operate while Task 2 can be seen the phase where convergent processes take over for idea exploration.

If one follows the results of the study by Wallas (1926), however, Task 2 is not a phase where only rule-based process operates. Although the exploration through transformations of single idea may imply that convergent thinking maps onto Task 2, as Wallas (1926) suggests, convergent thinking can arise from both associative and rule-based processes. Thus, a simple mapping of divergent and convergent thinking, and a mapping of generation and evaluation onto Task 1 and Task 2 respectively is not possible. Each phase involves generation and evaluation of ideas. This is particularly valid for design problem solving which requires interlocking processes of perception, cognition, and notation. The representations used during designing requires both perceptual and cognitive processes. Thus, designers find and use any way to ease the cognitive load.

Such a statistically significant predominance of product creativity of the group which received no intervention may suggest both interventions, i.e., providing a visual source analog for associative reasoning and requiring the use of a set of rules, have no positive impact on creative performance. There can be two possible reasons for explaining the no impact of a visual analogy for novices. First, the students receive a source image instead of producing or selecting one's own source to generate design ideas. Dunbar and Blanchette (2001) propose that people are more likely to establish deeper analogies which may lead to more original ideas when they produce or select their own sources. Although the provided source is an exemplar of a successful composition, this may have created a block for possible retrieval of previous experience of similar solution that may lead to a more creative design for Task 1.

Second, design fixation can be a possible explanation for the low scores of AR group. In the expense of blocking retrieval of previous solutions, the instruction to use the visual display leads students to explore the source example through analysis. The retrospective reports of students indicate two main strategies for making associations to make a new composition. From a cognitive point of view, these strategies can be considered as adaptation which involves modification of a precedent, i.e., the source image in this case (see Oxman & Oxman 1992). One strategy, i.e., elemental adaptation as Oxman and Oxman (1992) describe, involves selection and transformational operations of a number of elements in the source image. As participants put, they extracted a set of elements to begin with and bring these elements together make a new a x a composition:

P008: I benefit from the image for selecting design elements and creating layers. The only reason for using these elements is because the image has similar ones…

P006: I used the geometric forms that are used in the image. I decided to make a composition by using triangle, rectangle, circle.

The second strategy involves not just a selection of elements in the composition but also includes identifying how the elements come together. In this strategy, elemental and schema adaptation exist together (Oxman & Oxman 1992). Schema adaptation involves modification of the schema of the precedent (see Oxman & Oxman 1992). The common result from the participants' analysis describes the existence of an axial organization of elements. As one participant put, this strategy involves both selection of elements from the composition as well as make use of an "axis" that is inspired from the source image:

P002: I am inspired from the lines and the axis. I created the unit by using the geometric shapes by changing their dimensions.

In addition to these strategies devised by the students, in Task 1 those students who are required to make use of the source image leads to a tendency to maintain a visual similarity between the source and the square unit composition. As Christensen and Schunn (2007) points out using within domain exemplars, as in the first experiment, creates a tendency to copy from these exemplars when designers try to achieve novelty. In addition, the participants even consider the degree of resemblance to the source as a required feature or as a condition for success. One possible reason is that their conception for the primary goal of Task 1 seems to be designing a composition that resembles the source image. One participant described the designed product for Task 1 as echoing the source image referring particularly to the red square embedded with the grey triangle and red line like thin rectangles:

P010: When I first analyzed the image, I noticed geometries changing as they intersect and the breaking effect in the linear elements. Later, I designed a composition that resembles the linear elements like long thin rectangles, semi-circle and triangle (in the source image) by using them.

The AR experiment group is given a source example as a “primary generator”, however as Goldschmidt (2011) states the use of external sources sometimes leads to a low-quality solution in terms of the metrics by which it is measured (and/or other factors) as occurred in the experiment. In such cases it is claimed that the source leads the designer to a limited design search which will in turn hampers the designer to reach a high-quality solution. Whether the external source is an example of solution to the design problem (Jansson & Smith 1991) or it is a stimulus including within domain or between domain representation that are not directly related to the problem at hand (Goldschmidt 2011), this situation is described as design fixation.

While design fixation can be thought to be causing low product creativity, on the contrary, fluency scores provide evidence of a productive effect of using a source example. Using a particular reasoning strategy has a positive impact on the creative process of students. The first hypothesis therefore was partially confirmed. They indicate that although the participants are first year students, they generated significantly higher number of ideas compared to other groups. As Ozkan and Dogan (2013) states first year students’ primary motivation and effort is usually in favor of originality and difference. In other words, first year students try to avoid copying the source and unconsciously avoiding design fixation. This shows that although the use of a source example does not warrant better quality of products, it leads to a more enriched design process with more design alternatives. This finding differs from the studies such as Casakin (2010) where the instruction to use a visual analogy assisted students to come up creative products as experienced architects. This does not show, however, that they failed to perform as creatively as other groups.

Goldschmidt (2011) claims that an external source, in this case the source image distributed to AR experiment group, has a positive impact if it provides affordances that contributes to the design search. It can lead to “a wider and/or deeper search and to a good choice of a leading idea” (Goldschmidt 2011, p. 93). As a way to avoid fixation, Goldschmidt (2011) suggests the transformation and abstraction of the source for making the design search wider and/or deeper, however first year students may lack procedural knowledge as well as experience with which they could make such transformations or abstractions. If, as Goldschmidt (2001) states, to use an analogy for solving an ill-structured problem requires more cognitive resources for novices, then it may create an increase on the cognitive load which may also hinder subsequent phases of refinement and evaluation of design as seen in the results of Task 2.

The comparison between the control group and the group which received shape rules indicates a statistically significant difference also. While there are some particular reasons, such as being unfamiliar or inexperienced with the workings of shape rules which may explain the impairing effect with pairwise comparisons, the overall dominance of the control group in product creativity may be associated with cognitive load caused by both interventions.

Both interventions might have increased the cognitive load for the students. Thus, rather than assisting the students to perform better in terms of product creativity, the students were putting extra cognitive effort to examine the strategy available to approach the given design problem. As studies of cognition in other domains (Kalyuga 2011; Sweller 1988, 1994) suggest while students are being trained in the use of problem solving strategies by solving given problems, such situations cause a diminishing effect in the ability of students to focus on the task because it produces a heavy load on the cognitive resources. As occurred in the experiment, students had to share cognitive resources such as attention, memory between exploring the visual display given and exploring the given design problem.

The cognitive load theory deals with difficulty in learning and problem solving (Sweller 1994). The difficulty of learning new tasks can change from being easy to impossibly hard. Such variations in the ease of acquisition can be due to many factors which includes the amount of information or the amount of effort required to achieve mastery (Sweller 1994) as in design learning which heavily relies on an individual effort by the learner. Design studios utilize solving design problems as a learning device to learn how to design. So, any problem-solving task for first year students is an attempt to figure out a way to solve the problem at hand or to apply the previously learned solutions. More importantly, all the tasks that first year students are dealing with becomes learning tasks (Kalyuga 2011).

Most current descriptions of the Cognitive Load Theory present three types of cognitive load based on the cognitive processes during learning: extraneous load, intrinsic load, and germane load (DeLeeuw & Mayer 2008; Kalyuga 2011; Sweller 2005). Intrinsic load is described as the type of cognitive load that is caused by the complexity of the learning materials when learner relies on working memory to consider various elements of information that are connected to each other at the same time (element interactivity) (Sweller 1994). Extraneous load is described as the load imposed by engaging the learner with activities or tasks that do not support the learning objective which emerge from the way the task is organized or presented. CLT was originally developed to devise means for the reduction of extraneous cognitive load in learning (Sweller 1988). The third type of cognitive load, germane cognitive load which was added to the Cognitive Load Theory at a later stage (Sweller et al., 1998) accounts for the intentional cognitive effort, and is associated with "the effortful construction of and automation of organized knowledge structures or schemas and the corresponding cognitive activities that directly contribute to learning" (Kalyuga 2011, p. 3)

Although the study does not measure learning using post-instruction or post-test subjective rating scales, evaluating the results of the experiment from the Cognitive Load Theory perspective may be helpful in explaining the differences in performance among the three experiment groups. The way to use a source example and to use shape rules for Task 1 does not differ in the ways the instruction is presented to the participants. However, when compared to the control group, it becomes obvious that the intrinsic load is increased because of the increase in task complexity. For the AR group, the instruction to use a source example invokes activities like analysis, abstraction of the given image and transformation of generated ideas consequently. For the RbR group, the intrinsic load is caused by the effortful exploration of using shape rules and develop an understanding of their workings at least on an operational level.

