

Chapter 1. Introduction

This chapter begins with the motivation for carrying out this doctoral research. Then, it establishes its main subject and research areas; discusses aims and objectives and outlines working hypotheses. Finally, it provides a summary on the research scope, method and structure.

1.1 Motivation

Designing is considered to be one of the most challenging and important human activities; it is complex, requires high intelligence and skills, and its' results have a major effect on society. Many studies have been done on the nature of designing during the past three decades yet it is surprising how limited the knowledge in this area is. The research in architecture has been mainly concerned with the design process: it approached design as a problem-solving in an ill-defined domain and dealt with its theoretical aspects using the introspective knowledge of designers and empirical methods to model it. There is also a significant number of studies concerning expertise in architectural design. More recent attempts to predict behaviour in complex design tasks have indicated a growing interest in the subject of cognitive and learning styles and cognitive abilities. Among the latter studies, it is spatial abilities and visual reasoning that have been commonly recognised as crucial for designing. Almost forty years ago, Ghiselli (1966) and Smith (1964) demonstrated for high-spatial individuals to typically outperform those lacking in such skills in design tasks. In problem solving, however, the role of spatial and other cognitive abilities remains under-researched. The situation with cognitive styles is similar. While there are studies indicating that students receive higher grades in fields that are compatible with their styles (Hattie, 1999; Drysdale *et al*, 2001), there is a lack of understanding how they affect reasoning in design. It is also still unclear how the above styles and abilities fit into the *design ability* – a construct that integrates qualities any individual must have to be able to handle a design task. The above brought up an idea of exploring a number of individual cognitive abilities and learning styles further, to facilitate a better understanding of how they are integrated into the problem-solving behaviour on administered design tasks (the *process*), how they manifest themselves in design *product*, what their roles are in academic performance, and, ultimately, what their relation to the design ability may be.

1.2 Subject, Research Areas and Structure

The main subject of the current study is researching individual differences in *design ability* in the domain of architecture. Design ability is a set of qualities that, according to a vast number of researchers, designers have to possess to be able to do their job, which are expected to affect the way they do it (Schön, 1983, 1992; Cross 1992, 1995; Bennet, 1996; Löwgren and Stolterman, 1998; Bernstein, 1998). As this field of study is very broad and multifaceted, this thesis explores a limited number of cognitive abilities and styles assumed to contribute to the design ability in architects. It suggests a method of demonstrating how they affect problem solving during design tasks and academic performance.

Dealing with the topic of individual differences and design abilities usually involves a diverse range of aspects, including personality, cognitive abilities and styles, gender, age, domain knowledge and other. Thus, our initial understanding of the subject, or the theoretical foundation of the thesis, draws upon literature from many sources, including cognitive science, psychology, design studies and imagery research. The suggested methodology is based upon theoretical and empirical knowledge, data-collection, observation, and exploration techniques, and methods of analysis developed within the above domains.

The problem of individual differences in design ability is addressed via the exploration of three major areas of research, termed as:

- § Input / ability factors
- § Process
- § Product

The *input* is related to the subject of *design ability* which has a major unresolved concern. That is, it is not evident which cognitive abilities and styles are inherent to designers. Cross (1992, 1995) provided the most comprehensive up to date synopsis of the thirty years of knowledge in the field of design ability complemented with his own profound analysis. But, he did not seem to come much closer to identifying which human abilities are necessary for designing. It is also unclear whether design ability is a particular ‘designerly way of knowing, thinking and acting’ – a construct embedding cognitive skills and thinking styles specific to designers – or it is ‘a multi-faceted cognitive skill, possessed in some degree by everyone’ (Cross, 1995, p. 115).

Thus, a decision had to be made on the qualities of the design ability to be regarded as the most important for designing, or likely to be possessed by the majority of designers, and having a consistent affect on their problem-solving. Ultimately, the choice of *ability factors* was based on (1) the analysis of pertinent literature, indicating common views of the qualities essential for designers/architects; (2) the availability and reliability of psychometric tools for their examination; and (3) the knowledge gained via our earlier experiments. Thus, the exploration of in the *input* in this study can be seen twofold: the focus is both on *how* a number of *ability factors* influence problem solving as well as understanding better *what* constitutes the ability to design. The latter can be attained via discovering, whether the *input* has a consistent impact on design problem solving, is reflected in design solutions, and predicts academic performance.

The second major area of exploration is the *process*. It is concerned with conceptual or preliminary design typically defined as a series of activities by which designers navigate through an abstract problem domain trying to find or invent entities that allow elaborating the problem description and arriving at initial design solutions. In this study, the knowledge of the problem-solving behaviour is gained via conducting protocol studies followed by the exploration of designers’ actions and strategies reflected in video records, external representations, retro- and introspective self-reports and questionnaires. It is researched in relation to the *input* as this study tries to determine how the measured styles and abilities affect or regulate the process of problem solving during administered design sessions.

The third area of exploration is the *product* or the final design solutions. It is linked to the *process* and the *input* by the commonly accepted idea that individual design abilities are one of the major sources of variance in design results. Thus, the main purpose of this part of the thesis is to see how individual cognitive styles abilities affect the process of sketching, and the quality of outcome. Researching the *product* involves collecting assessments of design solutions based on a taxonomy that adequately reflects the constituents of the input.

Finally, there are ratings of academic achievement provided by the course supervisors, based on design projects’ grades. They are intended at supplying a useful source of data that, among other goals, helps establishing whether any of the *ability factors* could serve as predictors of the domain performance.

The thesis is concerned with researching individual problem solving. It is not viewed as a limitation as an important proportion of design activity remains the work of single individuals; there is no convincing evidence proving that co-operation modifies the nature of the basic processes implemented in the design solution development and evaluation. And, as this study is restricted by the (relatively) small number of participants, it offers only tentative generalisations concerning common patterns in cognitive processing among the groups of involved individuals.

Figure 1 provides a visual account of how the subject of individual differences in design ability is approached in relation to the three major areas of research.

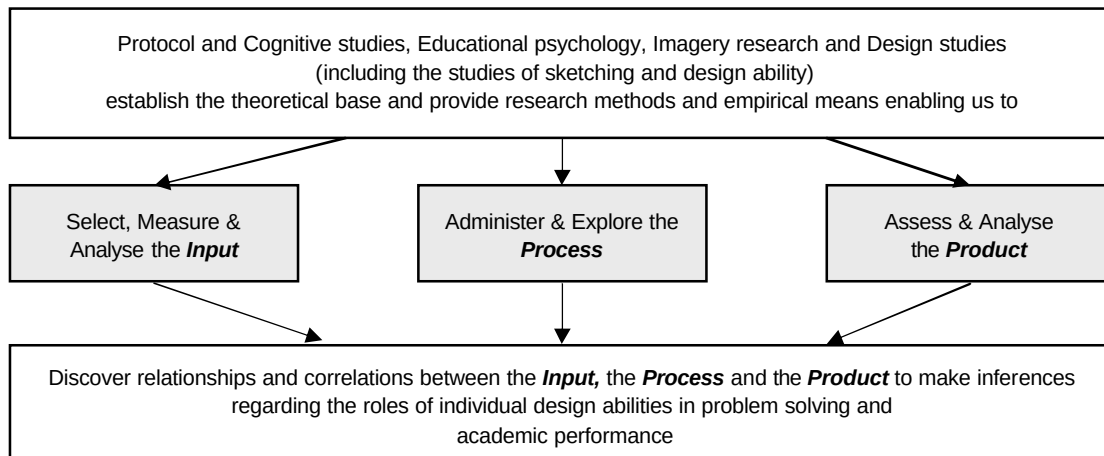


Figure 1. Research areas and structure

1.4 Hypothesis

The main hypothesis is that certain differences in designers' individual internal and external problem solving strategies and, ultimately, products of their expertise – designed artefacts – can be explained by the differences in their cognitive styles and abilities. It is suggested that (a) designers with different cognitive styles are inclined to adopt different approaches to design situations and to use different strategies during problem solving; (b) individual differences in design reasoning and problem solving could be correlated with the differences in individual cognitive abilities; (c) there may be correlations between the measured cognitive styles (or strategies) and cognitive abilities; and (d) it is likely that a number of observable or measurable characteristics of students' drawings and generated design solutions would in some way reflect different aspects of their individual styles and abilities.

The above hypothesis is based on the assumption that, as many researchers have suggested, designing depends upon an individual's design ability, which essential characteristics correspond to the *ability factors*. If this is the case, then persons with similar cognitive styles, will structure their problem solving in somewhat similar ways. Equally, similar cognitive abilities will lead to a degree of similarity in internal and external cognitive processing. This may result in certain comparable features of the generated drawings. Which also means that the results of this study are potentially generalisable, that is, could be applied to other design tasks and situations, involving other individuals. A possibility for this study to have a wider application is largely based on the nature of the design ability constituents explored. Individual cognitive styles are the preferred ways of action regulation in dealing with complex problems, and their essential feature is stability – they are believed to consistently manifest themselves in different problem situations. The cognitive roles of the measured domain related abilities/skills are also rather well researched and appear to be fairly consistent, though the extent of their use varies across tasks and situations.

1.5 Aims and Objectives

The aim of this study is the exploration of relationships and correlations among individual learning styles, cognitive abilities, design reasoning, produced design solutions, and the judgements of academic performance.

This research is to determine and elucidate:

- the likely roles of individual cognitive abilities in design problem solving, their possible reflection in produced design solutions and relation to academic performance;

- the likely roles of individual learning styles in design problem solving, their possible reflection in produced design solutions and relation to academic performance;
- correlations among the measurements of learning styles, abilities and academic performance;
- correlations among the measurements of cognitive styles, abilities, design problem solving and produced design solutions;
- generalisable tendencies or preferences for different styles and strategies in problem solving behaviour among different groups of individuals; and
- learning styles and cognitive abilities that may have a noticeable impact on problem solving and academic performance and may be viewed as essential to the design ability.

The objectives are arranged according to the three main areas of research and the analysis. The first set of objectives is related to the *input* research area, where we intended to:

- select the *input* – a number of cognitive abilities and learning styles viewed as important for designing and contributing to design ability;
- select empirical models and instruments for the *input* assessment;
- conduct experiments, extract data and perform statistical analyses of individual as well as group cognitive styles and abilities;
- obtain data on academic performance through the reports of students' supervisors supported by the records of academic grades (on design projects only); and
- explore relationships and correlations among the measurements of styles and abilities and academic performance

The second group of objectives is related to the *process* research area, where we intended to:

- prepare design sessions and post-session interviews and questionnaires;
- develop an approach to the analysis of problem solving activities in relation to the *input* and to the *product*;
- extract and analyse data related on the students' learning styles and strategies through the exploration of the structure of cognitive actions/processes from protocols (external and internal representations);
- extract and analyse data on the students' cognitive abilities through the exploration of the structure of cognitive actions from protocols (external and internal representations);
- extract and analyse data on individual cognitive styles and strategies from introspective reports and questionnaires; and
- correlate protocol data on abilities and styles with the measurements of individual learning styles and abilities from psychometric testing

The third group of objectives is related to the *product* research area, where we intended to:

- develop a taxonomy enabling correlating the *ability factors* with the *product*;
- have the product assessed and analysed by professional architects based on the chosen taxonomy and in accordance with their domain experience;
- compare assessments of the design product with supervisors' reports;
- correlate the measurements of individual styles and abilities with the assessments of design solutions and academic performance; and
- correlate group scores of students with similar styles and/or abilities with the assessments of design solutions and academic performance.

And, finally there's a set of goals, related to the multivariate analysis of all available data, where we intended to:

- perform statistical analysis of the *input*, the *process* and *product*, i.e. correlate the differences in subjects' approaches to problem-solving with the differences in their cognitive abilities and styles, academic performance and produced design solutions (based on the preceding clustering and identifiable trends); and
- elucidate preferences for particular problem solving behaviour in relation to the *input* and the *product* (based on the preceding clustering and identifiable trends); and

- summarise the role/s of students' cognitive styles and abilities in academic performance and problem-solving (i.e. which constituents of the design ability have the strongest or the most consistent links to the *process* and the *product* across all groups of subjects) to, ultimately, add to our understanding of what constitutes the ability to design.

1.6 Organisation of Thesis

The thesis is organised as follows. Chapter 2 provides theoretical fundamentals, which have informed this study and allowed to contextualise it within the reviewed research literature. It is divided into three major parts. The first part is concerned with the notion of *design ability* and presents an overview of findings on the subject – its structure and components. The main focus is on the individual cognitive styles and domain-related cognitive abilities, and their functions in designing and design education. The second part reviews several major theories of the design *process* with its models overviewed, followed by a discussion of their relevance to the present study. The known functions of design ability in problem solving are also summarised. The third part addresses the issue of design *product*, namely the role of sketches in design. It contains a synopsis of studies that relate design drawings to the design ability and the design process.

Chapter 3 informed the final method and experimental design discussed in Chapter 4. It contains a discussion of factor-analytic literature, research methods and techniques, and assessment instruments brought together with a purpose of (a) providing a theoretical overview of methodological approaches commonly used in design studies, and (b) establishing the knowledge base and the rationale for the experimental design and empirical studies presented in Chapters 4, 5 and 6. It is organised into three sections, corresponding to the three research areas.

Chapter 4 contains a synopsis of this study's methodological approach and experimental design. It elucidates its research plan, data-collection and assessment techniques and research method. This includes discussing the choice of ability factors, selection and application of psychometric tools and techniques, evaluation taxonomies and types of applied analyses.

Chapters 5 is the first part of the empirical study, presenting Experiments I-III supplemented by data extraction, analyses and discussions. Experiment I is a psychometric study assessing a number of visual-spatial and ideation factors believed to contribute to the design ability. Experiment II is another psychometric study evaluating individual positions on Wholistic-Analytic and Visual-Imagery dimensions of learning styles, also viewed as a part of the design ability. Experiment III is a dataset containing the judgements of academic achievement based on design projects' grades reported by course supervisors. The main purpose of this part of the empirical study is to provide the estimates of the students cognitive development and learning preferences, which could be subsequently correlated with the *process* and the *product*; to research interconnections and correlations among the ability factors; and to determine which factors could be regarded as good predictors of the domain performance.