The Cognitive Load Theory is also helpful in explaining the statistical differences in process-oriented evaluations of instructed groups and the control group. The participants of the control group were able to display design behavior that is consistent with implicit processing with almost no externalization of design idea generation processes. However, the increased intrinsic load compared to control group because of increased task complexity caused the other two groups to externalize more to reduce the cognitive load.

To comprehend the given design tasks or situation in the experiment, part to part and part to whole relations in compositions should be processed simultaneously which can generate high levels of intrinsic cognitive load (Kalyuga 2011). Cognitive load does not always inhibit learning and it is actually necessary for learning (Kalyuga 2011). When students start to generate possible solutions and establishing connections both mentally and visually between pairs or quadruples of a x a compositions or directly trying possibilities in the nine-square framework in working memory, they actually experience intrinsic cognitive load. While intrinsic load is necessary for comprehending the tasks, the students need to provide all the necessary cognitive resources to accommodate this load without exceeding the limits of working memory capacity (Kalyuga 2011). While this increase on intrinsic load enhances the performance of idea generation for the participants of AR and RbR group, it may have a detrimental effect on the performance in Task 2 which requires Type 2 thinking characterized as slow, rule-based, and analytic. Consequently, Task 2 caused an increase in mental simulation which could correspond to increased cognitive load (Evans & Stanovich 2013) because it requires the students to define relations between axa units through emerging new shapes or alignments between elements in units and thus, as Cash and Maier (2021) suggest it may reduce designers' overall processing capacity since cognitive load was also defined as a working memory load (Sweller 1988).

In addition, the lack of a cyclical behavior, which means going back to Task 1 after a dissatisfaction with the result of Task 2, is evident in the sketches collected from the participants. The need for starting over idea generation phase might have demotivating effect on the designer since it requires more cognitive and physical effort. As Newstetter and McCracken (2001) observed, once students have an idea, they tend to stop considering alternatives, and act as though designing is a linear process. Furthermore, there is no indication of a movement from Task 2 to Task 1 which may occur as a result of an evaluation, which may be due to a lack of ability to alternate between two types of processes. While there is a lack of cyclical behavior of move between generation and evaluation for all three experiment groups, the intervention seems to have detrimental effect on the products' creativity. Thus, the only change between intervention and no intervention conditions may be the increase in cognitive load. However, the increase in cognitive load particularly influences the creative performance in Task 2. In other words, interventions do assist students in performing more creatively in design process however students fail to come up with a solution that fulfills the problem definition, or they fail to see their solutions are not satisfactory.

This can be explained as a failure to evaluate the products of Task 1 during Task 2. One possible reason relates to the lack of domain and procedural knowledge which implies that the necessary rules, procedures, and strategies have not been learned or at least not learned to the requisite level to evaluate the products of Task 1.

Dual-process theory provides two possible explanations for the low performance of AR and RbR groups. Firstly, it is possible to describe a link between association and fixation based on the interaction between Type 1 and Type 2 processes driven by explicit content given to the AR group. Type 1 processes which are roughly characterized associative, provides immediate associations to the given source image based on prior experience and rapidly evaluate the current situation. It appears that students do not make the effort to evaluate further according to the problem requirements in Task 2 where Type 2 thinking can override and make a slower but deliberate evaluation. This evaluative process may just reinforce the design idea produced rather than testing and evaluating the idea and its transformations in the new context (nine-square framework). During designing, students construct one composition at a time which is also pragmatically cued to be the most relevant one. Then, it is subject to explicit or analytic evaluation which complies with a satisficing principle in this case being a unified whole composed of possible transformations of Task 1 brought together. So, students may be failing to move from Type 1 process to Type 2 process to be successful in Task 2 or the failure for analytic evaluation can be caused by an effort-minimizing strategy which is the tendency to engage in a serial associative cognition with a focal bias. This tendency is described as the acceptance of the relations already established without exploring alternatives.

Serial associative cognition with a focal bias was termed by Stanovich (2009) to explain processes that is not rapid as in Type 1 thinking but "rather inflexibly locked into an associative mode that takes as its starting point a model of the world that is *given* to the subject" (p.68). This is introduced as a possible concept to explain what is happening particularly in Task 2. Although it is related with matching bias and confirmatory bias in particularly selection tasks, it offers some potential ideas in relation to misconceptions of novice students (Newstetter and McCracken, 2001). It can be argued that analytic thinking is occurring in the task but rather in a shallower way.

Secondly, increased cognitive load caused by instructions to employ a particular reasoning strategy has an impact on novelty and the number of ideas (Sun & Yao 2012). The results of Experiment I partially support the study by Sun and Yao (2012). They show that the cognitive load related to reasoning strategies help improve novelty and quantity of ideas. However, for first year students in Experiment I, the cognitive load seems to have a positive impact on the number of ideas while it decreases the novelty scores for both AR and RbR groups. As discussed before, employing a certain reasoning strategy introduces an increased demand on working memory and consequently for Type 2 processing especially in Task 2.

The fact that some participants stop in Task 2 without moving back to Task 1 implies that they reason from the a x a unit produced in Task 1 and systematically generate associations based on that unit and its transformations without constructing another model for the design task at hand. Then, how can first year students be guided to employ alternative reasoning strategies that are commonly used in design that can help them to generate other possible solutions while working on the same problem in a cyclical manner?

5.2. The Order Effect of Associative and Rule-Based Reasoning Strategies

Designers goes through divergent and convergent thinking processes iteratively (Tversky & Chou 2011) and they employ associative and rule-based reasoning strategies concurrently (Goldschmidt 2016). On the other hand, a pedagogical strategy needs to be devised to introduce both types of reasoning in design studio environments alternately. It is also important to explore if there is a specific sequence for introducing these reasoning strategies. Experiment II provides the means for investigating the order effect of associative and rule-based reasoning strategies on creative output and creative process.

Before the discussion of product-oriented evaluation of the second experiment's results, the participants' design behaviors will be discussed in reference to their retrospective accounts. The comparative analysis of three experimental conditions showed that regardless of the differences in interventions, there were common features among study participants with regard to their design activities. Newstetter and McCracken (2001) list five novice misconceptions of design. Three of them are of interest for this study, which are "ideation without substance", "design shutdown", and "design routinization" (pp. 67-68). These novice misconceptions of design can explain the observations involving the lack of cyclical behavior in students' design process.

First, ideation without substance is used to describe the necessity of evaluation of ideas based on informed decision making and analysis (Newstetter & McCracken 2001). Task 1 involves a conjectural approach while Task 2 allows a designer to check whether the selected design idea meets problem requirements. Students' retrospective reports and collected sketches indicate that these selections are not further evaluated after completing Task 2. As one participant put it, they generated various ideas for Task 1 as they thought it might be helpful to produce alternative ideas however, they usually brought together nine of the square compositions just to complete the task:

> P031: I thought this design is not enough. I thought that if I design a couple of more squares, it may be beneficial for my final design… In the second part of the design [referring to Task 2] I produced enough number of units and I brought them together on the first impulse. I tried to use all three transformations [stated in the exercise sheet].

The students recognize the potential benefits and necessity for success of generating multiple "speculative solution ideas" (Ball & Christensen 2019). Task 1 involves problem structuring in parallel to the generation of ideas since it is the idea-generation phase of designing (Goldschmidt 2016). Especially when students employ a particular reasoning strategy, there is more divergent thinking than convergent thinking in Task 1 as shown in Experiment I (see Table 174 and Table 179). However, they seem to be unaware of the fact that these ideas serve "as conjectures that allow designers to clarify their understanding of the problem" (Ball & Christensen 2019, p. 38) as shown by Darke (1979) and Lloyd and Scott (1995).

Second, design shutdown refers to the tendency to focus on one single solution after idea generation stage. An ideal design process involves a cyclic behavior moving back to an ideation stage where alternatives are reconsidered after an evaluation stage. So, in line with lack of an evaluation of a generated idea which is required in Task 2, students tend to stop without considering alternatives and focus all their energy on that one idea and its transformations in Task 2.

Last, design routinization refers to the lack of movement from Task 2 to Task 1 which suggests that students act as if designing is a serial or linear process. "Design routinization" helps us describe students' avoidance to go through ideation-evaluation cycles in the first experiment. Basadur et al. (1982) and Basadur (1995) explain in detail the notion of ideation-evaluation cycles. Guiding the first year students through repeated ideation-evaluation stages can be helpful as an intervention to have them experience cycles of ideation and evaluation by also instructing them to employ a particular reasoning strategy to solve the same design problem. The order of such instruction and its effect on students' creative performance is the main subject of inquiry in this phase of the study. Thus, the set-up of the second experiment looks into whether an intervention to overcome these three misconceptions mentioned above might be useful or not. The three-stage set up of the experiment is schematically described as shown in Figure 28.