Chapter 6 is the second (and final) part of the empirical study concerned with individual conceptual design. The quantitative and qualitative methods of protocol analysis, introspective reports and questionnaires are used in Experiments IV and V as a means of examining and elucidating how design contexts and intentions are embedded in design drawings along with analysing designers' reasoning reflected in retrospective verbalizations, introspective self-reports of the imagery use and questionnaires. The acquired data is explored both as the process and as the likely outcome of abilities and styles of problems solving of this study's participants. Experiment VI is concerned with the assessment of design solutions produced in Experiment IV. Judgements are done along a number of parameters enabling subsequent exploration of the relationships and correlations between the *product*, the *process* and the *input*.

Chapter 7 contains a summary of major findings capitalising on the most significant relationships between spatial abilities, learning styles, design performance and academic achievement. It articulates and discusses the final conclusions in relation to this study's aims and objectives. It offers some recommendations and reflects upon the research process. It also contains an outline of the future research objectives and directions.

Chapter 2. Theoretical Framework: Areas of Research

This chapter presents an overview of the cross-disciplinary research that establishes the theoretical base for the current study. It is a selective summary of the earlier studies in creativity, cognitive and design studies, educational psychology, studies of sketching and imagery research brought together on the basis of their relevance to the subjects of *design ability*, *design process* and *design product* and, correspondingly, divided into three major sections. Chapter 2 discusses a number of outlooks on design problems shared by many researchers from different fields and relevant to the current study; it establishes how this work fits into the latest design research and what its expected contribution is going to be.

Structure-wise, this Chapter begins with a synopsis of findings on the design ability: its recognized role and components. It is concerned with individual *cognitive styles* and *cognitive abilities*, and their influence on design problem solving and academic performance. The second section discusses some of the major developments on the subject of design process, and its relation to the design ability. The third section is concerned with design product, or the role of sketches in design, including their functions in problem solving (the process) and relation to the design ability. Every section contributes to the outline of the research scope.

2.1 Design Ability

The term *design ability* has been in use for a long time. As it often happens in design research and education communities, different authors assign different meanings to it. Cross (1992, 1995), in his review summarizing thirty years of research into the nature of design ability, defines it as ‘what a designer needs to be able to handle a design task’. He pinpoints six key aspects of the design ability that have been identified over the years: (1) managing goals and constraints, (2) coping with ill-defined problems, (3) problem structuring, (4) generating solution concepts, (5) thinking by drawing, and (6) intuitive reasoning. The researcher then reformulates the design ability postulates by maintaining that designers must be able to (1) solve ill-defined problems, (2) produce novel and unexpected solutions, (3) use nonverbal, graphic / spatial media like sketches and scale models as a means of problem-solving, (4) apply imagination and constructive forethought to practical problems, (5) adopt solution-focusing strategies, (6) employ abductive, productive and appositional thinking, (7) work with several design solutions in parallel to understand the problem-solution space, (8) tolerate uncertainty and work with incomplete information.

According to Arvola (2002), the above system of classification incorporates at least three groups of separate factors: some relate to the design situation, others to methods of designing, while the rest deal with design goals. Thus, in his summary of research on design ability, the author suggested structuring it differently. Design goals are characterized by producing novel and unexpected solutions to ill-defined practical problems, under uncertain situations, with incomplete information. To generate these solutions, a designer needs to apply imagination and constructive forethought in a solution-focused strategy characterized by abductive, productive and appositional thinking. And while several design solutions are explored in parallel by the means of sketching and other graphic/spatial modelling media, designer also uses it as a way of understanding the problem-solution space.

Both versions of the above classification are compelling, yet their application in the context of the current study is more than problematic. They consist of factors representing concepts, descriptions of processes or multidimensional constructs, and not cognitive abilities, skills and styles that support design reasoning, or which a designer needs to be able to succeed in his/her profession. That is, this classification presents serious difficulties in terms of evaluating the factors it describes by the means of existing psychometric instruments.

A different approach was suggested by Löwgren and Stolterman (1998) who distinguish between designing, closely relating it to skills and knowledge base, and the ability an individual

needs to perform well as a designer. Viewing design as a process arranged/guided in a way that allows generating a new form for a client's task, and working out its properties, they argue that a designer needs to possess a number of different abilities: (1) modelling a new form requires creative and analytical abilities; (2) decision-making calls for critical ability; (3) working with a client requires rationality and communicative ability; (4) designing structural properties requires insight and understanding of technology; (5) designing functional properties requires insight and knowledge of exploitation/usage; (6) designing ethics-related properties requires insight and knowledge of values and ideals; and (7) designing aesthetical properties requires the ability to generate a form as well as the knowledge of composition.

Continuing to address the issue of design ability, researchers further identify it as the "constructive intentional intelligence". This definition incorporates two composite aspects: first, the designer has to be constructive, i.e. creative and innovative; then, s/he must be intentional, that is aiming to change the world in a certain intended way. Additionally, Löwgren and Stolterman (1998) argue for design intelligence to require an advanced ability to think logically but also to be characterized by a developed synthetic thinking. Synthesis is defined as a process during which composite artefacts are created by assembling parts or components, or, equally, as combining data concerning different elements supported by wholistic thinking.

Wholistic thinking is another essential attribute of design ability according to Löwgren and Stolterman, since designed items are expected to operate not only independently but also in different contexts, as parts of a larger whole. Being able to see how the 'whole' could be created based on incomplete information is another fundamental component of the design intelligence. As is the ability of wholistic assessment to form opinions concerning the quality of a design solution, and being able to assess it from different angles by purposeful changing perspectives.

Another important aspect of design intelligence relates to mental imagery properties, i.e. imagination, plus an ability to externalize or give certain shape to what is being visualized by the mind's eye. Thus, an ability to work with media such as sketches or scale models to arrive at complete design solutions is another essential component of design intelligence (Schön, 1983, 1992; Bennet, 1996). On the whole, Löwgren and Stolterman regard design ability as an ability possessed to a certain degree by everyone, whereas the aptitude for its different constituents may vary significantly.

Bernstein's (1988) description of what he calls a "design mind" is similar to one of the design intelligence by Löwgren and Stolterman. He argues that a designer can perceive or create associations and construct relationships that need being communicated. S/he has to be able to link less significant pieces to produce a bigger whole, or relate "the object to its purpose, the object to the user, and, most importantly, he has to relate the object to the user to the environment in which that object is being used." (Bernstein, 1998; p. 204.) According to the researcher, a designer is a synthesizer. In other words, he or she possesses an ability to synthesize different factors into a coherent whole.

Design is also about observing and clarifying relationships, as well as a constant search for new relationships and new associations. Additionally, a designer is an explainer employing visual thinking to understand and communicate. Every designer is expected to love things, care for design and demonstrate passion for the product. Other abilities, according to Bernstein, that are vital for a designer are: imagination, creativity, lateral thinking, and curiosity. He notes that designers constantly ask reframing questions, such as: 'What if?' and 'What would have happened if the question was asked in a different way?' Also, a designer expects a design solution to be logical, although he or she may employ somewhat illogical means of attaining it. In problem solving, their main purpose is to try identifying and then resolving the right problem, not just any problem. Additionally, design does not take place in isolation but happens where ideas collide. Therefore, openness and extroversion are also crucial for designing.

Similar to Löwgren and Stolterman, Cross (1995, 1999), continuing with the subject of design ability, discusses the idea of design intelligence and suggests that at least a number of its essential components have to be supported or represented by cognitive abilities. In his article called "Natural intelligence in design" (1998) he constructs his argument based on the

statements made by famous designers and concludes that design is rhetorical, exploratory, emergent, opportunistic, abductive, reflective, ambiguous, and risky. Also, sketching ability enables a designer to deal with different levels of abstraction in parallel: it allows him/her to think about the fundamental concept of a design, while reflecting simultaneously on critical details; sketches allow a designer to move freely between different levels of detailing. It is particularly important during the early phases of a design process. Moreover, designers use sketches for identifying significant issues, in addition to using them as cues for remembering important pieces of information, which they discover during designing. Another fundamental characteristic of sketching ability is that it facilitates problem structuring during solution attempts, and enables emergent features and properties recognition in solution concepts.

There are certain issues related to this classification. As most of these ability constituents are closely associated with the functions sketches have in design (or were identified after the recognition of these functions), they are typically researched from the perspective of underlying cognitive processes, and seldom in relation to the cognitive abilities and styles that these processes are based upon. That is, these design ability constituents represent complex constructs that have yet to be defined in terms of the styles and abilities that support them.

Several other important concerns arose from the summary of the design ability research. Although Cross (1995, 1999) provided the most comprehensive up to date analysis on the issue of the design ability, he did not emphasize the distinction between the advantageous and the necessary aptitudes (i.e. likely to be required for any design task). It is also unclear whether the design ability is a particular 'designerly way of knowing, thinking and acting' or, as the researcher mentions prior to this statement, it is 'a multi-faceted cognitive skill, possessed in some degree by everyone'.

The issue of cognitive abilities designers need to have or develop, versus designerly thinking style, innate or acquired, has been raised in many studies, particularly in the domain of creativity (Perkins, 1981; Sternberg, 1988; Torrance, 1984, 1998). While other literature suggests that the qualities that make a person a successful designer include individual abilities, skills, styles of thinking, knowledge, environment, personality, and more. On the whole, there is a lack of agreement in the theoretical underpinning of the design ability notion and a need in further empirical support of the many arguments concerning its properties.

2.1.1 Cognitive Styles & Learning Strategies in Design Ability

The above studies indicate that certain (designerly) thinking styles contribute to design ability, as, in order to work successfully in design one has to adopt a specific way/s of reasoning, such as wholistic, logical, critical, abductive, reflective, and so on. They correspond well to a number of cognitive or learning styles that, for a long time, have been a subject of research in different areas of psychology.

A cognitive style can be defined in general terms as consistent individual differences in the ways people experience, perceive, organise, recall and process information (Goldstein & Blackman, 1978; Messik, 1984). It is reflected in the organisation of information in memory, the speed and accuracy of decision-making under uncertainty, the global or macro approaches to dealing with problems, the preference for different problem solving strategies, and the profile of intellectual dispositions (Messik, 1976, 1984; Sternberg & Grigorenko, 1997).

One of the early theories of cognitive styles describes them as adaptive control mechanisms of the ego that mediate between needs and the external environment (Wallach & Kogan, 1965). They have also been viewed as a self-consistent mode of functioning which individuals show in their perceptual and intellectual activities, and an expression of psychological differentiation within characteristic modes of information processing (Witkin & Goodenough, 1971, 1981). Claxton and Ralston (1978) describe it as an individual's habitual way of responding to and using stimuli in a learning environment. According to Guilford (1980) it is a person's characteristic style of acquiring and using information. Laschinger and Boss (1984) believe it is the way individuals organize information and experiences. McFadden (1986) and Cornet (1983)

suggest that cognitive style is characterised by a consistent pattern of behaviour within a range of individual variability. Kallen, in the more recent research (1997), distinguishes cognitive styles and personality styles. Similarly, Riding and Rayner (1998) describe cognitive styles as a relatively fixed aspect of learning performance that influences individuals' general achievement in learning situations. They argue that cognitive style is an independent construct or psychological notion, not related to intelligence, personality and gender.

Sternberg (1997), as well as a number of other theorists of cognitive styles, locates them at the intersection between personality and cognition, in a sense placing them in both domains, where styles express the manner of cognition and are uncorrelated with intellectual capacity. This description includes both cognitive and affective traits and may seem confusing as it is more typical of how the *learning* styles have been defined. Sternberg explains the difference by the advancement of the concept of cognitive style which started in the 1970's as it gained popularity among educators (Sternberg, 2001). Back then, the notion of styles developed in two directions through research in educational and vocational psychology. Some investigators attempted to apply traditional cognitive styles to school settings, seeking explanations for students' individual differences in achievement and performance. Others created new frameworks for studying learning and teaching styles based on empirical observations. They produced several domain-specific theories of styles, including theories of learning styles (Dunn & Dunn, 1978; Gregorc, 1979; 1985; Renzulli & Smith, 1978).

As a result, there are no universal definitions for these terms and a considerable confusion in the literature as numerous authors use them interchangeably. Garity (1985), for example, maintains that both cognitive and learning styles have been used as a description for the cognitive process of thinking, perceiving, and remembering. Kocinski (1984) defines learning style as the way a person learns best and believes that it may be cognitive or affective or a combination of both. McFadden (1986) thinks most definitions of learning style as well as cognitive style, describe variations in individual information processing.

Other researchers believe that there is a technical difference between the terms. *Cognitive* style deals with the form of cognitive activity – thinking, perceiving, and remembering – not with its content. Whereas *learning* style is seen as a broader construct, combining qualities that are constitutionally fixed with characteristics that are open to environmental modification. Schultz (1985) and Allinson and Hayes (1988, 1996), for example, refer to cognitive styles as the characteristic ways of using the mind and consider them among the elements underlying learning styles. Similarly, Keefe (1982), Sewall (1988) and Zarghani (1988) view learning styles as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment, and have cognitive, affective, and psychological components.

Further away from the original definition of cognitive styles are the Jungian theorists, including Myers (1962, 1980) and McCaulley (1974, 1976), who have been promoting the idea of individual learning styles as reflections of different types of personality. In Badenoch's (1986) study into personality type, preference for learning style and instructional strategies, the author focuses on individual behaviour resulting from interaction with the environment. The term is also referred to as aptitude (or attitude) or treatment interaction (Borg & Gall, 1983). Whereas Fuhrmann and Grasha (1983) looked at learning styles as social interaction of the students with their peers, teachers and course content.

There seems to be a clearer distinction between *cognitive styles* and *learning* (or *problem-solving*) *strategies*. A style is considered to be a fairly fixed characteristic of an individual, while strategies are used to cope with situations (Riding, 1991). Strategies may vary from task to task, and may be learned and developed. They usually imply operations followed to minimise error during the decision-making process. At a basic level styles and strategies can be distinguished by the 'degree of consciousness' involved (Sternberg & Zhang, 2001). Styles typically operate without individual awareness and imply a higher degree of stability, whereas strategies involve a more conscious choice of alternatives and are task- and context-specific. Additionally, different strategies can be mapped onto one or more style constructs; that is many different strategies could be classified as indicators of a particular style, though with unequal

accuracy (Lohman & Bosma, 2002). Although again, the two terms have been used interchangeably (Cronbach & Snow, 1977).

Summarising the above, *cognitive style*, as the majority of researchers describe it, is an independent construct or a psychological notion, not related to intelligence, personality and gender. It is an important component of individual differences. It is related to a range of behaviours, including learning performance, social responses and occupational demands. It is fairly fixed and is closely associated with the preferred learning style, where the latter is influenced by biology, experience and conscious control, and is, therefore, viewed as a broader construct. Learning style is also seen to be rather consistent across a wide variety of tasks (Honey & Mumford, 1992). Cognitive and learning styles are distinct from learning strategies as the latter can be learned and are task-specific. Another characteristic of learning strategies is that they are socialized and developed in interaction with others. Cognitive and learning styles are potentially useful in education as a means of characterising stable individual differences that influence the effectiveness of teaching and learning; they may also predict different aspects of the problem-solving behaviour and academic performance (Messick, 1984; Miller, 1987).

2.1.2 Cognitive & Learning Styles in Design and Academic Performance

There is little research, particularly empirical and case studies, concerned with the functions of cognitive (or learning) styles in problem-solving in design and architecture, and their relation to academic and professional performance. Some of it has shown that students receive higher grades in fields that are compatible with their cognitive styles (Hattie, 1992, 1999; Drysdale, *et al.*, 2001), which is similar to findings in many psychological studies (Matthews, 1991; 1995). Other studies argue that matching teaching style with learning style produces an environment wherein students can learn better and, therefore, succeed academically (Parlett, *et. al*, 1988; McCaulley, 1990). While most of the related literature deals with identifying learning styles that are characteristic of different areas of design or design education; it seldom connects them to performance or problem-solving (Wallach & Kogan, 1965; Lawson, 1990).

There is also no agreement, and a clear lack of the supporting evidence, as to which cognitive or learning style models could be effectively applied in design research, viewed as predictors of the domain achievement or of the performance on design tasks. Many cognitive and learning style models assess different constructs, generating results that are hard to relate. The sheer number of dichotomies used led to a serious failure of accumulated theoretical support and a lack of well-grounded findings tested through replication. There is little evidence on the relation between style labels. The few comparative studies that have been conducted, were concerned with their constructs validity, which suggested two distinct cognitive families (Riding & Cheema, 1991; Riding & Rayner, 1998). And while there is evidence of the relationship between label constructs that fit with these families, there is no direct or easy comparability between them, and no agreed ‘core’ technical vocabulary. There is also a lack of empirical research comparing test batteries and performing cross-validation through a confirmatory factor analysis (CFA) to verify they measure common factors. And insufficient evidence of correspondence of assessment results when tests share theoretical foundations.

The situation with learning styles is even more dubious, resulting from a greater number of models, complexity and uniqueness of their constructs, and the same lack of cross-label comparative research (Coffield, *et al.*, 2004).

The limited literature linking styles to performance has traditionally been the studies of creativity. An early psychological survey of American architects (MacKinnon, 1962) showed the most creative of them to have *Intuition* (one of the learning styles as assessed by Myers-Briggs Type Indicator (*MBTI*, 1975)) as a strong preference. A more recent study of Royal Designers for Industry yielded similar results (Davies & Talbot, 1987 in Durling *et. al*, 1996).

Research by Peterson and Sweitzer (1973) suggested that architecture students were on average more *field dependent* (similar to ‘wholistic’ cognitive style) than the student population

as a whole. By contrast, Bergum (1977) and Morris and Bergum (1978) discovered that architecture students were, on average, more *field independent* (comparable to 'analytic' cognitive style) than business studies students.

Newland, Powell and Creed (1987) also pursued this direction as they studied learning styles among architects. They argued that 'architects show a strong requirement for interpersonal engagement that enables them to act with confidence and be perceived as being in control' (Newland, *et al.*, 1987, p.21). The researchers developed a system of assessment using Kolb's (1976) classification of learning styles that divided architects into four groups. *Dynamic designer-learners* base their understanding on the incidents of life and the dynamic, dramatic or active events. Their senses constantly interact with the world and get quick feedback, working in an opportunistic fashion. The latter allows them to switch rapidly from being entrepreneurs to producing designs. *Contemplative designer-learners* have a learning style that is a combination of reflective observation and abstract conceptualization. A few of them can complement their reflective nature by concrete experience or active experimentation. *Common-sense designer-learners* are abstract thinkers. As designers they can survive by combining it with active experimentation or concrete experience, which is the opposite of abstract conceptualization. These learners make capable planner-architects. *Zealous designer-learners* dwell on both sides of the axis opposing active experimentation and reflective observation. They are fundamentally reflective but need to interact with the concrete world to be able to understand it. This makes them the 'doers' rather than the 'observers'. Zealous learners possess a practical approach; they get their knowledge by using close possibilities.

The more recent studies of architecture students by Demirbas and Demirkan (2003), and Kvan and Yunyan (2005) utilised the same psychometric instrument to determine how individual learning styles affect the performance in design studios. In the first study, it has been discovered that there are significantly fewer students with the accommodating learning preference as most of the students are *assimilators* and *convergers* (Demirbas & Demirkan, 2003). Whereas the second study recorded a low percentage of convergers and accommodators, and a high proportion of *assimilators* and *divergers* (Kvan & Yunyan, 2005). In the latter study, in one studio, a statistically significant correlation was shown for convergers to achieve significantly lower marks, while the performance of accommodators, divergers and assimilators did not differ significantly. At the same time, assimilators succeeded in the other studio.

There have been other important contributions to the field of learning styles in design made by Cross, Durling and Johnson (1996a; 1996b), who utilised the previously mentioned Myers-Briggs Type Indicator (MBTI, 1975). This popular tool for the assessment of personality types divides different kinds of mental activities into four dichotomous groups of preference: extroversion (E) – introversion (I), sensing (S) – intuition (N), thinking (T) – feeling (F), and judgement (J) – perception (P). Each individual is expected to favour one type of activity on each scale. The subjects were art-based design students, whose preferred way of learning design appeared to match their teachers' preferred way of teaching at the time of experimentation (studies took place in UK design schools). The research showed that over than three quarters of architects preferred to rely upon Intuition in problem-solving or learning situations, whereas 91% of students of fine arts also preferred Intuition, but nearly three quarters also preferred Feeling. Over three quarters of design undergraduates (from interior design, graphic design, furniture design, and design marketing) had a preference for Intuition and the majority also favoured Perception. A quarter fell into Extroversion-Intuition-Thinking-Perception category, suggesting that they find intuition more appealing than thinking, and would strive for maximum freedom pursuing intuitive goals. And, as intuition is a process of perception, a student of design would typically exhibit a perceptive attitude when dealing with the outer world.

These results are similar to the data from other studies that have employed MBTI to identify the character and the temperament profiles of architects and designers (McCaulley, 1990; Brown, *et al.*, 1994). They discovered that the preferred profiles of their sample of landscape architects were Intuitive-Thinking and Intuitive-Feeling types. Lawson (1993) also observed in a controlled study that architecture students tended to adopt a more intuitive approach when tackling a problem solving activity.

Based on the research results, Durling, Cross and Johnson concluded that designers' strategies for problem-solving are different to many other professionals, as they choose the intuitive way of working. They favour teaching which begins with a bigger, broader picture and conceptual information. Then, they like being explained details, guided toward prospect opportunities and given alternative viewpoints. They prefer lightweight structure, allowing guided exploration, teaching that involves objective data that is both logical and analytical, and is based on examples showing concrete things. One third of designers, however, are more comfortable with more subjectivity, a person-centred approach, and find opinions important. By contrast, non-designers prefer teaching which begins with details and facts, and then progresses to generalisations in a guided step-by-step manner. Still, whereas there were styles characteristic of occupational groups, there was no universal schema of design learning that suited all designers.

There have been other assessment tools used in the studies of architects and designers. Gregorc model (MSD, 1985) was applied to a sample of 4,546 students over a 4-year period from 1993 to 1997 in the study of Drysdale, *et al.* (2001). Academic performance based on learning style was found to be significant in 11 of the 19 courses, with the largest effect appearing in art. It was argued that science and math-related fields are better suited to learners who think sequentially; while random wholistic learners excel in fine arts and design courses. All learning styles perform equally well in the liberal arts and social sciences.

Similar to the above literature, this study evaluates a number of learning styles to determine which of them are characteristic of design education and can serve as predictors of academic performance on design tasks. It also discusses their trainability via design education, as well as application in different design situations. While the ultimate purpose of the learning style theory is to provide explanations for the problem-solving behaviour during administered design tasks, that is, based on the measures of individual learning styles.

There is another group of factors believed to affect performance on design tasks as well as academic achievement – domain-related cognitive abilities.

2.1.3 Cognitive Abilities & Skills in Design Ability

There is a clear distinction between cognitive styles and cognitive abilities. Cognitive styles are defined as describing *how* or in what way people process information, while cognitive abilities are defined as *how well* they do it. That is, while cognitive styles delineate functional dispositions toward processing information, cognitive abilities show how much, how well, or how accurate individuals process visual, semantic or numerical stimuli. Additionally, abilities typically describe peak performance, that is, while styles can be bipolar, abilities are unipolar – ranging from zero to a maximum value (Riding, 1996).

In cognitive research, human abilities are typically defined in relation to a certain cognitive task or a class of cognitive tasks, or 'any activity in which a person engages, given an appropriate setting, in order to achieve a specifiable class of objects, final results, or terminal states of affairs' (Carroll, 1993, p.10). That is, any task in which correct or appropriate processing of mental information is critical to successful performance.

In design, the term 'ability' has been addressed by many researchers, with a broad range of meanings ascribed to it. It may imply complex multidimensional constructs, with many underlying cognitive abilities and skills, thinking styles, and associated with it knowledge and skills, such as: *sketching ability* (Cross, 1995, 1999), *imagination* (Bernstein, 1998) or *creative ability* (Bernstein, 1998; Löwgren and Stolterman, 1998). It may illustrate less complex constructs. For example, ability to *generate a form* (Löwgren & Stolterman, 1998) is likely to be supported by visual-spatial and ideation abilities (this is yet to be empirically validated), but cannot be separated from the associated with it graphical skills. It may describe a unidimensional cognitive ability, except its close association with thinking styles or problem-solving strategies, such as: *analytical ability* (Löwgren & Stolterman, 1998) or *abductive ability* (Bernstein, 1998). Or it could entail a number of cognitive factors, such as visual-spatial

abilities, combined together in *visual thinking* (Bernstein, 1998). In addition to obvious difficulties with investigating the roles of these constructs in problem solving, there is a lack of psychometric tools for their assessment, which is a serious problem in the input research area.

Thus, this study, adopted a factor-analytical view on the design ability constituents: it addresses those of them that (a) correspond to uni-dimensional cognitive factors, (b) can be measured by the means of existing psychometric instruments, and (c) are supported by a large body of empirical research. It also resorts to terminology used in factor-analytical studies. Carroll, whose work incorporated the results of a systematic exploratory factor analysis of over 460 human ability data sets, defined ability as an ‘actual power to perform an act, physical or mental, whether or not attained by training or education’ (Carroll, 1993, p.4). He regarded the term as neutral, i.e. neither an aptitude nor a skill or achievement.

There are around 70 separate primary cognitive factors recognised by the author, some of them fit well into the research of design ability.

First, there are visual-spatial abilities, including *manipulating spatial relations*, *spatial scanning*, *gestalt* or *closure flexibility*, *spatial orientation* and *spatial visualization*. During the last thirty years of studies, these abilities have been argued to be important by many design researchers, although with certain differences in the employed terminology (Bernstein, 1988; Schön, 1983, 1992; Bennet, 1996; Cross, 1992, 1995; Löwgren & Stolterman, 1998)¹. Most engineering, architectural and geometric problems involve these factors. Visualisation, for example, requires spatial thinking, comprehending the interior structure, recognizing how to combine parts together, in many cases, with imaginative rotation or transformation demand (Carroll, 1993). There are problems in the field of assessing visual-spatial abilities since people who participate in cognitive tests utilize a number of different strategies to attain correct answers. Another major issue is difference in cognitive styles or ways of thinking, which may be a reason for a broad fluctuation in factor loadings of the visual ability tests (Carroll, 1993).

There is also a number of design-related abilities that belong to the domains of learning and memory addressed in the Carroll’s work. Bernstein (1988), for example, suggests that design work requires *associative memory*, or the ability to form arbitrary associations and remember which stimulus are paired to one another; and *visual memory* – the ability to form an image and use it for recognition or recall. *Perceptual speed* is another ability viewed as of a particular relevance to designing as it allows rapid doing-seeing loop in sketching.

Another area, discussed by Carroll and related to design, is what he refers to as idea production. It has been argued that designers must have high *associational fluency*, that is swiftness in thinking of a series of different but semantically associated responses to a given stimuli; *sensitivity to problems* – speed and efficiency when thinking about solutions to practical problems, or new ways of using objects; *originality/creativity* – speed and efficiency in producing unusual or original responses to specified tasks; *figural fluency* – speed and efficiency when generating figural responses to specified tasks; and, finally, *figural flexibility*, that is speed and efficiency in dealing with figural tasks that require a variety of approaches to attain a solution (Bernstein, 1988; Löwgren & Stolterman, 1998; Cross, 1992, 1995). In his analysis of the idea production area, Carroll emphasizes that further research is required to establish to what extent the above factors can be distinguished from one another, as well as what to base this differentiation upon.