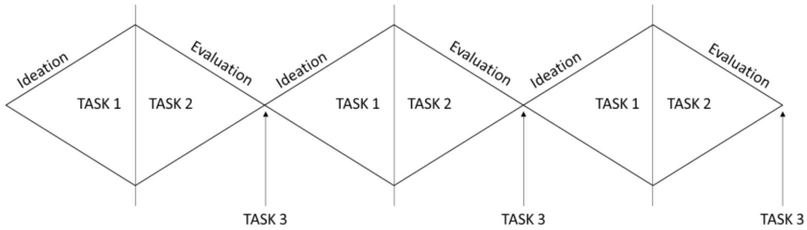

Figure 28. Ideation-Evaluation cycles in the Experiment II.

Regardless of the order in which the two reasoning strategies are introduced, there are a number of issues to be discussed in relation to retrospective reports and collected sketches provided by the students. Apart from being as a tool for collecting data regarding students' individual reasoning strategies and design processes, Task 3 is considered as a place for reflection (Schön 1984; Schön 1987b) or a phase for reflective observation (Kolb 2015) followed by a concrete experience of a particular reasoning strategy. Based on the content of Task 3, there is no explicit report of a transfer of experience gained from the previous design situation. All the participants tend to treat discretely each design task in the sequence although the same design problem is given in each phase in all the sequences. However, more research is needed if instructing students to solve the same design problem repeatedly by employing different reasoning strategies fails to overcome the misconceptions mentioned previously. This also may indicate that first year students need an explicit guidance to make connections between phases in the sequence and that they can be asked to make these connections explicit.

The second experiment investigates the order effect of two forms of reasoning on the creative performance of students. The analysis of the data indicates that the order in which students used specific reasoning strategies in a series of design tasks has some significant effects on students' creative performance, which confirms Hypothesis 2. The C-AR-RbR sequence provided the most significant impact on first year students' creative performance in Task 1.

Starting with a precedent to the series of design exercises depicts a negative effect on the creative performance of the students in both Task 1 and Task 2. Although the literature presents numerous cases of how the use of associative reasoning strategies, like using visual analogy, enhance creativity, when sequences starting with AR are compared to other sequences (C-AR-RbR, C-RbR-AR) it is found that preliminary individual design explorations improve students' performance. Such AR strategies can enhance creativity if a student designer is guided to construct an understanding of the design situation preliminarily.

The discussion in the previous section about the increased cognitive load in the conditions which require a certain form of reasoning strategy support the advantage of the sequence starting with no instruction. For Task 1, an individual design exploration which allows familiarization with the given design problem provides a significant difference on the creativity of the product.

The comparison between C-AR-RbR and C-RbR-AR shows that the order of AR-RbR increases the quality of the product creativity. The steady improvement in overall creativity evaluations in the sequence of C-AR-RbR (see

Figure 11) supports the impact of AR-RbR sequence on the quality of the product creativity. Pairwise comparisons of RbR-AR-C and RbR-C-AR for Task 1 shows that starting with a set of given shape rules to the series of design exercises has only a significant effect only when it is followed by an associative reasoning strategy in this series of design exercises.

From dual process perspective, all of the sequences provide "cycling repeatedly through a process of divergent and convergent thinking" (Vidal 2010, p. 412) while the design problem remains the same. So, while each sequence allows each participant solving a number of problems, it may also allow a transfer of experience and accumulation of knowledge gained from this experience. Thus, such a sequential structure may facilitate learning mechanisms to acquire knowledge on two forms of reasoning strategy.

Sweller (1994) establishes two learning mechanisms: "schema acquisition and the transfer of learned procedures from controlled to automatic processing" (p.296). Schema can be described as "a cognitive construct that organizes the elements of information according to the manner with which they will be dealt" (Sweller, 1994, p. 296). As schemas are constructs that knowledge of a subject matter is organized into, which also determine how new information is dealt with, there are schemas for dealing with problems as well, which are patterns of thought or behaviors that organize categories of information and the relationships among them. Such schemas are used to recognize a solution based on the classification of problems into categories according to how they will be dealt with. Then, as Sweller (1994) states, "learning to solve problems occurs by learning problem categories defined by the moves required for solution" (p.297).

As acquiring schemas occur gradually and incrementally while a learner solves numerous and various problems to construct categories defined by the moves required for solution, the transfer of learned procedures from controlled to automatic processing occurs slowly as a result of practice. As familiarity with a domain or a particular problem is gained, cognitive resources can be directed to other activities. The sequential structure of the experimental conditions is expected to ease the cognitive load while directing cognitive resources that are needed for particular subtasks since as one moves through a sequence the load on the working memory to understand the design problem will decrease. The low performance of AR and RbR groups indicates that the participants had to devote attention to the required ways of forms of reasoning strategies while solving the problem.

There are three significant points with regard to results from Task 2. First, the sequence of C-AR-RbR significantly improves students' creative performance in comparison with other sequences except the RbR-AR-C sequence. There is no statistically significant difference between C-AR-RbR and RbR-AR-C. The C-AR-RbR sequence has the highest scores for the other four statistically significant evaluations. In addition, its pairwise comparisons of overall creativity scores with sequences starting with AR makes it a more successful ordering. In C-AR-RbR sequence, students first conduct an individual design exploration which allows familiarization with the given design problem which in turn might prepare them for a better structured design exploration following either rule-based or associative reasoning strategy. This shows that further instructions seem to be more meaningful or have an impact on the learner's performance (see Schön 1987a) followed by an initial familiarization.

This result also indicates that the interference effect caused by explicit instructions (Berry & Broadbent 1988; Reber 1996) can be overcome by allowing familiarization of the design problem before any instruction. In other sequences where participants' first encounter with the design problem also involves application of a particular form of reasoning strategy, it is revealed that these instructions have debilitating effect on their performance because instruction to use a particular reasoning strategy distract the students from the ways of dealing with the task (Reber et al. 1980). This is also supported by the results of the first experiment where participants of AR and RbR groups have a creative process in Task 1 but failed to produce more creative products in Task 2.

Second, the comparison between C-AR-RbR and C-RbR-AR indicates that instructions to use a strategy like visual analogy helps first year students more to improve their performance (see Casakin & Goldschmidt 1999) after having them go through a preliminary design exploration that allows familiarization with the given design problem.

Third, the sequence of C-AR-RbR with a steady improvement in the performance of students in Task 1 indicates the creative performance gets better when students first explore the design problem on their own before getting introduced to a specific form of reasoning strategy.

Gabora's (2005) model of creative thought bears a relevance to the design process in C-AR-RbR sequence and can provide some insights on the predominance of the sequence starting with an individual design exploration which allows familiarization with the given design problem. Gabora (2005) describes creative thought as a process of "honing in on a vague idea through re-describing successive iterations of it from different real or imagined perspectives" (p.262). She suggests that this approach can be used to describe how creative thought occurs in "situations in which a creator discovers serendipitously that a solution to one problem is provided by what was considered a completely different problem" (p. 276). Thus, this approach involves the interaction between problem and context. While Task 1 and Task 2 are similar in the sense that they both require a student to design a composition, Task 2 requires the use of the output of Task 1 and its transformations and the evaluation of them in a new context. In addition, the changing design situation in Task 1 throughout all the sequences also brings a new context.

Gabora's model suggests a process starting from an individual's past knowledge. Idea generation starts with associative processes which facilitates forging of connections between attributes of ideas and concepts bounded with the context. These ideas are then honed by an analytic process. The context can be taken as design situation. According to this model, as one dwells in the design situation, the creative thought follows a path starting with associative process towards a more analytic process in a serial manner.

The C-AR-RbR sequence seems to provide a similar process described by Gabora's model. From this perspective, a student can recall past knowledge to construct a conceptual framework that can help solve the problem or contribute to their understanding of the problem during when they are not impaired by an extra cognitive load. In the second encounter with the same design problem, s/he also needs to utilize a visual display as an aid to solve Task 1. S/he is now required to incorporate the knowledge from his/her experience and the design knowledge of the product (see Cross 2007). Following this, in the third encounter with the same design problem, s/he is required to understand and apply another strategy to solve Task 1. The sequence of C-AR-RbR seems to increase cognitive load in a gradual way thus allowing the construction of a conceptual framework that has the potential to contribute to an understanding of the design problem (Gabora, 2005). Creativity increases as this sequence allows a process in which the problem can be solved, elaborated, or understood more deeply as one moves through the sequence (Gabora, 2005). These elaborations also seem to enhance the conceptual framework of students by enabling students to have more insight through reconsidering the problem recursively (Gabora, 2005).