There is another distinct area of factor-analytical research – it deals with reasoning abilities, some of the properties of design ability fit well into it. Carroll (1993) discusses *communication* ability, a quality often viewed as important for designing by many researches and addressed by Bernstein (1988) and Löwgren and Stolterman (1998). It mainly involves talking and listening and is not related to reading or writing abilities. However, lack of psychometric tests that allow

¹ In this study, we use *visual-spatial ability* as an all-encompassing generic concept; i.e. as “the ability to formulate mental images and to manipulate these images in mind” (Lean & Clements, 1981 p. 267). Similarly, when referring to *spatial visualisation* we understand it as “the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object” (McGee, 1979 p. 893).

measuring communication ability without the use of writing, has proven such assessment difficult. Another important ability is *inductive reasoning* ability – the ability to see a common underlying characteristic in given material, for example: a pattern, a concept, a class membership, a rule, a process, a trend or a causal relationship, and make generalizations based on experienced or seen cases. Bernstein and others considered this ability of a particular significance, whereas Cross (1995) argued for even a greater importance of the *abductive reasoning* ability. Studies of cognitive abilities, however, rarely refer to the latter one. But, if abductive reasoning could be defined as reasoning via which explanatory hypotheses are formed and evaluated (Thagard & Shelley, 1997), or as reasoning from the observed fact to the inferred cause, then the ability for abductive reasoning could potentially be seen as a part of inductive reasoning defined earlier.

Other cognitive factors and general reasoning abilities can also be argued to play important roles in designing; they include: logical reasoning, learning abilities, imagery, meaningful and free recall memory, length estimation, perceiving gestalts or closures, and so on. Space limitations, however, necessitate a focus only on those factors that concern this study's input research area and have been formerly discussed in the design ability literature.

Finally, there are many issues related to the above ability factors. Some concern the extent of their use across tasks and situations as, similarly to learning styles, it may depend on the strength of personal preferences. Others discuss the abilities trainability and their link with academic performance. The next subsection will address some of them in further detail.

2.1.4 Cognitive Abilities in Design and Academic Performance

As most students of architecture enter higher education with little experience in the discipline, a large part of architectural education is concerned with acquiring new ways of seeing, thinking and doing, and the development of various abilities and skills. The visual-spatial and ideational abilities have long been recognised as having a major importance. Yet, the relationship between them and architecture remains mainly intuitively compelling, as the research has been somewhat inconclusive; the evidence was both in support of and refutation of this relationship.

Visual-spatial abilities in design and academic performance

Spatial ability of an individual usually describes the ability to manipulate or transform the image of spatial patterns into other arrangements (Ekstrom, *et al.*, 1976). A lot of the research concentrated on determining the factors that underlie spatial ability and the characteristics of such factors (Cooper, 1975; Glushko & Cooper, 1978; Lohman, 1979; Pellegrino, *et al.*, 1984; Shepard & Feng, 1972; Shepard & Metzler, 1971). Visualisation, however, has seldom been studied as a means of problem solving (Rieber, 1995). A limited amount of studies explored the relation between spatial aptitude, measured by traditional test batteries, and spatial performance in the real world (Hegarty & Kozhevnikov, 1999).

There have been, however, many predictive studies conducted to assess the role of spatial abilities in forecasting job success and academic performance. Occupations which have a strong correlation with spatial visualization included architecture (Smith, 1964; Chronbach, 1970; Ghiselli, 1973); structural design (Alias, *et al.*, 2002, 2003); computer aided design (Sorby, 1999); engineering problem solving (McGee, 1979; Hsi, *et al.*, 1997); mathematics (Tillotson, 1984), and a number of others (Lichert & Quasha, 1970; Pribyl & Bodner, 1987). Lichert and Quasha also found statistically significant correlations between spatial visualization abilities and grades in several vocational-technical education courses including drafting and printing.

Some of the former studies showed that an individual with a developed sense of spatial ability would outperform those who are lacking in such skills in design tasks (Ghiselli, 1966; Smith, 1964), or would have higher calculus scores (Eisenberg & McGinty, 1977). A number of researchers from Southern Africa (Visser, 1981; Taylor, 1980, 1981; Millroy, 1985) have reported that students who score poorly on tests of three-dimensional spatial ability are at risk as regards to passing engineering drawing and design courses. Several studies have claimed that

students with different spatial abilities enter different professions (Eisenberg & McGinty, 1977; Scarr 1996). The existence of a broad range of screening and admission procedures – from the records of earlier academic merit to the aptitude tests and entry examinations – may provide additional support for the latter assertion.

The above suggests that a developed spatial ability is a prerequisite to high achievement, yet the studies examining exceptional performance proved to be inconclusive. Initially, they assumed that the exceptionality is based on general, inherited characteristics. The relationship between general ability and superior performance, however, revealed only low correlations (Guilford, 1967; Hunt, 1980; Cooper & Reagan, 1982; Doll & Mayr, 1987 cited in Ericsson & Smith, 1991). In most cases, connecting superior cognitive abilities to exceptional performance has one major difficulty: the specific characteristics that are supposed to account for exceptional performance have become so integrated with that performance, there is a strong possibility that such capabilities have been acquired as a result of the extensive domain experience (Chang, *et al.*, 1985; Ericsson & Smith, 1991).

This has led researchers to investigating performance from an acquired skills perspective. The approach is called the "expertise approach" (Ericsson & Smith, 1991). The findings in support of it showed that spatial visualisation in architects declines rapidly after retirement from their profession (Salthouse, *et al.*, 1990), suggesting that spatial visualization is related to architectural skills rather than abilities. At the same time, architects are consistently more accurate at tasks involving spatial visualisation than lay people. Yet, it also takes them longer to encode the stimulus materials on these tasks. It is uncertain, therefore, whether this evidence would still be present if time for encoding was restricted (Salthouse, 1991). It is also not clear, whether developed spatial skills were present in architects before the extensive occupational training took place. Salthouse *et al.* described it as "differential preservation" versus "preserved differentiation" (Salthouse, *et al.*, 1990; Salthouse, 1991). Whereas the first expression implies that people's experience in architecture leads to the enhancement of their spatial abilities; the second one means that the developed spatial abilities architects possess have always existed.

The issue of "differential preservation" or the trainability of visual-spatial abilities has been raised by many researchers. Several studies have claimed spatial visualization skills cannot effectively be taught through typical instructional methods (Salkind, 1976). Bertoline (1988) suggests that spatial visualisation skills are developed through life experiences. He argued that children who are exposed to appropriate learning environments would have stronger spatial visualisation skills later in life. An equal number of studies have found that spatial visualisation can be improved through instruction (Gillespie, 1995). Sexton (1992) concluded that it is indeed possible to improve spatial visualisation skills if the instruction was appropriate and the delivery time sufficiently long. A limited number of studies have shown spatial visualisation can be taught in a short amount of time. Braukmann (1991) was able to significantly improve spatial visualisation skills during just eighteen hours of engineering graphics instruction. Pellegrino (1984, 1988) claimed substantial success in the training of spatial ability by means of extended practice. Potter and Van der Merwe (1983, 1998) produced a series of studies concluding that learners experiencing difficulties can be trained in perception and use of mental imagery in drawing tasks. After receiving training, students' scores in tests of three-dimensional spatial perception improved; and so did their engineering drawing and overall performance in design courses. Similar results have been reported by Sorby and Baartmans (1996) working with engineering students, suggesting that the instructional procedures may have a significant influence on the development of visual-spatial abilities and associated with them graphical skills. If trainability is true, and sketching is the effective means of developing spatial skills, while the advancement of spatial skills improves sketching; then discovering the range of relationships between spatial abilities and design drawings is a matter of methodology.

On the whole, the question of whether spatial visualisation can be taught or developed remains unanswered. Many researchers in architecture and engineering graphics accept that it can be improved through experience, which tends to contradict the findings in many psychological

studies. The present research does not specifically aim at presenting new arguments defending either viewpoint, but takes both views into account. It adopts the expertise approach to the extent of considering domain-specific knowledge, skills and strategies students acquire through their learning experiences and practice.

Visual memory in design and academic performance

There is another group of cognitive factors that plays an important role in designing; it belongs to the domains of learning and memory (Carroll, 1993). One of them – visual memory, or the ability to form an image and use it for recognition or recall, is explored in the current study. It is connected with visual-spatial abilities as both spatial orientation and spatial visualisation require some use of short-term visual memory (Carroll, 1976). Visual memory has been viewed as a single ability as well as a construct when separated into several discrete sub areas referred to as long-term memory, short-term memory and working memory (Avons & Phillips, 1980, 1987; Phillips, 1983; Baddeley, 1986; Logie, 1995).

There are several approaches to researching the phenomenon; two are the most common in factor-analytical studies and cognitive psychology. The first views it as an independent cognitive factor integrated in the superordinate broad ability termed *visual perception/processing* (McGrew & Flanagan, 1998), along with other nine narrow cognitive visual-spatial abilities plus imagery, as proposed by Carroll (1993, 1997). According to this approach, it is structurally separated from imagery, which has been regarded either as an undifferentiated, single ability (Carroll, 1993), or as an independent construct (Dean, 1994). The second approach views visual memory as a mental imagery property, structurally integrated into this complex phenomenon along with other functions and properties (including visual-spatial abilities). Imagery research (and visual memory studies) includes short-and long-term memory theories, working memory models, creativity research, neuropsychology, visual-spatial cognition, and so on (Mandler & Ritchey, 1977; Hock, *et al.*, 1978; Goodman, 1980; Pedzek, *et al.*, 1989; Brewer & Treyens, 1981; Hollingworth, 2004, 2005). The present study wishes to avoid the problems of the imagery debate summarised in Kosslyn (1994), and, equally, deep commitments to Carroll's structural model of human abilities. It adopts a functional view of visual memory to bypass the subject's controversy – it will not enquire into the underlying mechanisms and the role/place of visual memory in relation to superordinate constructs. It is treated as an independent cognitive factor, as this thesis is concerned with certain associated with it capabilities believed to affect design reasoning and academic performance. It is recognised, there are multiple neural sub-systems supporting spatial and visual memory (Farah, *et al.*, 1988). These sub-systems allow encoding single pieces of information in multiple forms. These multiple encodings within mental representations are a productive resource for problem solving (Mani & Johnson-Laird, 1982; Chi, *et al.*, 1989; Payne, 1993).

Despite the evident importance of visual memory in design reasoning, its functions and contribution to design and architecture require further study. Chase and Chi (1981), who investigated the recall of architectural plans by experts and non-experts in architecture, attributed the lack of experimental evidence, as well as the difficulty in finding adequate empirical support, to the complexity of design tasks and cognitive resources involved. More than twenty years ago they stated that the scheme for addressing these issues in a structured and feasible way had yet to be designed; this remains true to the present day.

There have been studies, though, that generated enough empirical support for some conclusive results: they addressed the trainability of visual memory and its connection to domain performance. It has been demonstrated, for example, that practicing in visual arts (Kolb & Whishaw, 1990), or being involved in occupations relying upon the extensive use of spatial memory (Maguire, *et al.*, 2002) allows the human brain to make more and stronger neural connections, thus improving the performance of visual memory. The general role of practice has long been recognized as essential if individuals are to retain what they learn (Brownell & Chazal, 1935; Brownell, 1956; Rathmell, 1978; Chase & Chi, 1981; Cook & Dossey, 1982; Coburn, 1989). The role of the exposure to the right means of training or learning environments

is also supported by a wide range of studies of cognitive abilities. It has been demonstrated, for example, that Japanese students are consistently better at visualisation and visual memory abilities due to the applied instructional methods and their experience with hands-on space relations activities (Iben, 1988; Simmons, 1995). Whereas the recent decline in the observable performance on visual memory and visualisation tests among engineering and art students in US and Australia, may be attributed to the use of CAD tools, replacing other types of activities. And, correspondingly, it is also the lack of efficiency of modern educational programmes in the ability training (Bruce, 1999; Knipp, 2003).

Traditionally, the literature connecting academic performance to visual memory has been concerned with learning and functional disabilities preventing successful acquisition and utilisation of knowledge and skills (Eden, *et al.*, 1995; Payne & Jordan, 1995; Cornoldi, *et al.*, 1999; Park, *et al.*, 2000). It has been shown, for example, that students with poor visual memory had difficulty remembering reading material visually presented to them. And that poor visual memory was highly correlated with below-average reading decoding, math, and overall academic achievement (Hays & Pereira, 1972; Taylor, *et al.*, 2002). Poor and good visual memory of symbolic sequences was found to correlate highly with low and high English achievement respectively (Meeker, 1966). Other studies showed that good visual-spatial memory performance was associated with academic success at school (Aronen, *et al.*, 2004). In architecture, the role of visual memory in academic performance has generally been treated as a factor integrated in the broader constructs of spatial intelligence or mental imagery, i.e. seldom explored separately. And, similar to other spatial abilities, the research in this area has been somewhat inconclusive. The negative effect of poor visual-spatial memory on academic performance, particularly in occupations that rely upon the extensive use of visual-spatial abilities, has been established. However, it is unclear whether the high-ability individuals would typically outperform others with average (or 'normal') abilities on design tasks, or whether a developed visual memory could serve as a predictor of academic success in design education.

Ideational abilities in design and academic performance

There is a third group of cognitive factors researched in the current study. Similar to visualisation and visual memory, it has a recognized role in design and is a part of the design ability (Bernstein, 1998; Löwgren & Stolterman, 1998). It belongs to the area of idea production and includes: associational and ideational fluency, figural fluency and flexibility, and flexibility of use (Carroll, 1993). This idea has traditionally been associated with the domain of creativity. Torrance, in his most widely used set of tests (*TTCT*; Torrance Tests of Creative Thinking, 1966), evaluates fluency, flexibility, originality and elaboration as key factors determining creativity in an individual. Similarly, Williams (1980) defines creativity in relation to four cognitive factors – fluency, flexibility, originality, and elaboration; and four affective factors – curiosity, imagination, complexity, and risk-taking. There are also several areas in cognitive psychology concerned with creativity and perception that have a relevance to the study of design ideation (Koestler, 1964; Simonton, 1988; Finke, *et al.*, 1992, 1995, 1999; Smith, 1995), each relating cognitive structures and processes to various aspects of creative activities, some also linking them to the underlying ability factors.

This study draws upon the knowledge from the above research but will not delve into the domain of creativity as the design of its empirical part does not ensure enough data for making compelling judgements. That is, we avoid making claims regarding the nature or constituents of creativity, its relation to intelligence and environment, the roles of different cognitive and affective factors contributing to the phenomenon, or underlying it cognitive processes (discussed by Guilford, 1956; Torrance, 1964; Guilford, 1967; Perkins, 1981; Nickerson, *et al.*, 1985; Clark, 1989; Sternberg, 1988, 1990; Sternberg & Lubart, 1991; Khatena, 1992; Colangelo & Davis, 1997). But we will attempt establishing connections and correlations between the measurements of the *input*, certain characteristics of the *process* (related to the area of idea production primarily), creative qualities of the final *product* and academic performance. In other words, this study adopts the Person, Process and Product (without the fourth *P* – Press or

environment) approach broadly used in the psychological studies of creativity (Murdock & Puccio, 1993). Yet, the idea production abilities will be treated as independent cognitive factors with no inferences made concerning the superordinate construct of creativity.

The major difficulty with researching this group of factors is similar to the problems of visual-spatial ability and visual memory research – a reliable scheme for addressing the role of ideation in design reasoning is yet to be designed. There have been a great number of systematic methods for idea production developed to aid generating alternative designs and improve the quality of the final product (reviewed by VanGundy, 1998; Shah 1998; Kulkarni, 1998). They, in addition to the evident role in problem solving, have to be underpinned by individual ideation abilities. Yet, despite several claims and much anecdotal evidence confirming the usefulness of idea production abilities and methods that draw on them in design, the formal experimental support indicating how these factors facilitate problem solving, or help generating ideas in real design situations is very limited. At the same time, there are studies that argue for the rules and procedures for ideation methods to have been specified arbitrarily, regardless of the nature of the problem being solved, while the effectiveness or even appropriateness of these methods for design problems may vary (Shah, *et al.*, 2002). Similarly, in creativity research, despite a great number of instruments assessing individual abilities, hardly any of them take a process perspective for evaluating the effectiveness of idea generation techniques, i.e. explicitly examine aspects of the creative process (reviewed by Puccio & Murdock, 1999). There have also been many issues raised in factor-analytical studies, concerning the predictive validity and reliability of these instruments (Hocevar, 1979; Chase, 1985; Carroll, 1993). Another opinion suggests that idea generation abilities in design may need being evaluated by metrics different from those commonly used in the creativity research, i.e. intended to assess non-utilitarian artefacts (Shah, *et al.*, 2002). That is, whereas fluency and novelty are typically considered as the primary measures of ability to generate ideas (Torrance, 1962, 1964), architectural design must also satisfy intended functions to a pre-defined set of specifications.

The trainability of idea production abilities has also, largely, been a subject of discussion within the creativity domain. Still, there has been very limited attention devoted to improving performance in the area of ideation, despite the great interest in enhancing creativity (Sternberg, 1988; Sternberg & Lubart, 1991). There has been a program of research by Maltzman (1960), who described a successful procedure for eliciting original responses in humans increased through instruction and practice. Other studies have indicated that fluency, flexibility, risk-taking, originality, and playful exploration may respond favourably to training (Amabile, 1996). The existence of systematic idea generation methods aimed at producing alternative designs and improving the creative outcome also suggests ideation (or creativity) could be related to the knowledge of appropriate strategies. According to Torrance (1966, 1974), the effects of treatment intervention suggest the growth of creative thinking resulting from teaching procedures and environmental conditions. It has also been found that motivation and testing conditions (Bamber, 1973; Halpin & Halpin, 1973) and exposure to diverse information (Clapham, 2000, 2001) could influence the ideation scores. The current research does not aim specifically at presenting new arguments defending or opposing these viewpoints, but considers their possible influence on certain characteristics of the collected data. It enquires about the students' familiarity with idea production methods and looks at the speed and control in drawing, since they can influence the quality and/or the quantity of produced design drawings and/or the number of responses to figural ideation tasks.

Most of the literature connecting academic achievement to idea production has also been the studies of creativity. In design courses, Sawyers and Canestero (1989) found ideational fluency to relate to design grades and a comprehensive lab project in interior design. Both popular fluency (popular response within the test group) and original fluency (original responses within the test group) scores were significantly correlated with the course grade and with the final project grade as students with high grades also scored high on ideational fluency. In other research, the predictive validity of idea production scores has also been significantly correlated with creative achievement in the 9-month, 7-year, 22-year, and 40- year longitudinal studies

(Torrance & Wu, 1981; Miller, 2002). Torrance's (1981) 22-year longitudinal study, Yamada and Tam's (1996) reanalysis, and Plucker's (1999) reanalysis of the Torrance's data have concluded that the creative index is the best predictor for adult creative achievement. Plucker (1999) found that adult creative achievement is explained by the TTCT score about 50%, which is three times larger than that of IQ score. This study adopts a similar approach when looking at the relationships between idea production abilities, academic performance (reflected in design studio grades and supervisors' reports), and quality of produced design solutions.

Summing up the above, the question of whether and to what extent, visual-spatial abilities, visual memory and idea production factors are changeable through treatments or interventions specially designed or intended to change them is exceedingly complex. Evidently, students' aptitudes and instructional treatment variables interact (Cronbach & Snow, 1977; Snow, 1977). Yet, there is not enough recommendation regarding the use of these abilities; and no single instructional treatment has been found optimal for all kinds of students, as individuals differ in a variety of cognitive aptitudes for learning from instruction. Additionally, both aptitude and strategy variations have been described with regard to cognitive abilities (Kyllonen, *et al.*, 1984; Kyllonen, *et al.*, 1985). Aptitude may limit strategy selection or predict performance within strategy subgroups or both (on cognitive tests as well as in real design situations). Conversely, strategy choice could be unrelated to aptitude, but the effectiveness of the implemented strategy could be limited by aptitude. It is thus understood that if (or as) students develop strategies in the use of their abilities, they may significantly alter the performance on design tasks (or ability tests); this may lead to the inconclusiveness of the linear correlations between the *input*, the *process* and the *product* in this study, and, as a result the need for a different methodological approach. And this could be true for all ability factors, i.e. for each group of abilities and cognitive styles explored.

2.2 Design Process

Much research concerned with the nature of designing has been carried out in the past three decades. In architecture, it could be grouped into four major categories, as originally proposed by Akin (1978): (1) dealing specifically with the design process and using empirical means for its study (Eastman, 1970; Krauss & Myer, 1970; Foz, 1973; Baer, 1976; Akin, 1978); (2) utilising formal or algorithmic formulations for different data-storage or processing aspects of design (Newell, 1970; Freeman & Newell, 1971; Herot, 1974; Henrion, 1977); (3) approaching design as an example of problem solving in an ill-defined domain (Reitman, 1964; Eastman, 1969; Newell, 1970; Simon, 1973); and (4) dealing with the theoretical aspects of architectural design using the introspective knowledge of designers and empirical methods to model them (Moran, 1970; Simon, 1970; Goumain, 1973; Ramam, 1973; Weinszapfel, 1973). Additionally, there are studies interested in the domain expertise (Foz, 1973; Akin, *et al.*, 1987).

The above studies are based on principally different outlooks on designing established in the history of design. Two of them are regarded as fundamental for investigating design processes or design thinking. The first is the *information-processing* view providing a classic foundation for understanding design problem solving. It interprets design processes as a search within a state-space toward an ill-defined goal (Newell & Simon, 1962; Newell, 1968; Simon, 1962, 1966, 1983). This view, however, is only partly adequate for design problems. An alternative view, *reflection-in-action*, regards the design process as a reflective action, taking place throughout the whole duration of designing. Designers guide design processes by making decisions related to their perception of problems (introduced as situations) and continuously communicate with their drawings in search for solutions. This quality of design tasks was investigated by Schön helping to address some of the problems typical of the earlier studies viewing design as a search process. In his understanding, designers would rather engage in constructing design problems than finding their solutions (Schön, 1983, 1987; Schön &

Wiggins, 1992). Designing is seen as an iterative, “trial-and-error” decision process that relies on knowledge, experience, and intuition. The present study integrates both views on designing.

Most design process theories feature unique models derived from prescriptive, descriptive or investigative analysis to help accounting for observed behaviour in empirical studies.

Prescriptive approach presents idealized models of the design process prescribing the steps that should be followed by a designer. Asimow (1962), Mead and Conway (1980), Hubka (1982), Pahl and Beitz (1984), French (1992) and others described what they believed to be the best approach to the design of a system or artefact. The objective was to recapture design decision-making activities so that designers could follow a clear procedure from the formulation of the problem to its final solution effectively and efficiently. A formalized protocol could insure none of the previously identified stages were omitted during problem solving efforts.

Descriptive models provide an explanation of a phenomenon in context, reducing the obvious complexity with a coherent, rigorous framework. They have to account for the observed behaviour, as well as be applicable outside the specific case for which they were developed. In design, descriptive models simply describe typically occurring sequences of activities based on introspective or anecdotal evidence (Dym, 1994; Mostow, 1985; Sullivan & Mutch 1986). Researchers adhering to this approach argue that the process which designers actually follow is quite different from the idealized prescriptive account.

Investigative (explorative) models attempt discovering useful information about a phenomenon through systematic speculation, by variation of basic parameters with a help of techniques developed in psychology and behavioural science (Cross, 1984; Ullman, *et al.*, 1988; Cross, *et al.*, 1992; van Someren, *et al.*, 1994; Cross, *et al.*, 1996). This may take the form of functional analysis and decomposition of a model to allow for the replacement of components with new functionally equivalent ones. The technique particularly effective when applied to design is protocol analysis (Ericsson & Simon, 1993).

There are several other, less common (in design studies) approaches. *Predictive* models, for example, forecast the behaviour of a phenomenon over time. *Planning* models extend predictive models; they involve simulation and evaluation of alternatives in search of good performance for achieving goals. *Axiomatic* models claim there is a fundamental set of principles (axioms) that determine a good design practice. *Cognitive* models attempt to gain insights into actual cognitive processes that underlie creative thinking, etc.

Most design studies researchers break design into several different stages. Most stage models are prescriptive – they view designing as a series of steps to be followed in a top-down, step-by-step manner (Blessing, 1994; French, 1992). There are also a number of descriptive process models that present design as proceeding in a series of consecutive steps. Asimow (1962), for example, divides design into three phases: (1) feasibility study, (2) preliminary design, and (3) detailed design. The feasibility study involves identifying design problems and finding possible useful solutions. The preliminary design is analysing and synthesising design solutions discovered during the first phase; it leads to identification of the best design alternatives for a given problem. Finally, detailed design brings concepts explored in the second phase to the master layout plan and the specification of components on paper. Asimow called this chronological pattern the “morphology of design,” arguing that all design projects follow the same sequence of development though each would have its own peculiar history.

Sanoff (1977) described design process as the transformation of information through the stages of (1) analysis, (2) synthesis, and (3) evaluation. He viewed designing as a continuous problem solving activity, during which each individual idea is transformed through the same set of design strategies. In the analysis phase, a complex design problem is first broken down into parts to allow exploring relationships among them. The synthesis phase puts the parts together to form a solution and to integrate diverse concepts into a whole. In the evaluation phase, alternatives are tested and compared leading to the selection of a good design solution. Also, evaluation might generate new design problems for further analysis and synthesis in the design cycle. All designers go through these stages to reduce errors and to refine design solutions.

Rowe (1987) created a model based on observations of designers in action, comprising: (1) sketching concepts and images, (2) exploring design ideas, (3) investigating design themes, (4) mapping task constraints, (5) resolving conflicts, and (6) developing concepts. He viewed the design process as a sequence of episodes, each focusing on a different aspect of the problem. Occasional deliberate "blinding" to selective problems gives designers a degree of freedom, and allows exploring possibilities without the pressure of considering all task constraints. It also results in backtracking – going back to an earlier point of the solution development if it proved unworkable. The researcher suggested the cyclic nature of designing – as it would "to and fro" between the episodes of *speculation* and *evaluation* utilized to define the problem and explore potential solutions. Speculation is applied to vague or ambiguous problems when additional exploration is needed, evaluation is used where the problem is more defined.

The more recent model of problem-solving in design proposed by Goel (1995) involves four development phases: (1) problem structuring and problem solving containing a minimum of three progressive stages (2) preliminary design, (3) refinement, and (4) detail specification. The four basic phases may be arbitrarily broken down into many more specific design steps, but are believed to capture the essence of the design process. Each phase differs depending on the type of information dealt with; the degree of commitment to generated ideas (which increases as the design gets refined); the level of detail attended to (beginning with general decisions about functional systems and progressing to decisions about specific aspects or details of each functional system); the number and types of transformations engaged in; and the symbol systems needed to support the different types of information and transformations (Goel, 1999).

Most design process models can be categorised into two groups: (i) based on designers' activities or actions towards realising a design task, and (ii) based on phases or series of stages of design object evolution. One widely accepted view found in the literature describes the design process as consisting of multiple iterations of three basic activities: *analysis*, *synthesis* and *evaluation*. The names ascribed to these activities may vary, the meanings remain the same: (1) analysis deals with understanding the design problem and considering requirements and specifications, (2) synthesis deals with generating ideas and solutions through the design space exploration, (3) evaluation deals with matching design solutions (or its elements) against the requirements, specifications, and existing trade criteria. Phase-based, sequential models of the design process usually emphasise the design progression in terms of the amount of information known concerning the details of its implementation (its physical embodiment). Phases may be amplified with more specific activities or steps present in the activity-based models.