Another crucial point to emphasize is that as students encounter the same design problem for the second time and the third time, each participant's conception of design problem would change compared to the previous design situation. Thus, any model of creative thought should consider the difference between an initial state and later states during design process dealing with the previously engaged design problem. Gabora's (2005) model describes the occurrence of creative thinking not as a process of selection occurring in parallel among alternatives but rather as construction of ideas where actualization of potential is driven by the context. In reference to this model, multiple attempts for solution to fulfill the same design problem is necessary for creative performance.

The results suggest that the order of employing reasoning strategies has a significant effect and a consistent increase on the overall creativity scores. Thus, the order of change in framing of the problem definition influences the creative performance since cognitive state changes as with each encounter of the same design problem. Instruction to employ reasoning strategies in a certain order, therefore, has an effect where a certain change of cognitive states in a certain order leads to an incremental change.

Controlling the order of change may have several educational implications for design studio pedagogy. First, the individual exploration of design problem is necessary for any subsequent instruction on creativity and reasoning strategy to be meaningful for novices. Second, from a dual-process perspective, the design situation in the control group condition allows a student to cope with the design problem regardless of his/her individual differences or aptitudes in idea generation. Starting with such a free design exploration allows students to focus their attention to understand problem definition. Third, it is unknown whether a student approaches Task 1 with a divergent or a convergent thinking strategy. However, it is apparent that it requires both an idea-generation phase and idea-evaluation phase to select a particular solution to move onto

Task 2 which requires transformations of the selected idea. It, therefore, involves a preliminary evaluation of the selected idea for making a larger new whole. Thus, Task 1 requires the use of both Type 1 and Type 2 thinking. As one moves through the sequence the need for Type 2 thinking seems to increase. For the experimental condition where one needs to start a visual display, there are two motivations that guides a student. First is to understand the given whole. Second, the urge to avoid design fixation and being original (Ozkan & Dogan, 2013) may also lead student to broaden their attention and to illustrate new issues for evaluation while also encouraging a more focused and analytical approach to design problem solving (Howard-Jones, 2012). Starting with a visual display at the first encounter with the design problem may result in fixation (Howard-Jones, 2012) which may then lead to a cognitive load that inhibits both problem solving and learning.

When the ratings of criteria for Task 2 are considered to understand the order effects of instruction to use a specific reasoning strategy, the effect of cognitive load is apparent on them. Particularly for the ratings of shape emergence (see Figure 20) , shape variation (see Figure 22) and unity (see Figure 23), there is an incremental increase in the scores in the sequence of RbR-AR-C. When a student is first asked to bring nine of the initial squares, which is generated by using shape rules, the low scores for Task 2 can be an indication of high cognitive load caused by the instruction to use a specific reasoning strategy. The lowest scores in the first encounter mostly belongs to a condition that involves using shape rules. As participants of RbR-AR-C group moving through the sequence, an incremental increase can be seen on the ratings for shape emergence, shape variation and unity. These criteria also belong to the indicator of creativity grouped under elaboration. Elaboration involves refining and evaluating a selected idea. These processes require the use of Type 2 thinking which is dependent on working memory. Thus, the increase of scores in Task 2 in RbR-AR-C scores is considered meaningful as the cognitive load caused by the instruction to use a specific reasoning strategy decrease.

The results obtained may seem inconclusive. In fact, they provide insight into the effect of explicit instruction on students' performance on generating ideas and evaluating them from dual process perspective. The effect of instructing students to use a specific reasoning strategy is variable in accordance with the mode of processing the instructions undergo. For Task 1, the movement from an individual free exploration of a design problem to the introduction of an associative reasoning strategy which is followed by a rule-based reasoning has a positive impact on overall creativity of the products in idea generation phase. For Task 2, which involves both idea generation and its evaluation, the same sequence is successful however the increase in cognitive load should be decreased if an incremental increase is aimed throughout the sequence. Thus, it is important to find ways for easing the cognitive load for the students. The explicit instruction in the first and second experiment involves only the use of certain strategies. In the following section, the findings support that first year students can be shown how to use of a certain reasoning strategy (Goldschmidt 2001). It shows that it is possible to use a combination of instruction and practice if the instruction accompanied with a lecture on how to use a certain reasoning strategy can ease the cognitive load by providing relevant and salient content for the task.

5.3. The Effect of Explicit Instruction for Associative and Rule-Based Reasoning Strategies on the Creative Performance

Experiment III aims to investigate the effects of a lecture on forms of reasoning before a design problem as a pedagogical strategy. It compares participants' creative performance undertaking a design problem in two instructional settings: first group starting to design with a visual source analogue and a lecture on associative reasoning in design, and the second group starting with a set of shape rules and a lecture on rule-based reasoning in design. The experimental setup also provides means to observe if the familiarity or exposition to certain reasoning strategies with a lecture influence the creative performance of students compared to those who were not exposed to such a lecture.

Design is taught by using a combination of instruction and practice as in any other domain however learning to design requires an extensive amount of practice. In design studios, while the practice is aimed at providing multiple encounters with design problems with a varying degree of complexity, the instruction is often in the form of guidance to learners along the way after a certain amount of experience and familiarity is gained through practice. Complex mental skills are argued to be learnt through two complementary processes. Lane et al. (2008) refers to these types of processes as experience-based and model-based processes. The main problem for design remains to be providing model-based knowledge, such as a set of instructions or a recipe.

There has been research on the benefit of introducing any form of guidance such as prescribed design processes or lectures though empirical research however they failed to show their effectiveness. Wales and Stager (1977) points out that some design educators have tried to build on research to support and enhance the practices of design professionals by advocating “guided design” as a pedagogical strategy. Guided design relates to providing procedural maps based on prescribed processes that good designs must follow. Eastman (2001) states that, while it seemed intuitively a good strategy for teaching novice designers, empirical research does not support its effectiveness.

Atman and Bursic (1996) state that there is no statistically significant difference between groups who had read a chapter from a design textbook and those who had not. Newstetter (1998) discovered that students discard the prescriptive methods and begin to design as they see fit while they also try to show themselves as they follow the methods. Eastman (2001) suggests that the tools and methods introduced by the instructor failed to be seen relevant by the students. Furthermore, Oxman (2003) states that studies utilizing lectures and textual or visual material do not assure the acquisition of design thinking skills.

Research on the effect of explicit instructions and lectures in other domains presents two important findings which can provide some insight for design learning. First, any material provided to students should offer a meaningful content that they can relate to or see a value that they can use. The relevancy and saliency of instructions, therefore, is a determinant factor on its effect. Second, explicit processing of complex materials creates a disadvantage relative to implicit processing. So, explicit instructions seemed to have a particular kind of interference probably because of an increase in the cognitive load.

It is observed that the lecture developed as part of Experiment III provided relevant and salient instructions for the design tasks involving to use a precedent. Although, the studies with novice design students indicate that such potential aids to design learning generally fails, the results of this study show that the lecture on reasoning strategies has a positive effect on solving the problem with the aid of a visual display. As Lane et al. (2008) showed it with dynamic control task, providing guidance where a subset of information about a design task is first introduced and then allow the learners practice subsequently, have more benefits compared to practicing without any guidance in the case of associative reasoning strategies.

The effect of instruction on how to make an analogy with a source image has a significant effect on students’ creative performance. The findings of comparison between the group which received no instruction on how to make an analogy by using a source image and the group which received an instruction supports the results by Lane et al. (2008). The instruction introduced a number of methods that can be employed with a similar visual display. The instruction and the example used, therefore, is salient and relevant for students and they are successfully able to transfer and utilize this knowledge subsequently.

The content of the lecture can be a determinant factor for the increase in creative performance of the group which utilizes a visual display. The lecture provides several ways or strategies to utilize a case for idea generation. Thus, the reason for the predominant success of AR group appears to be caused by the relevancy and saliency of instruction on associative reasoning strategies. It explicitly includes demonstrations of particular strategies for design ideation. However, this result leaves a question open. The successful performance does not rule out the possibility that improved performance is a result of participants doing better because they encounter a similar design situation. In other words, the question is whether the lecture helped them to learn about associative reasoning strategies or it just simply provided strategies to act appropriately in certain specific design situation. Another reason can be that associative strategies might have been more easily assimilated since they seem to be easier to perform and more familiar.