Despite the commonly adopted view of designing as a course of actions characterised by a number of clearly identifiable stages (or series of events) performed in a certain sequence, real life design is never simple or straightforward. Designers execute activities like: analysing, brainstorming, calculating, choosing, communicating, deciding, decomposing, defining, developing, discussing, documenting, drawing, evaluating, exploring, generating, integrating, inventorying, judging, justifying, managing, modelling, negotiating, observing, optimizing, presenting, reading, reflecting, searching, selecting, simulating, solving, specifying, structuring, taking initiatives, talking, testing, thinking, unifying, validating, verifying, and writing. These activities can occur as mental or physical activities, as creative or rational activities, can be performed consciously or unconsciously, by a group or by an individual, in the context of discovery or in the context of justification (Kroes, 1996), for knowledge acquisition, application, or communication, or involve objective or subjective interpretation (Dorst, 1997).

Some activities may occur more often in the design process than others and some actions may occur in a certain sequence. The occurrence and the sequence of the specific design activities in design processes may depend on the specifics of a design task or a design discipline, knowledge and levels of expertise, methods and strategies utilised, individual thinking styles, personality traits, cognitive abilities and skills involved, and so on. None of the existing design process models, therefore, can fully describe or completely formalise a real design process.

2.2.1 Design Process in Present Study

A significant number of researchers have now come to the conclusion that it is uncommon for problem solving to proceed consecutively through a number of independent stages, prescribed by various methodologies. The idea that solving design problems cannot be analysed as a linear process composed of several stages is mainly present in empirical studies based on actual design activities. Design problem-solving is an opportunistically organised type of activity: it doesn't progress as a series of cycles that consist of actions occurring in a fixed order, such as analysis, synthesis and evaluation (Visser, 1994). It is not a process going from analysing the problem specifications to synthesising the solution, as problems do not antecede solutions – both are defined and developed simultaneously (Mayer, 1989, 1995). Designers, rather than going through the three stages of analysis, synthesis and evaluation, constantly generate new task goals and redefine task constraints. Analysis is a part of all phases of design process and synthesis can occur during its very early stages, as solution development does not always derive from an analysis of all relevant aspects of the problem (Akin, 1979, 1984). Thus, in later studies, the term *analysis* has been replaced by *formulation* or similar terms and *synthesis* is now used to refer to a *precursor of evaluation* (Gero, 1998).

Additionally, it is impossible to identify independent stages occurring consecutively, even as a part of iterative cycles (Visser, 1994). The opportunistic nature of design activity manifests itself in the intermingling of solution generation and solution evaluation activities and the interweaving of problem structuring and problem solving (Carroll & Rosson, 1985; Cross, 1984; Schön, 1988; Dasgupta, 1989; Visser & Hoc, 1990). This is because design problems are ill-defined; even when a design task is highly specified, design situations are always partly indeterminate. To formulate a design problem, the designer must frame a design situation – set boundaries, select particular factors and relations for consideration, and apply a degree of coherence to be able to continue with designing. The work of framing is very rarely done by one intense effort at the beginning of a design process. Designing leads to discovering new criteria for design: problem solving triggers problem definition (Schön, 1988).

Contrary to these observations, prescriptive approaches provide characteristics of ideal, rather than existing or observed design processes and can seldom be really applied (Blessing, 1994). Descriptive studies, on the other hand, often uncover behaviours that contradict current prescriptive design models. For example, designers may exhibit 'an early appearance and persistence of a kernel idea; a lack of generation of alternatives; design fixation or lack of flexibility on the designer's part; use of subjective judgment in decision-making; reluctance to change after a design decision is made; and 'satisficing', wherein a designer is satisfied with a sub-optimal solution' (Condoor, *et al.*, 1993, p. 277). And, surprisingly, these or other performance 'flaws' do not necessarily decrease the quality of design solutions. Still, in spite of the obvious advantages, descriptive models also reduce the multifaceted nature of the design process by coherent rigorous frameworks describing typically occurring sequences of activities, although being based on real introspective or anecdotal evidence.

Another common concern in the studies of design processes is the proliferation of approaches that betokens a serious failure of accumulated empirical support due to the absence of well-grounded findings tested through replication. It is, in part, due to the lack of theoretical coherence and overarching synthesis of the main models, and, in part, due to the differences in agenda of various design studies, which generated the impression of a research area that had become fragmented, isolated and, ultimately, ineffective.

Thus, given the ambiguity and complexity of the issue, there seems little use in adopting (or developing) a methodology that links design ability to a prescriptive or a descriptive model. An explorative approach seems more appropriate at this early stage of the research development. In design research, exploration typically involves a data-collection method of protocol analysis developed to answer open questions of: *how do people...?* or *which problems are involved by doing...?* Over the years, it has become the fundamental and most broadly applied technique for investigating design processes. It allows to yield a richer and more meaningful account that

reflects the situation being studied more accurately. Until recently, much design research utilising protocol analysis has been conducted with the aim of observing and exploring rather than hypothesis testing, leading to conclusions which are hypotheses for further study. The reason for this is the difficulty in gathering and recording the desired data and the lack of well-definedness of the resulting data (Gilmore, 1990). As the technique advanced, there have been new approaches suggested, including combining protocol analysis with introspective reports, semi-directed interviews and questionnaires. They allow addressing some of the limitations of protocol studies by reducing the ambiguity of available data and facilitating more accurate readings (further explained in Subsections 3.2.1 and 3.2.2).

It also seemed advantageous for this study's observation and exploration to be guided by a theoretical framework, even if this framework had to be sketchy and temporary. It was applied to (a) help conceptualising individual problem solving, and (b) as a guidance for the interpretation of the observed behaviour. Thus, the thesis employs an incorporative approach combining qualitative and quantitative techniques, and enabling the use of several partial design process models in an integrated manner. It draws on a number of generalisations developed within the prescriptive and descriptive models and applies the explorative approach (involving several experiments) to test the proposed hypothesis. The quantitative and qualitative methods of protocol analysis, introspective reports and questionnaires are used for obtaining the baseline information as starting points for interpretation, rather than for articulating generalisations.

2.2.2 Design Ability in Design Process

In order to address the link between design ability and problem-solving, research must focus on the precise relationship between low-level processes required to perform psychometric tests of abilities, and high-level processes required for domain-specific tasks, such as understanding a building from its plans. The latter includes knowledge acquisition processes for directing search, encoding processes for knowledge directly depicted in the plans, understanding conceptual knowledge communicated in the plans, as well as representational and inferential processes required for developing three-dimensional images of buildings (Chase & Chi, 1981, in Gobert, 1999). At the same time, both aptitude and strategy variations have been described in regard to cognitive abilities, where aptitude may limit strategy selection or predict performance within strategy subgroups both on cognitive tests and in real-life situations. And, while strategy choice could be unrelated to aptitude, the effectiveness of the implemented strategy could be limited by aptitude (Kyllonen, *et al.*, 1984; Kyllonen, *et al.*, 1985). In addition to individual differences in abilities and strategies, there are also cognitive (or thinking) styles, domain skills and knowledge, and other variables that are likely to affect problem solving on every level. Not surprisingly, the method for addressing these issues in an integrated, straightforward and feasible way is yet to be designed.

There are, though, a number of studies that have tackled these problems in past. A process-analytic approach has been used to examine quantitative differences in observed performance as well as qualitative differences with regard to the strategies used by individuals on spatial processing tasks (Shepard & Metzler, 1971; Shepard & Feng, 1972; Cooper, 1975; Sternberg & Weil, 1980; Pellegrino & Kail, 1981; Lohman & Kyllonen, 1983; Bethell-Fox, *et al.*, 1984; Kyllonen, *et al.*, 1984; Kyllonen, *et al.*, 1985). Past research has shown that there are at least two effective strategies employed on spatial visualization tasks (Carpenter & Just, 1986; Glushko & Cooper, 1978; Hunt & MacLeod, 1979; Kyllonen, *et al.*, 1984). One such strategy is a *constructive approach* in which individuals mentally construct visual representations of objects that require transformations necessary for problem solution. An *analytic strategy* consists of employing a sequential feature-by-feature method of comparison and transformation. Similar strategy differences have been found underlying performance on orthographic projection items (Cooper, 1983; Pellegrino, *et al.*, 1984; Lajoie, 1986).

There is little or no research of this kind addressing other groups of design ability factors, including ideation, and many unresolved issues associated with existing methods. Many parts of a design process (including orthographic projections) require complex mental transformations,

as do many tests of spatial visualization. It is extremely hard to identify which spatial ability measures are correlated with which part of the performance, as there are alternative strategies for solving similar problems. It is also unclear whether all visual thinkers differ in individual repertoires of strategies and/or abilities, or whether there are group similarities, what these are based upon, and so on. Also, because standardized tests only exist for a number of visual-spatial abilities (and not orthographic projection items, etc), it is difficult to compare research in this area. It is hard to predict whether similar strategy differences would occur with different test formats, or what types of aptitude strategy interactions might apply to them (Lajoie, 1986).

An alternative method – to hypothesise the demand for abilities in completing a complex task to, subsequently, test it in real life performance – has also been suggested in past (Egan & Gomez, 1985; Li, 1999). The problem with this approach is that one can not tell in advance what kind of abilities are required for an individual as both the task and the performance determine their need, that is every class of tasks and actions as well as every utilised tool or technique draw upon certain concrete abilities. In design, this method remains largely a theory awaiting its empirical validation as there are too many unresolved issues and implementation difficulties associated with it.

There is another approach – adopted in this research. In studies linking cognitive abilities and styles of thinking to performance, it has been used sparingly as it draws upon literature from diverse and often indirectly related sources to, in the first place, establish whether it could offer a suitable means of analysis (for instance – Gobert, 1999, on comprehension of architectural plans, Seitamaa-Hakkarainen & Hakkarainen, 2000, and Tai *et al.*, 2001 on individual spatial abilities, cognitive styles and their interaction in sketching). Similarly, this study's primary concern is not an in-depth examination of the contribution of certain individual characteristics to the design performance by one of the established methods (largely because of the associated with them issues, waiting for their resolution), but offering an alternative potentially useful combination of data sources, and a schema for their interpretation. Even proven inefficient, the suggested approach will point towards future research directions and indicate futile leads.

Our method can be summarised as an integration of a number of theories and methodologies from the design process and the design ability domains that deal with similar ideas – to establish a range of links between them, manifested in real life performances. There are several parallel and/or interacting notions in the theories of styles of thinking, cognitive abilities and characteristics of a classic design process that are being addressed in the present study. This includes relating preferences for different learning styles, measures of ideation and visual-spatial abilities, to the development of sketches (vertical or horizontal), the types and the occurrence of external representations produced (diagrammatic, pictorial, sentential, 2D or 3D, etc), the summaries of individual design processes and introspective statements denoting different approaches (wholistic or analytic, visual or verbal, etc), and strategies (deductive or inductive, top-down or bottom-up) in problem solving, etc. And, ultimately, correlating them with the assessments of design solutions and academic performance (the relevant theoretical framework and methods of research are further explained in Chapter 3, Subsection 3.3.1).

As there are no principal differences among the types of data extracted from external and internal representations (although via different methods and techniques) and many correspondences in underlying theories, there is one integrative schema for addressing relationships and correlations between the design ability and the design process. It is presented in Subsection 4.2.3 concerned with protocol studies, and is relevant to all collected datasets. The more detailed explanation of the adopted approach, including the range of analysed factors and interactions between them, is presented in the empirical part of the thesis.

2.3 Design Product

Section 2.3 discusses the third main area of research – design *product*, and its relation to design ability and design process. In this study, the *product* is external representations describing or

depicting design alternatives and final design solutions, generated by students during individual protocol sessions (Herbert, 1988; Goldschmidt, 1991).

Freehand sketches are usually understood when referring to external representations in the preliminary design, although they may also include digital images (2D and 3D), scale models, drafts done with mechanical aids and CAD, graphs, diagrams and other symbolic as well as sentential notations (Purcell & Gero, 1998). It is primarily sketches that have been explored in relation to the design process (Cox & Brna 1995; Scaife & Rogers 1996), or design ability (Millroy & Rochford, 1985; Ferguson, 1992; Bertoline, *et al.*, 1995) with some of the literature specifically addressing architectural design tasks (Schön, 1983; Akin, 1986; Goldschmidt, 1991, 1994; Goel, 1995; Suwa *et al.*, 1998). Similarly, in this research, sketches and diagrams are the focus of attention, while much consideration is also given to sentential representations.

2.3.1 Design Drawings in Design Process

In design, drawing appears to dominate all aspects of behaviour – from initial concept generation through to detailed fabrication of concrete solutions. Thus, much contemporary research has focused on this domain to investigate the nature and determinants of drawing behaviour. The recent progress mainly concerns the technical aspects of drawings. The systematic studies of design made it clear that sketching and cognition are closely coupled (Herbert, 1988; Fish & Scrivener, 1990; Goldschmidt, 1991, 1995; Schön & Wiggins, 1992; Goel, 1995; Suwa & Tversky, 1997; Purcell & Gero, 1998; Suwa, Purcell & Gero, 1998; Verstijnen, *et al.*, 1998), yet relatively little is known about the cognitive processes that support drawing activity. The major developments on this subject were summarised in an extensive study by Purcell and Gero (1998). Their work provides a comprehensive review of the research concerned with different kinds of representations, including: figures, diagrams, sketches, and their connection to imagery. From their summary of design research literature, and literature in adjacent fields of research (e.g. Humphreys & Bruce, (eds.) 1989) various functions of sketching and underlying them cognitive processes could be identified.

Fish and Scrivener (1990) presented arguments for sketches to *facilitate transition* from general descriptive propositional knowledge into specific depictive information. Researchers theorized that in a creative design process the depictive information is scanned to extract new and often original descriptive information, which, in turn, may be translated into a new depiction, and so on. They believe that the primary reason for designers to sketch is their need to see the results of the synthesis or manipulation of objects, without executing such operations in the physical world.

In a series of papers, Goldschmidt (1991, 1995) analysed protocols of design sessions involving novice and expert architectural designers. From this material she developed a model of the design process, described the role sketching plays within the process, and suggested the cognitive processes supporting the observed design activities. The design process is broken into ‘moves’ – chunks of design reasoning pertaining to an entity being designed, and ‘arguments’ – statements about the design or its aspects. Arguments within moves can be of two types – ‘seeing as’ and ‘seeing that’. There is a dialectic type of argumentation between the two modes of seeing in design happening in rapid alternation. ‘Seeing as’ is based on analogical or metaphorical thinking and is directly linked to sketching – it occurs when a designer sees and *reinterprets* the figural properties of a sketch, described as the *emergence* of new figures within its current figural interpretation. Arguments involving ‘seeing that’ are made while sketching and while examining a sketch; they are non-figural statements about the design dealing with the design consequences of the newly acquired sketch meaning. Translation between the modes of seeing stimulates new ideas through the *reinterpretation* of information, suggesting that sketches are more than records of thinking – designers associate them with new abstract concepts, functional issues, or meaning when revising their previous drawings. *Vagueness* and *ambiguity* of sketches are important components of creativity, as unclear, ambiguous sketches are often used as metaphors for the objects to be designed (Goldschmidt, 1991). Having studied how designers use mental images in problem solving, the author suggested that sketching gives

rise to interactive imagery and enhances reasoning of visual analogies; the two operations are closely associated (Goldschmidt, 1995).

Similar to Goldschmidt, Goel (1995) argues that *vagueness* and *ambiguity* of sketches play an important role in the early stages of designing. These properties help postponing making commitments to discovered solutions or design elements until the designer is ready to do so; they also support *reinterpretations* of various sketch elements. In a similar vein, Gross *et al.* (1995) maintains that drawings are important in the early part of the architectural design process as they embody abstract and high level design ideas allowing a degree of *uncertainty* about particular physical attributes. Additionally, sketches promote the *recognition of emergent features* and *properties* of the solution concepts. They help designers to make *lateral transformations* in the solution space – creative shifts to new alternatives (Goel, 1995).

Schön and Wiggins (1992) further explored the cognitive role of drawings in design, suggesting that designers develop their products by engaging in an interactive communication with the media of drawing. According to Schön (1983) lines ‘back-talk’ to a designer while drawing, giving an indication on how to proceed. He describes designing as a reflective conversation with materials or “reflection-in-action” where sketches help designers to find the *unintended outcomes* – the surprises that keep the exploration going. Schön and Wiggins (1992) view design as a cyclical process of sketching, interpreting and taking the sketches further. Designers frame a design problem, set its boundaries, select particular elements and relations for attention, and impose on the situation a coherence that guides subsequent moves. The designer visually registers information, ‘but also constructs its meaning – identifies patterns and gives them meaning beyond themselves’ (p.135). Thus, the structure of a design process is composed of ‘seeing-moving-seeing,’ an alternation of discovering – ‘seeing’ and then designing – ‘moving’ (Schön 1992; Schön & Wiggins 1992).

Based on Schön’s and Wiggins’s developments, Suwa and Tversky (1997) aimed at discovering how architects use and interact with their drawings, the sorts of information they extract, their roles in a reflective conversation, and so on. They argued that drawings provide designers with *visual cues* for identifying important issues, and that seeing different types of information in sketches drives the *revision* and *refinement of design ideas*. Additionally, designers use sketches as cues for remembering important pieces of information discovered during designing. Thus, one of the roles of external representations is as *memory aid*. Another fundamental characteristic of sketching is that it assists *problem structuring* during problem-solving, as well as it promotes *emergent features* and *properties recognition* in solution concepts. Architectural drawings also reveal designers’ thinking graphically and *facilitate problem solving* and *creative effort*.

Other researchers from design studies share similar outlooks on the functions of sketches in design. Cross (1995, 1999) suggests sketching allows *simultaneous exploration* of the problem space and the solution space, assisting the designer to converge on a matching problem–solution pair. Linked to this is another key feature of design sketches – they assist *problem structuring* through solution attempts. Sketching also enables designers to deal with different *levels of abstraction in parallel* – it allows them to think about the fundamental concept of a design, while reflecting simultaneously on critical details. Additionally, sketches promote the recognition of *emergent features* and *properties* in solution concepts helping the designer to make the *creative shift* to new alternatives (Cross, 1995; Goel, 1995; Suwa & Tversky, 1997).

Designers are also argued to think by sketching, while design drawings are seen as *conversational* in their nature. They assist in what Goldschmidt (1995) called the ‘dialectics of sketching’, the dialogue between the reflective criticism of ‘seeing that’ and the analogical reasoning and *reinterpretation* of ‘seeing as’ provoking *creativity*. Another purpose of concept sketches is ensuring *quicker communication* and *retrieval* at the early stages of design, by providing combined visual and factual descriptions for better evaluation and concept selection.

Based on the above developments, Purcell and Gero (1998) presented a theoretical overview of four interconnected research areas – design studies related to drawings, working memory, imagery reinterpretation, and mental synthesis. The research was largely concerned with

investigating the ways in which sketching stimulates creativity in design and cognition. The main focus was on the positive role that sketching plays in *reinterpretation*. Another theme was that reinterpretation provides new knowledge and that this new knowledge leads towards *further reinterpretation*. These suggestions are in agreement with iterative models proposed by other researchers, ranging from a dialectic type of argumentation between ‘seeing-as’ and ‘seeing-that’ (Goldschmidt, 1995), interactive ‘conversations’ with the media of drawing (Schön & Wiggins; 1992), and movement from description to depiction (Fish & Scrivener; 1990).

Suwa, Purcell and Gero (1998, 2000) further explored the role of design sketches in the architectural domain by introducing action categories that organize protocol data into four main groups: physical, perceptual, functional and conceptual, in accordance with designers' cognitive processes. From the analysis undertaken, three major functions of design sketches have been outlined. First suggests sketches serve as a representation/record of a thinking process available for later revision and inspection – they function as an *external memory*. Second tells sketches provide *visuo-spatial cues* for the association of functional issues. Third proposes that designers determine when or in which way to think about functional issues by having a cognitive *interaction* with sketches. Correspondingly, sketches serve as a physical setting in which design thoughts are “constructed on the fly in a situated way”.

The above research argued that sketches are cognitive support tools that designers rely upon for visual reasoning and problem solving, especially during conceptual stages of the design process. Yet, the empirical evidence for the cognitive processes that underlie drawing activity is limited, largely due to the methodological reasons, as accessing and interpreting the relevant data is a demanding task to undertake. Even more difficult is interpreting cognitive processing linked to functions of drawings in design and occurring during various sketching activities – in relation to supporting it cognitive abilities, learning styles and strategies, skills, knowledge, and so on. The limited literature that has addressed similar issues in past (discussed in Subsection 2.2.2), has neither succeeded in offering an integrative and reliable approach nor have the applied methodologies been thoroughly empirically validated.

2.3.2 Design Ability in Design Drawings

There are several ways of approaching sketching in relation to design ability. Design drawings can be explored in association with imagery, underlying cognitive abilities and styles, acquired skills and knowledge (Millroy & Rochford, 1985; Ferguson, 1992; Bertoline, *et al.*, 1995); as an independent construct of visual-spatial intelligence termed *graphicacy* or *graphic intelligence* (Balchin, 1976); as a separate *sketching ability* – one of the design ability properties characterised by thinking by drawing and underpinned by a number of cognitive abilities and styles (Cross, 1992, 1995, 1998; Löwgren & Stolterman, 1998); and so on. The present research reviews these approaches, without intending at presenting new arguments defending either viewpoint. They were considered when developing this study's method of addressing relationships and correlations between the ability factors and the product.

Graphicacy was first explained by William Balchin (1965) who suggested there are four types of basic intelligence - verbal, social, numerical, and visual-spatial – that relate to literacy, articulacy, numeracy, and graphicacy. He defined graphicacy as ‘the communication of spatial information that cannot be conveyed adequately by verbal or numerical means’ (Balchin, 1985, p.8). It is the ability to understand and present information in the form of sketches, photographs, diagrams, maps, plans, charts, graphs and other non-textual, two-dimensional formats (Aldrich & Sheppard, 2000). It is also the capacity for both visualising and physically orienting oneself spatially, an eye for visual detail, sensitivity to colour, line, space, form, and understanding the relationships between them as parts of the whole (McKim, 1980). Graphicacy is usually interpreted as an ability possessed to a certain degree by everyone; that is, assumed among the modern adult population, as demonstrated by the widespread use of graphics aimed at the general public. It is seen as the primary ability in design, where it also involves a number of

graphical skills developed via learning and practice. They include: orthographic drawing, basic geometric constructions, surface development and modelling (underpinned by visual-spatial intelligence *and* the knowledge of descriptive and plane geometry); drawing and illustration techniques used for presentation, spatial problem-solving and communication (also viewed as an independent cognitive skill of *graphic reasoning*); and, recently, computer aided drawing fundamentals (Brazil, 1975; Schmid, 1996).

Sketching ability is different from graphicacy due to its primary concern with functions of freehand drawings in design. The roles that designers ascribe to such representations include: (1) generating concepts; (2) externalising and visualising problems; (3) facilitating problem solving and creative effort; (4) facilitating perception and translation of ideas; (5) representing real world artefacts that can be manipulated and reasoned with; and (7) revising and refining ideas. A large body of the design research views *sketching ability* as a part of the design ability or design intelligence, that is among the qualities designers need to possess to succeed in their profession (Löwgren & Stolterman, 1998; Cross, 1992, 1995, 1999). Although, as with most design ability properties, it is unclear whether the ability to develop and present ideas on paper is possessed to a certain degree by everyone (Cross, 1995; Löwgren & Stolterman, 1998) or it is a part of the ‘designerly way of knowing, thinking and doing’ (Cross, 1982, 1992, 1995), whether it can be improved, and whether it is attainable by any individual involved in design training or practice. It is also a complex notion embodying independent constructs, such as *thinking by drawing*; as well as composite aptitudes, such as an ability *to generate a form and compose* (Cross, 1995, 1999).

Thus, there are two main concerns arising from the sketching ability definition: (1) as its constituents are closely associated with the functions sketches have in design, they are usually researched from the perspective of underlying them cognitive processes, and not in relation to cognitive abilities and styles these processes are based upon; and (2) even when broken down into comprising it elements, the concept of sketching ability fails to separate between knowledge, skills, abilities and styles, therefore rendering any psychometric assessment extremely difficult.

The former efforts to distinguish the craftsmanship of design with its skills and its body of knowledge, from the ability a designer needs in order to function well, were fragmentary, mainly resulting in a suggestion that at least parts of the design and/or sketching ability are supported or represented by cognitive abilities (Cross, 1995, 1999; Löwgren & Stolterman, 1998). The situation with graphicacy research is similar. It is understood that the ability to draw and sketch, and to develop other related skills of graphicacy must be underpinned by the cognitive skills of graphic reasoning and spatial ability (Postigo & Pozo, 2004). But the significance of other abilities and thinking styles still need being defined, including their cognitive roles or how they are related to drawing performance.

There is a large body of factor-analytical literature concerned with sketches and sketching ability, that relates cognitive abilities to design. The link between visualisation and engineering design drawing, for example, is well established (Hammond, *et al.*, 1971; Pare, *et al.*, 1987; Ferguson, 1977, 1992). The research of Bertoline and his co-workers (1995) suggests that visualisation ability is central to design, and that imagery provides a bridge between design ideas and their representation in sketching/drawing. It has also been argued that the ability to draw is directly related to the ability to imagine, and that the ability to imagine will feed back into the ability to draw (Laseau, 2000). Drawing remains one of the most commonly prescribed activities for developing spatial visualisation ability in engineering students; as inferred from course outlines for engineering graphics.

There are studies in architecture presenting evidence of the relationship between the external representations used, and the ability to generate solutions from mental representations (Goldschmidt, 1991; Goel, 1995; Scaife & Rogers 1996; Kavakli & Gero, 1999, 2001). They view the development of external representations as a cognitive activity associated with the imagery properties, and contain arguments showing that designers use imagery to generate new form combinations to be externalised through sketching; and that they also sketch to generate

images in their minds. Two other studies, by Fennema and Tartre (1985), and Pribyl and Bodner (1987) show that problem solving employing sketching and diagramming strategies is favoured by high spatial ability students.

Several researchers addressed the link between visual memory and sketching (Ekstrom, *et al.*, 1976; Kosslyn, 1999). It has been suggested that training visual memory may help developing drawing skills, as sketching (particularly of the previously seen objects) relies upon the use of visual memory. Some studies argue that sketching and modelling improve the performance of the long- and short-term visual memory (Goldberg, 2000); and that perceptual motor skills, involved in haptic-visual exercises, are stored in memory, a gateway to long-term learning (Klatzky & Lederman, 2002). Other research indicates that visual-motor memory engaged in sketching activities yields better recall than visual memory alone (Hulme, 1979; Haxby, *et al.*, 2000). Thus, it has also been suggested for the hands-on activities to be considerably more efficient in developing visual memory than the CAD means (Knipp, 2003).