In the experimental studies investigating the effect of explicit instructions in other domains, it is found that the performance of the explicitly instructed subjects were poorer compared to control group which received no instruction about the content of the given task (Reber 1996). The same effect is found for the comparison between the group which received no explicit instruction on the use of shape rules and the group which received an introduction and a training phase on how to use shape rules to generate a composition.

The explicit instruction is counterproductive for the group using shape rules because the instructions given seems to provide no interpretable information. While Lane et al. (2008) suggest that providing guidance where a subset of information about a task is first taught and then allowing learners practice subsequently, appears to have more benefits compared to practicing without any guidance, the lecture on rule-based reasoning fails to provide a relevant subset of information about Task 1. In other words, the saliency and relevancy of instructions were not enough to take on a meaningful support thus it deviates the students from the ways of dealing with the task appropriately (Reber, 1996).

Rule-based methods are specific methods for generating and expressing design ideas that requires slow and analytic thinking processes. It heavily relies on Type 2 thinking process thus such methods are dependent on working memory. It creates a substantial demand on students' working memory as well as attention. This creates a cognitive load for the learner that may hinder the learner from performing other tasks.

The instruction in Experiment III is geared more heavily on improving skills and attitudes of idea generation (divergent thinking) with using a visual display. While the lecture introduces certain strategies for how to make use of a two-dimensional compositional visual display to generate new ones, it fails to provide the same amount of salient strategies in using shape rules to generate new ideas. The failure of instruction for how to use shape rules may be due to the need for individual exploration of workings of shape rules.

The results of the comparison between C group and I-RbR group and between C group and I-AR group indicates that free design exploration is better than or as good as instruction on how to use a reasoning strategy. More precisely, a lecture on rule-based design degrades students' performance and a lecture on associative design actually seems to be not any better than just letting students explore freely. The findings from the comparison between C group and I-AR group suggest that both free design exploration and instruction on how to use an associative reasoning strategy provide some information to build further information, yet the results do not indicate a significant improvement. These results, therefore, support the findings of the two previous experiments which emphasizes the necessity of individual's free design exploration. Such exploration allows the student to construct an understanding of the problem and illustrate issues that needs attention by reducing cognitive load for building further information and consequently decreasing demand on working memory and Type 2 thinking processes.

5.4. General Discussion

This study explored the impact of three interventions, which are designed as scaffoldings in design learning, namely explicit instructions, sequence of different interventions, and lectures. The first and foremost conclusion of the study is that students' performances starting a design task is best when they are freely exploring a design situation. The interventions, i.e., specifically a free exploration followed by a precedent followed by a series of rules and a lecture on associative reasoning in design, help when students already acquired some understanding and familiarization with the design task in hand.

An overall interpretation of this study's results indicates that facilitating creativity with explicit instructions lead to some costs that particularly affect problem solving, creative performance, and learning. Cognitive load that is increased by instructions deserves a particular interest. Cognitive Load Theory (CLT) builds on the understanding that there are two types of memory: working memory, which is limited; and long-term memory which is practically limitless (van Gog et al. 2005). Long term memory holds information in stored schemas and schemas are helpful for reducing working memory load (Kalyuga 2011). However, first year students are novices in both designing and learning to design. So, every encounter with a design task is a learning task for them (Kalyuga 2011). As schemas have not yet been acquired, any information of the problem has to be kept in working memory which can lead to a high demand on working memory capacity. As a result, the lack of capacity left for the formation of a schema hampers learning.

Developing effective and efficient instructional strategies to support initial skill acquisition has been the main focus of CLT research. First year design studios assume that all students have the same needs and capacity as individual learners. Individual design critiques seem to be the only pedagogical devices to respond to the differences in individual learners' needs and capacity. However, as van Gog et al. (2005) suggest, instruction for complex skill learning should be adaptive to the individual learners' needs and capacity, and should support and motivate learners in acquiring the ability to plan, monitor, and evaluate their own learning process.

Research on expert-novice differences has shown that experts perform better in their domain of expertise. As Ericsson and Lehmann (1996) noted, and as shown by many studies in design related domains, a knowledge-based approach to expertise is asserted by the research on expert-novice differences which equates expertise with having acquired a substantial body of knowledge during many years of experience in a domain. Ericsson and Lehmann (1996) provide evidence that experts who fit to this definition often do not show better performance as compared to less-experienced individuals.

Expert performance research has shown that the amount of deliberate effort to improve performance is more relevant for acquiring expert performance rather than the amount of knowledge in a domain. Ericsson et al. (1993) argue that extensive engagement in relevant practice activities provides the acquisition of expertise and individual differences lie in the amount of such relevant practice. Relevant practice activities for improving performance are called as deliberate practice (van Gog et al. 2005). These activities are initially designed by the teacher or the coach to support students to improve specific aspects of their performance in domains such as sports, chess, and music. To illustrate its characteristics, an example from sports can be considered. During a basketball match, a player gets to make a three-point shot for a certain number of times. The player also has to give his/her best performance in a limited time. When the player gets to work with a dedicated individual who constantly passes the ball to him/her, the player has dozens of shot opportunities during the same amount of time. The player also gets the chance to systematically explore ways of improving his/her performance. Ericsson et al. (1993) describe deliberate practice as organized sequence of appropriate tasks that are specially designed to improve the current level of performance. During the practice, the instructor monitors learners' improvement to decide on the timing for transitioning to more complex tasks.

van Gog et al. (2005), in reference to Ericsson et al. (1993) and Ericsson and Lehmann (1996), suggest that deliberate activities have two important features. First, they have an appropriate level of difficulty. Second, they enable successive refinement by allowing repetition, by providing opportunities to make and correct errors, and by providing informative feedback to the learner. If studio exercises are considered as deliberate practice activities to improve a skill, then these two features can be taken as a guideline. The sequence of C-AR-RbR being the most successful one has the potential to provide a framework for improving students' performance. It already allows repetition by providing opportunities to make and correct errors. It is possible to consider this sequence in a more flexible way. The experiment accommodated single takes for the three experimental conditions however the number of repetitions for each phase can be adjusted according to the complexity of the exercise.

There are various skills involved in designing. Lawson (2006) has proposed an overarching description of these skills. These skills include 'formulating', 'moving', 'representing', 'evaluating', and 'reflecting'. Moving refers to a whole group of skills that allows designers to generate solution or "generating ideas about whole or partial solutions" (Lawson 2006, p. 291). Formulating refers to the group of skills that is related to understanding and describing problems. Representing refers to the production of visualizations to think with. Evaluating skills are a range of skills that regulates the moves based on some set of criteria which may include objective or subjective evaluations. Reflecting refers to the group of skills of continuous monitoring and learning process. Lawson (2005) suggests that these clusters of skills may not develop in parallel, and they can develop in different amount of time. These descriptions can be helpful in diagnosing which skills need improvement and based on dual process accounts of reasoning which type of thinking processes they are associated with. In the context of this study, apart from individual differences, students in the experiments are good at generating ideas and instructions have a positive effect on the performance of generating ideas in Task 1. The lack of iterative moves from Task 2 to Task 1 indicates that there is especially a need for improvement of "evaluating" and "reflecting" skills. These skills are highly associated with Type 2 thinking processes.

These ideas suggest that novices should be provided opportunities to exercise evaluating and reflecting skills more often. Much research on design education has been focused on improving particularly the skills of moving which involves creating solution ideas, developing early ideas of solution (primary generators) and lateral moves which involves the transformation of an existing idea into a different one and vertical moves, which involves the development of an idea further with more detail. However, knowing when and how to evaluate is a fundamental design skill (Lawson, 2004) and needs special focus during learning.

Learning and comprehending what a composition is requires time if it is acquired only through learning-by-doing. Experientially learning the definition of composition through repeated trials and errors supported by feedback from the tutor demands heavily use of cognitive resources for novices. Thus, from CLT perspective, the cognitive load brought by the complex tasks may hamper the understanding of what a composition is and what designing a composition requires. While a student may acquire experience in constructing and generating ideas, the feedback obtained by grades or implicit evaluations such as disapproval of student's product may not mean much to students. That may be the reason why students ask what to do as an action since a definition of composition is not presented and s/he may not have strategies to overcome the possible paths of unsuccess.

Curry (2014) integrates Dreyfus' developmental model (novice, advanced beginner, competency, proficiency, expertise), and the three approaches to design methodology proposed by Lawson and Dorst (2013) (design as problem solving, learning, evolution) into a comprehensive model to facilitate the acquisition of design expertise that provides a procedural framework. He suggests that novices who have not yet acquired the requisite domain specific knowledge can benefit from the introduction of a design methodology that provides phases of problem solving as both a map and a procedural framework. On the contrary, Newstetter et al. (2001) state that empirical research does not support the effectiveness of providing procedural maps based on prescribed processes. However, Experiment III, supporting Curry's (2014) suggestion, provided some contrary evidence to Newstetter et al. (2001) on the benefit of providing novices such strategies particularly for associative reasoning strategies.

The experiential learning theory of Kolb (2015) is taken by researchers as an adequate framework to understand design learning (see Demirbas & Demirkan 2007). Kolb (1984) describes learning as "the process whereby knowledge is created through transformation of experience" (p. 38). In that process, a novice should "move in varying degrees from actor to observer, and from specific involvement to general analytic detachment" (Kolb, 1984, p.31). These transitions also correspond to required cyclical moves between two forms of reasoning, generation and evaluation, and implicit and explicit forms of learning for designers. Designers must be able "to reflect on and observe their experiences from many perspectives" (Kolb, 1984, p.30) and these activities requires slow and analytic thinking processes. Designers must be able to create concepts, schemas that integrate their observations and experiences into design reasoning strategies and these activities require both associative and rule-based processes. Designers also must be able to use these strategies to make decisions and solve problems and these activities requires both heuristic and analytic processes. Thus, to improve these abilities, design studio education should find ways to exercise two forms of reasoning and associated processes that are closely tied to divergent and convergent thinking processes with a consideration of creating opportunities for interaction between implicit and explicit forms of learning.

The results of experimental studies testing hypotheses regarding the impact of two forms of reasoning strategies on students' creative output and creative process collectively support an understanding of design based on an interplay between Type 1 and Type 2 processing, jointly affecting creative output and creative process. This aligns with the necessity of shifting between ideation and evaluation processes common in dual-process models of creativity reviewed by Sowden et al. (2015). A dual-process perspective also helps to explain the differences between novelty and fluency results in the Experiment I. It shows that the demand on Type 2 processes increases fluency in idea generation while has a detrimental effect on novelty of the creative output for novice learners. Based on the results of the Experiment II, the order in which certain reasoning strategies are employed also has an impact on the creative output. A gradual shift in the demand on Type 2 processes throughout the sequence may have a positive impact on students' creative performance. The comparison between the results of Experiment I and Experiment III shows that the increased demand on Type 2 processes caused by employing a certain reasoning strategy can be reduced by lectures on how to use that particular reasoning strategy.

CHAPTER 6

CONCLUSION

The primary motivation for this work has been to consider the cognitive content of design thinking as a basis for pedagogical strategies to be used in first year design studios. This motivation emerges from two concerns. First, students are seldom able to tell what they learn about design thinking. Second, the teaching methods applied in design studios are usually based on the studio instructors' own learning experiences and heavily relies on unstructured discussions. So, the primary interest has been to investigate how a more inclusive theoretical foundation can be established for a cognition-based approach to design education which particularly focuses on reasoning, creativity, and learning and what some pedagogical strategies can be for its implementation in design studio. Looking at dual-process theory of cognition has provided a starting point for a comprehensive cognitive framework for categorizing reasoning strategies used in design and explaining their link to creative performance and learning in design. For investigating possible pedagogical strategies, three different experiments were conducted which offer three different ways to incorporate two forms of reasoning strategies into two-dimensional composition exercises in a design studio setting. The results indicate that when students design the initial a x a unit (Task 1) without any instruction and without any prompt to utilize a certain form of reasoning, there is no difference among study groups. This is a simple design task, therefore, it might be that students manage to succeed equally well in this task regardless of the condition they are in. In Task 2, the 3 x a x a nine-square design composition task, however, there is a significant difference among groups in terms of the seven creativity criteria because the task is more complex than Task 1. Students who were not prompted to use any reasoning strategy performed better than the rule-based reasoning group and associative reasoning group. Following the cognitive load theory, students become overwhelmed with the constraints and requirements of the task that their performances decrease compared to the control group. The explanation could be that in both ruled-based and associative group, there is a significant load on working memory, since novices have not yet internalized neither of these reasoning strategies to use them fast and without effort as Type 1 reasoning. The results indicate, however, that when students go through Task 2 in a sequence starting with free exploration their performance increases and is the best among all the other triple sequences of reasoning strategies. Therefore, it can be said that being familiar with the design problem allows students perform better in adopting the instruction to use two forms of reasoning in the following stages in the sequence. The use of visual precedents in design problem solving is observed to improve creative performance after a free exploration of the design problem. An introduction of a rule-based strategy for idea generation is also observed to be more effective after a free exploration of the design problem followed by exposing students to an associative reasoning strategy to solve the same design problem. Thus, this sequence can be utilized as a cognitive scaffolding for students to exercise and become experienced in employing different forms of reasoning strategies.

With regard to the significance of specially designed lectures, it is found that lectures help students in using associative reasoning strategies only when compared to group of students who are in the associative reasoning group without any lecture. Lectures about rule-based reasoning strategies have a negative impact on students' performances and lectures about associative reasoning have neither positive nor negative impact when compared to students who are in the control group.

The body of research in cognitive science and creativity research has increased our understanding of the cognitive properties of design. To utilize this knowledge regarding design, design studio pedagogy should incorporate certain concepts in an operational sense. In Chapter 2, dual process accounts on reasoning, creativity and learning are reviewed which can function as a basis for design education. In the light of such basis, beginning year students may benefit from understanding the design process as a thought process that explores ways of reasoning.

The two important categories of design strategies, precedent (case-based) and rule-based design strategies are pedagogically applied in the design studio in various ways. Both strategies have been considered suitable for inducing students to complete a task with a focus on particular form of reasoning strategies and on the development of related skills. Precedent-based methods employ knowledge from prior designs relevant to the current problem at hand (Oxman, 1994). In this method past experiences are encapsulated as cases containing solutions to complex problems (Kalay, 2004). Rule-base design methods make processes explicit thus providing methods to learn how to complete a task in a stepwise manner. Methods are used to teach design to students as well as to help professional designers increase their performance (Daalhuizen 2014). Daalhuizen

(2014) argues that methods influence a designer's thinking patterns and mental models and he conceptualizes methods as mental tools rather than prescriptive processes. Dual process accounts on reasoning, creativity, and learning have the potential to develop our understanding of how design methodology influence a designer's thinking patterns.

Design studio instructors may be in favor of or excelled in one particular reasoning strategy, however, both methods provide particular benefits in acquisition of particular skills. The reasoning strategies students use are the result of their interactions with exercises in design studios because architecture students are not taught strategies for design problem solving in an explicit manner. Solving design problems is the main activity in design studios and it requires problem solving search. This search is dependent on limited working memory. Kirschner et al. (2006) state that learning is defined as a change in long term memory and indicate problem-solving search as "an inefficient way of altering long term memory" (p. 80). It is known that problem solving creates a huge demand on working memory (Sweller 1988) which creates a cognitive load that can affect learners overall processing capacity. So, although students may find a solution to the design problem at hand, problem-solving search can occur with no learning (Sweller 1988). Devising a pedagogical approach based on dual-process theory of cognition may be helpful to formulate guidance during instruction which takes into account working memory characteristics and functions.

Instruction in design studios provides an immersion that helps students to exercise and develop divergent thinking skills because it challenges students to solve novel problems. However, such activity which involves processing unfamiliar material also requires working memory. Thus, because of pedagogies ignoring the limits of working memory, design problems in studios hinder the exercise of idea evaluation and reflection. Adopting dual-process theory of cognition to shape design studio pedagogy can be helpful to include both idea generation and idea evaluation into the agenda of design studio pedagogy.

Idea generation has been considered necessary for increasing creativity in design as well as in various domains. Most of the studies in design creativity focus more heavily on improving skills and attitudes of idea generation (divergent thinking) than the skills and attitudes of idea evaluation (convergent thinking). Research on creativity and particularly analogical reasoning in design education mostly focuses on improving students' divergent thinking which is necessary for dealing with ill-defined problems. The findings in this research suggest that the same emphasis should be given to the improvement of the evaluation step in idea generation-evaluation processes placing it as an indispensable part of cycles of idea generation and idea evaluation in design problem solving for novices. Novices must learn to evaluate the ideas effectively in order to take advantage of generating various ideas.

This points out to two goals in design education. One goal is to help students to synchronize and develop a balance of divergent and convergent thinking (Basadur, 1990). Students should understand the necessity of idea evaluation as well as idea generation and the amount of time they require in different stages throughout the design process. Second goal is to foster students to understand better how attitudinal processes affect cognitive processes in design problem solving. This is more related to the novice misconceptions of design (Newstter and McCracken, 2001). The aim for design education should not focus only on the development of domain knowledge and experience in design but also aim for the acquisition of a designerly attitude.

Learning to design and learning to learn to design are the two main simultaneous tasks for any student especially in their beginning years. While the skills to fulfill these tasks are complex and acquired through repeated and long practice, the procedural knowledge is gained mostly experientially. The approaches during such instruction in design studios have been associated with problem-based learning, experiential learning or constructivist learning which are all identified as minimally guided approaches (see Kirschner et al. 2006). It is assumed that coaching students provides the necessary guidance for them to construct both problem solving strategies and on their own.

Design educators provide guidance in various ways, such as grades, instructions during the desk critiques, in the form of visual materials, or through lectures. Regardless of pedagogical devices, there are many factors that affect acquisition of such complex knowledge that is transferred through instructions in various ways. In this dissertation, two of them are pointed out and discussed. First, the content of any instruction should have a structure. Second, the relevancy, saliency, and sequence of instructions are key factors that affect learners' performance.

Design learning may require a combination of different types of instruction due to the nature of the problems that the profession deals with, however it is known that problem solving creates a huge demand on working memory (Sweller 1988) which creates a cognitive load that can affect learners overall processing capacity. Exercises used in first year design studios should be designed accordingly and minimize cognitive load that hampers learning and creativity.

In addition to design exercises, design critiques are an essential pedagogical device in design studios. In architecture, teaching heavily relies on criticism in design critiques. Dinham (1989) suggests that the reason for this may be either criticism is believed to be “the epistemological foundation of architectural thought” or it represents the “real world” (p. 81). Design studio culture and its conceptualization as being a simulation for the real-world practice seem to strengthen this understanding. Studio instructors should consider that “the way novice designers design is not the same as how expert designers design” (Curry 2014, p. 633) while devising their teaching strategies.

Although this study does not deal with it as a means for the acquisition of knowledge of design, the content of critiques is considered important through which a novice has the chance to observe an expert in action. The master-apprentice model especially occurring in design critiques seems to load the task of evaluation to the master where the master evaluates the product of the design process on behalf of the student. This makes the student a passive agent in the learning experience. The lack of domain knowledge and absence of explicit definitions may lead students to learn without knowing what to look for. The coaching, in Schön’s terms, is aimed towards compensating students’ lack of domain knowledge and guiding them to the refinement of a solution. Since most design studio instructors find it hard to be explicit on their reasoning for judgments on the products of the design process and to be articulate about how to develop their creativity (Rodgers & Jones 2017), students are left alone in efforts to understand not only how to generate multiple design ideas but how to improve a selected idea too. Talking with instructors and peers not just about the works but also about how they reason or what kind of strategies they explore with the aid of diagrams and sketches should be added to the tradition of design critiques to establish the notion of design process that can be talked explicitly as part of design knowledge.

This study offers findings and a useful scaffold for integrating the two forms of reasoning and for exercising these forms of reasoning comparatively early in their education. Through this scaffold, explicit instruction can be built on the performance of reasoning strategies by the introduction of information and topics that is relevant to their acquisition. The main purpose of such training is to increase an appreciation of the value of multiple forms of reasoning in design process.

6.1. Pedagogical Strategies

The prominent success of the C-AR-RbR sequence suggests a number of pedagogical interventions along the learning process. As discussed above a free individual design exploration is necessary to understand the design problem. As the cognitive load caused by understanding the problem at hand decreases after the first encounter, a more important opportunity arises. As the familiarity with the problem increases, it can be taken as the first moment to provide any form of explicit instruction. One of the main reasons can be that the provided guidance is now in a familiar context rather than a disparate and stand-alone explanation. In the study a single visual display was provided to the participants. The comparative studies between providing one single visual display and a set of similar visual displays need to be conducted to obtain better performance. Also, the distance of the selected visual displays needs to be studied. The transition from individual free exploration to the next phase can also be considered as a moment to provide a lecture on the relevant domain with cases or examples which will improve students' domain knowledge or at least develop and expand a visual library relevant to the task. The results of comparison between Experiment I and Experiment III suggest that the introduction for ways of utilizing a visual display also increased students' creative performance. A lecture, therefore, can also introduce a certain number of ways of looking at a visual source, how to analyze and generate an idea based on a successful example at this moment.

Once students reach a certain level of domain knowledge, then they may be introduced to an array of rule-based methods for generating ideas. Such methods involve languages that need explicit processing, and they increase the cognitive load of students since they are peculiar forms of expressing ideas. The strategy to have students use a set of visual rules provided to major insights. First, providing a set of visual rules to begin with had a negative effect on the creativity of the products. However, its effect on the creative process was a positive one although this strategy probably increased the cognitive load. This load was beneficial for leading the students to externalize more than the students freely explore the design tasks given. Increasing the number of visual rules gradually and keeping the initial shape the same is suggested as a better strategy to control the complexity of tasks. Second, the flexibility scores indicated that using visual rules had students to visualize lateral transformations in the design process. Moves such as repeating the same rule and jumping to another rule during the process can be helpful for incorporating divergence and convergence into the vocabulary of discussions in the studio.

As they will start to establish similarities from their past experiences of instructions and visual library, students may learn to extract rules from these. Thus, the transfer from implicit to explicit knowledge can be realized which may improve performance and speed up learning (Hélie & Sun 2010).

This dissertation offers the C-AR-RbR sequence as a cognitive scaffolding that may help instructors to organize a cognition-based content for design thinking in a step-by-step manner. It can also be utilized to develop a sequential program that involves a certain order of presentation for the materials and ideas in design reasoning to lead students to an understanding of basic ideas and structures. Although it requires more research on its utility and applications, it is offered as a starting point for application of certain reasoning strategies in conjunction that are used in design for idea generation.

6.2. Limitations

The study has some limitations. The results of the study could have been different if the experiments could have been conducted on the first day of the first-year students since they would not have any experience of design and design learning in a school of architecture. Having even a semester of experience may influence their performance.

The study is conducted only with first year students from a school of architecture in Turkey. Due to practical reasons, the number of participants was limited and less than expected especially in the second experiment. The number of participants and their diversity should be increased to observe the effect of different design pedagogies and different cultures.

The amount of time spent in both Task 1 and Task 2 in three different conditions remained unexplored. It could have supported the claims about the cognitive load that is brought using a specific reasoning strategy.

The experimental condition that directs students to use a source image only allows using a single analogy. The effect of using multiple sources also needs further investigation with a similar experimental set-up.

In the second experiment, only the six possible combinations of three different conditions were compared. The sequences where the same experimental condition is repeated three times were not tested. Undertaking the exercise repeatedly by employing a certain reasoning strategy may reveal different aspects of novices' performance. It may be also helpful to explore the learning effect of solving the same design task with the same reasoning strategy.

6.3. Future Studies

There are various potential future studies that can be based on the findings and propositions of the research. The first study would be to increase the number of participants from other schools and cultures in other parts of the world. This would help build a better picture for the effect of using forms of reasoning strategies among novices. It would particularly help to observe if there has been a success in overcoming the novices' misconceptions of design process and how it is achieved. A second study would obviously involve addition of other factors to be rated regarding design product and design process. Another study would be to pursue an experimental setup which would combine a sequential structure in the second experiment and the timing of instruction between the phases in the sequences. This setup might be helpful in obtaining some findings regarding the interaction between explicit and implicit forms of learning in relation to the effect of familiarity with the given design problem. A final study would be research that formulates expert views in between two tasks to test hypothesis about the content of the design critiques and their effect on students' creative performance.

Design education needs revision both in terms of content and pedagogical strategies for the acquisition of this content. Instructional approaches in design studios should be tailored according to the structures that constitute human cognitive architecture. The limits of minimally guided approaches in design studios need to be further explored.

Design instructors often use previous instructions they have experienced in their own education. They derive pedagogies from those experiences which remains as behavioral activities. On the contrary, as in any other domain, design learning needs an interaction between explicit and implicit learning. Dual process approach to design pedagogy can inform pedagogical strategies that can balance these two forms of learning.

It can also be helpful for studio tutors to devise exercises for students to understand and practice the relation between design creativity and activity.

Design studios tend to bring forward the act of making and identifying learning both through making and as a result of making. The praised part of design studios which are the conditions that relying on the implicit form of learning emphasizes learning design thinking by experiencing the processes and procedures of architectural design. The practice of design is not enough for learning to design. Basic design instruction has the potential to lead design educators to the acceptation of explicit instruction based on dual-process theories of cognition that can make up design thinking's content accompanied by the use of constructivist methods of instruction rather than extensive project work with minimum guidance.

Instruction in design studios could benefit from the introduction of a teaching strategy for structuring explicit knowledge on reasoning strategies that provides a cognitive scaffold as a sequential program. Novices could benefit from this sequential program for exercising reasoning strategies comparatively on the same design problem with the inclusion of explicit instructions such as lectures which can facilitate the grasp of explicit knowledge on design reasoning and application of the acquired knowledge to new instances. Defining design reasoning composed of different forms of reasoning with a dual-process approach would provide a way to make cognitive content of design as educational content from the beginning years of design education. At least, it would make instruction in design studios more effective and avoid students acquire misconceptions or disorganized knowledge.

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APPENDIX A

DESIGN EXERCISES

EXERCISE FOR THE CONTROL GROUP (C)

Tasarım problemi: KOMPOZİSYON TASARLAMA

1. Elinizdeki kare kağıtlara istediğiniz gibi istediğiniz sayıda doğru/eğri çizgiler çekin. Gördüğünüz şekilleri kullanarak **SİYAH** ve **BEYAZ** renklerde "8 x 8" ölçülerinde iki boyutlu bir kompozisyon tasarlayınız.

2. Bir önceki basamakta ürettiğiniz "8 x 8" kareyi bir birim olarak kullanarak, "24 x 24" olacak şekilde 9 tane birimi biraraya getirerek yeni bir kompozisyon tasarlayınız. Bu kompozisyonu tasarlarken aşağıdaki dönüşümleri kullanabilirsiniz:

a) döndürme,

b) aynalama (mirroring),

c) birimlerde kullanılan tasarım elemanlarına atadığınız renkleri değiştirme.

3. Tasarım sürecinizde tasarım elemanlarınızı nasıl ve neden seçtiğinizi, hangi tasarım elemanını nereye yerleştirdiğinizi, kullandığınız dönüşümleri, hareketleri veya kuralları çizimlerle ve yazarak anlatınız.

EXERCISE FOR THE ASSOCIATIVE REASONING GROUP (AR)

Tasarım problemi: KOMPOZİSYON TASARLAMA

1. Verilen görselden yola çıkarak “8 x 8” ölçülerinde **SİYAH** ve **BEYAZ** renkleri kullanarak iki boyutlu bir kompozisyon tasarlayınız. Verilen kare kağıtları kullanabilirsiniz.

2. Bir önceki basamakta ürettiğiniz “8 x 8” kareyi bir birim olarak kullanarak, “24 x 24” olacak şekilde 9 tane birimi biraraya getirerek yeni bir kompozisyon tasarlayınız. Bu kompozisyonu tasarlarken aşağıdaki dönüşümleri kullanabilirsiniz:

a) döndürme,

b) aynalama (mirroring),

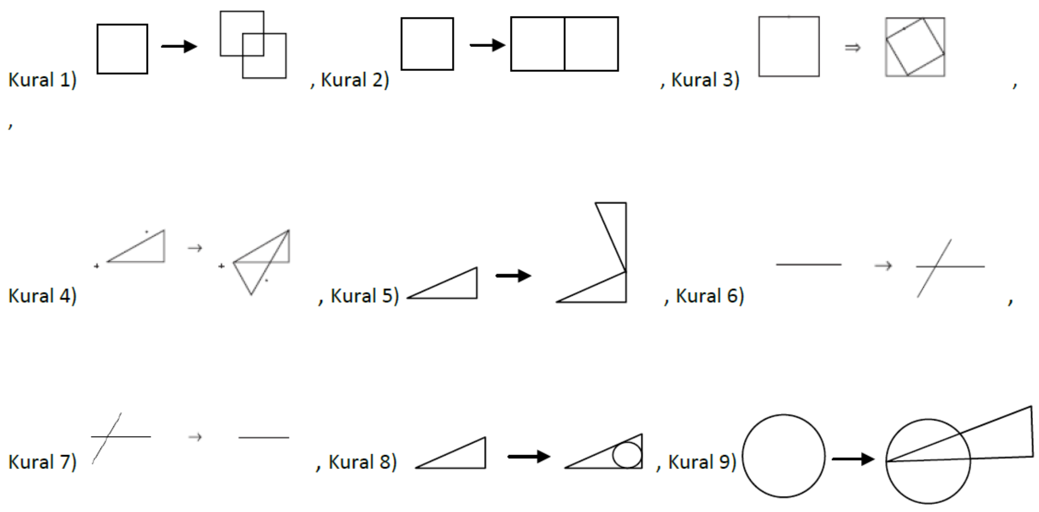
c) birimlerde kullanılan tasarım elemanlarına atadığınız renkleri değiştirme.

3. Tasarım sürecinizde verilen görselden nasıl faydalandığınızı, hangi tasarım elemanlarını neden ve nasıl seçtiğinizi, hangi tasarım elemanını nereye yerleştirdiğinizi, kullandığınız dönüşümleri, hareketleri veya kuralları çizimlerle ve yazarak anlatınız.

EXERCISE FOR THE RULE-BASED REASONING GROUP (RbR)

Tasarım problemi: KOMPOZİSYON TASARLAMA

1. Aşağıda verilen kuralları kullanarak bir komposizyon üretiniz.



(Hangi kuralları hangi sırayla kaç defa kullandığınızı her farklı sıralama için yazılı olarak kaydediniz ve 3. basamakta belirtiniz.) (Her kuralı en az 1(bir) kez, en fazla 7 (yedi) kez kullanabilirsiniz.)

Ürettiğiniz kompozisyon içinde gördüğünüz şekilleri veya şekil gruplarını verilen siyah renkli kalemi kullanarak görünür hale getirin. Seçtiğiniz şekilleri veya şekil gruplarını "8 x 8" ölçülerinde bir karenin içinde düzenleyerek **SİYAH** ve **BEYAZ** renkleri kullanarak iki boyutlu bir kompozisyon tasarlayınız**.** Verilen kare kağıtları kullanabilirsiniz.

2. Bir önceki basamakta ürettiğiniz "8 x 8" kareyi bir birim olarak kullanarak, "24 x 24" olacak şekilde 9 tane birimi biraraya getirerek yeni bir kompozisyon tasarlayınız. Bu kompozisyonu tasarlarken aşağıdaki dönüşümleri kullanabilirsiniz:

a) döndürme,

b) aynalama (mirroring),

c) birimlerde kullanılan tasarım elemanlarına atadığınız renkleri değiştirme.

3. Tasarım sürecinizde size verilen kurallardan nasıl faydalandığınızı, hangi tasarım elemanlarını neden ve nasıl seçtiğinizi, hangi tasarım elemanını nereye yerleştirdiğinizi, kullandığınız dönüşümleri, hareketleri veya kuralları çizimlerle ve yazarak anlatınız.

CURRICULUM VITAE

Name Surname: Batuhan Taneri

EDUCATION:

PhD in Architecture, Izmir Institute of Technology (2021)

Thesis: An Investigation Into Architecture Students' Creative Performance While Using Associative And Rule-Based Reasoning Strategies: Exploring A Dual Process Approach In Design Education

M.Sc. in Arch: Izmir Institute of Technology (2013)

Thesis: Architecture students' perceptions of design and its transformations throughout their education

B. Arch: Izmir Institute of Technology (2007)

PROFESSIONAL EXPERIENCE:

Lecturer (Part-time), Faculty of Fine Arts and Design, Izmir University of Economics. (2019 – 2021)
Research Assistant, Faculty of Architecture, İzmir Institute of Technology. (2013 – 2019)
Research Assistant, Faculty of Fine Arts and Design, Izmir University of Economics. (2008 – 2013)

PUBLICATIONS:

2021- **Batuhan Taneri**, Fehmi Doğan. "How to learn to be creative in design: Architecture students' perceptions of design, design process, design learning, and their transformations throughout their education", Thinking Skills and Creativity, Volume 39, 2021, 100781, ISSN 1871-1871, https://doi.org/10.1016/j.tsc.2020.100781.

2020 – **Batuhan Taneri**, Fehmi Doğan. "The Order Effect of Associative and Rule-Based Reasoning Strategies in Design Learning", in *Ninth International Conference On Design Computing and Cognition.*

2019 – Fehmi Doğan, **Batuhan Taneri**, Livanur Erbil. "Use of analogies, metaphors, and similes by students and reviewers at an undergraduate architectural design review", Artificial Intelligence for Engineering Design, Analysis and Manufacturing, 33(1), 69-84. doi:10.1017/S0890060418000057

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