Among the literature linking ideational abilities to actual performance, there are studies relating it to sketching (Hocevar, 1979; Stroebe & Diehl, 1994; Van der Lugt & Hemberg, 2002). They are based on techniques employing sketching (i.e. *brain sketching*) developed to facilitate idea production (VanGundy, 1988). These studies claim for sketching to support the ideation process by (1) enhancing a re-interpretive cycle in the individual thinking process, (2) supporting re-interpretation of each other's ideas in group activity, and (3) improving accessibility to earlier ideas (Van der Lugt, 2002). Sketches are argued to stimulate creativity in idea generation groups, especially in the immediate individual idea production process by providing new directions for idea generation in an individual generate-interpret cycle. They may also facilitate a more integrated group process, by allowing better access to the earlier ideas, especially in the shared parts of external memory (Van der Lugt, 2002; Van der Lugt & Hemberg, 2002). Other studies, linking ideation to sketching, traditionally belong to the domain of creativity. They suggest there is a high correlation between creativity and proficiency in domain relevant skills, such as sketching; and both are necessary when producing the creative product (Amabile, 1996). Another view can be found in factor analytical literature arguing for the figural fluency scores to be largely a reflection of motor speed and manual control in drawing, or a speed of doodling, as all test measures require responses in a limited time and scores are linked to the performance rate (Carroll, 1993). While figural flexibility tests may also have different visual and reasoning components present (Carroll, 1993). Thus, it may be hard to separate figural ideational factors from other associated with them abilities and graphical skills.

There is also literature linking different cognitive or learning styles to sketching, though very limited in terms of the number of applied methodologies. There is a substantial amount of studies utilising traditional educational approach – relating learning styles and attitudes to overall success in design disciplines, including engineering drawing and CAD, that is by correlating them with grades or other measures of academic achievement (Simpson, 1978; Swanson & Anderson, 1982; Young, 1998). The results, however, are hard to compare due to the multitude of models and assessment tools employed.

Much less studies examined other aspects of the design performance, such as the production of external representations in relation to individual styles of problem solving (Yokomoto, *et al.*, 1995; Hakkarainen & Hakkarainen, 1999; Tai *et al.*, 2001, Alias *et al.*, 2002). And little or none research has utilised a process-analytic approach to examine how different actions and processes involved in sketching are correlated with various dimensions of individual learning styles. The reasons are common for all ability factors – there is no single integrative method of addressing these issues and too many unresolved concerns associated with existing approaches.

This study's way of exploring the relationship between the design product and the design ability draws on a number of methods and techniques (factor- and process-analytic, phenomenological, and psychometric) further elucidated Subsections 3.3.1 and 4.2.5.

Chapter 3. Theoretical Framework: Methods of Research

Chapter 3 overviews literature from a number of sources, including cognitive science, psychology, design studies, imagery and creativity research. It contains a discussion of factor-analytic literature, research methods and techniques, and assessment instruments brought together with a purpose of (a) providing a theoretical overview of methodological approaches commonly used in design studies, and (b) establishing the knowledge base and the rationale for the experimental design and empirical studies presented in Chapters 4, 5 and 6. This chapter is organised into three sections, corresponding to three research areas.

Section 3.1 is concerned with the design ability; it presents a summary of the major factor-analytic and psychometric theories and models that contributed to the current understanding of cognitive styles and cognitive abilities. This includes a synopsis of the most popular assessment instruments and techniques, as well as an overview of the associated with them issues.

Section 3.2 corresponds to the process research area; it reviews a number of data collection and analysis methods that have been broadly applied in design studies. They include protocol analysis, intro- and retrospective reports, and questionnaires utilised in the present research. The motivation behind integrating these approaches, as well as their dangers and limitations are also being discussed.

Section 3.3 is related to the product research area. It contains a summary of the theoretical and empirical studies of design drawings, and a review of the design product assessment methods and taxonomies, including the major issues associated with them. It also establishes an integrated methodological base for addressing relationships and correlations between the design ability, the design process and the design product presented in Subsection 4.2.3.

The overall purpose of Chapter 3 is to explain which theoretical and empirical studies, research methods and techniques of evaluating the input, examining the process, and assessing the product were considered relevant to the current research and contributed to the final method and experimental design elucidated in Chapter 4.

3.1 Design Ability

This part of the research is a continuation of the design ability discussion pertaining to two groups of ability factors – cognitive abilities and learning styles – viewed from the perspective of existing factor-analytic and psychometric theories underlying different methods of their assessment and analysis. Subsections 3.1.1 and 3.1.2 contain overviews of factor-analytical literature, theoretical research and empirical studies developed within the fields of cognitive science and psychology. They informed the choice of assessment tools and techniques applied in this thesis (further elucidated in Chapter 4).

3.1.1 Evaluation of Cognitive & Learning Styles

A significant number of cognitive styles have been identified and studied over the last 40 years of research. *Field independence* versus *field dependence* is probably the one most well known (Witkin, 1962). It refers to an inclination to approach the environment in an *analytical*, as opposed to *global*, fashion. At a perceptual level, when undergoing cognitive testing, field independent personalities are able to distinguish figures as discrete from their backgrounds² compared to field dependent individuals who experience events in an undifferentiated way. Additionally, field dependent individuals have a greater social orientation relative to field independent personalities. At the basis of all cognitive style theories is the argument that preference is governed by ability, that is when an individual finds a particular mode easier and

² As assessed by the *Manual for the Embedded Figures Test*, by Witkin *et al.* (1971).

more comprehensible, he is likely to resort to that mode regardless of whether it is appropriate for the set task (Ernest & Paivio, 1971).

Other formerly defined cognitive style labels include: *levelling* versus *sharpening* – individual variations in remembering that pertain to the distinctiveness of memories opposed to the tendency to merge similar events. *Reflection* versus *impulsivity* – individual consistencies in the speed and adequacy with which alternative hypotheses are formed and responses are made. *Conceptual differentiation* – differences in the tendency to categorize perceived similarities among stimuli in terms of separate concepts or dimensions, and many other labels.

These are some of the popular models of cognitive styles among the 19 suggested by Messik (1984). More recent literature reveals over 35 labels referred to as cognitive (in some studies ‘thinking’) styles. The comparative analysis suggested many of them could be clustered into two principal groups, or two groups of qualitatively different types of reasoning (Riding & Douglas, 1993). The first principal cognitive style group comprised of multiple dimensions was labelled a Wholist-Analytic (W-A) cognitive family. The models within it share similar characteristics to the most prominent style label – field dependence-independence. In a work context, analytic individuals tend to be compliant, their thinking relies on logical sequences and vertical reasoning, they prefer structured approaches to decision-making, apply systematic methods of investigation, and are especially comfortable when handling problems requiring step-by-step solution. Wholist individuals, on the other hand, tend to be nonconformist, their thinking relies on impulsive synthesis and lateral reasoning; they prefer rapid, open-ended approaches to decision-making, rely on random methods of exploration and work best on problems favouring a wholistic approach (Zeleny, 1975; Lynch, 1986).

In addition to field dependence-independence, the Wholist-Analytic cognitive family includes: impulsivity-reflectivity (Kagan, 1965); leveller-sharpener (Holzman & Klein, 1954); simultaneous-successive (Das, 1988); diverging-converging (Hudson, 1966); tolerant-intolerant (Gardner, 1959; Holzman & Gardner, 1959); flexible, control-constricted automatisisation versus restructuring (Gardner, 1959); and right- versus left-brained (Torrance & Rockenstein, 1988) models. Other labels from the same group are: conceptual integration; cognitive simplicity versus cognitive complexity; compartmentalization; conceptual articulation; scanning (broad versus narrow); risk taking versus cautiousness; adaptors-innovators; abstract-concrete and random-sequential thinking; broad-narrow categorisation; conceptualising styles – relational versus analytic; and several others (Riding & Cheema, 1991).

The second cognitive family identified was Verbal-Imagery (also Verbal-Visual). It determines whether an individual is inclined to represent information during thinking verbally, or in mental images (Riding & Cheema, 1991). The Verbal-Imagery (V-I) mode is thought to be independent of the superordinate Wholist-Analytic dimension (Riding *et al.*, 1993). A classification of individuals as imagers (visualisers) or verbalisers has started with Galton (1880; 1883) examining imagery types. Later biographical studies, introspective reports and psychometric research have also provided evidence that individuals differ in the extent to which they favour verbal or visual strategies when they are processing different kinds of information (Krutetski, 1976; Richardson, 1977). A more recent research by Presmeg (1986) and Bishop (1989) also distinguishes visualisers and non-visualisers, where visualisers are individuals who prefer to use a visual method for solving a problem which may be solved by a visual or a non-visual method. It has also been argued that, while most people are likely to adjust their strategies according to the nature of a given task, there are some who appear to be heavily dependent upon one or the other type of coding (Kagan & Kogan, 1970). This dependency, as well as the styles’ stability across tasks and over time, is equally characteristic of the Wholistic-Analytic cognitive dimension (Ausburn & Ausburn, 1978).

The Verbaliser-Imager cognitive family includes: *sensory modality preferences* (Bartlett, 1932); *verbaliser-imager* (Riding & Taylor, 1976); and *verbaliser-visualiser* (Richardson, 1977) labels. There are three main assessment tools for the V-I cognitive style that have been developed and validated in past (Paivio, 1971; Richardson, 1977; Riding & Taylor, 1976; Riding & Calvey, 1981; Riding & Buckle, 1990); plus a recently designed and tested Verbal-

Imagery Cognitive Style test (VICS) awaiting its further empirical validation (Peterson, *et al.*, 2003). There are also questionnaires developed to assess imagery abilities; they measure both verbal and imaginal/visual abilities. The commonly used ones include the Betts Inventory (Betts, 1909), the Marks Vividness of Visual Imagery Questionnaire (Marks, 1973), and the Gordon's Scale of Imagery Control (Gordon, 1949), while a sophisticated multidimensional verbal-visual questionnaire has been awaiting its further development since Kirby *et al.* (1988). Similar situation can be observed with the equivalent (in terms of the measured dimensions) learning style models – there are very few empirically validated assessment tools that include a V-I mode (excluding Dunn & Prashnig, 1991; Leutner & Plass, 1998; and some others).

Table 1 contains a summary of the most distinctive features associated with Wholistic-Analytic and Visual-Imagery modes present in most of the cognitive and many of the learning style models.

Table 1. Features associated with four cognitive/learning styles, classified by Riding & Douglas (1993)

Analytics	Wholists	Imagers/Visualisers	Verbalisers
• Structured exploration • Prefer facts to concepts • Learn more easily when they can study rules sequentially • Apply step by step approach to problem solving • Feel most comfortable when they don't have to risk error as they learn or resolve problems • May feel intimidated as they fear making errors	• Impulsive synthesis • Prefer concepts to facts • Prefer having a general overview of the problem and concrete experience • Apply random, rapid, open-ended approaches to problem solving • Welcome risk and experimentation as a part of their learning or problem solving • Enjoy and benefit from communicating with others	• Mentally visualize data to conceive ideas or while thinking • Remember and understand best through watching, prefer visual data • Need visual stimulation • Usually have a strong imagination	• Represent information verbally during problem solving • Remember much of what they read, prefer verbal/written data and communication • Like to interact verbally • Have an ongoing inner dialogue which helps them remember and understand

The present field of learning styles is even more complex than of cognitive styles – there have been a greater number of models and psychometric tools developed – over 100 according to Mitchell (1994), each emphasizing more or less different aspects. Some of them assess dimensions similar to those present in the W-A and V-I cognitive families (Schmeck, 1988), many include additional aspects related to biology, personality, experience, environment or conscious control, and some offer their unique, distinctive scales. As a result, some researchers treat cognitive and learning styles as interchangeable notions, while others view them as principally different constructs. Additionally, there is literature, in which various connections between cognitive styles and learning (or learning styles) have been identified. For example, field independent individuals have been found to learn more effectively under conditions of intrinsic motivation and influenced less by social reinforcement (Messick, 1978).

Riding and Rayner (1998) have also synthesized a large body of literature on learning styles. They proposed a separate four-level model that groups students' learning preferences into learning processes based on experiential learning, orientation to study, instructional preferences, and development of cognitive skills and learning strategies. According to these researchers, the main difference between cognitive and learning styles is the number of style elements considered and the cognitive styles' bipolarity. That is, the learning style may not only entail many different elements – physiological, cognitive, affective, perceptual, behavioural, and so on, they are usually not 'either-or' extremities. One may or may not have any particular element in one's style, whereas the absence of one element does not necessarily imply the presence of the opposite element.

The four fundamental approaches to styles classification originally summarised by Riding and Rayner (1998), allow to distinguish between the four types of learning styles instruments, including: (1) assessment tools based on instructional preferences; (2) social interaction models; (3) information processing models; and (4) instruments evaluating personality levels.

The information processing (also termed cognitive processing) group contains the majority of labels evaluating dimensions that match well the Wholist-Analytic mode. Some of them also include the Verbaliser-Imager dimension, which makes them very similar to the two cognitive style families suggested by Riding. Many of these labels stem from the cognitive style and hemispheric specialisation theories (summarised by Bradshaw & Nettleton, 1981). That is, individual preferences for particular approaches to organising and representing information are seen as having a clear physiological basis.

Fitting in the information processing group, Kolb (1984), proposed a theory of experiential learning that involves four principal stages: concrete experiences (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE). The CE/AC and AE/RO dimensions are polar opposites; and Kolb postulates four types of learners (divergers, assimilators, convergers, and accommodators) depending on their position on these two dimensions. Pask (1976) has described two principally different learning styles: serialist versus holist. Whereas serialists prefer to learn in a sequential fashion, holists are inclined to learn in a hierarchical manner (i.e. top-down). The 4MAT framework based on the work of McCarthy (1980) suggests four learning modes i.e. analytic, imaginative, common sense, and dynamic. Gregorc's (1985) Mind Styles Delineator divides learners into: concrete sequential (CS), abstract sequential (AS), abstract random (AR), and concrete random (CR). Dunn, Dunn and Price's (1985-1989) model includes auditory, visual, verbal, tactile, and kinaesthetic sensory modalities; as well as global versus analytic hemispheric preferences.

This study applies the Riding's theory of cognitive styles to help accounting for the performance on design tasks because the designers' reasoning is thought to be characterised by a distinct wholistic, visual approach, which is high on imagery (Lawson, 1997; Durling, 2001). It was, though, decided upon choosing an equivalent (in terms of the measured dimensions) learning style model, as thinking styles in design are usually learned, socialized and developed in interaction with others. Therefore, being at the median between studies of cognition and studies of practices they are likely to be explained better by the properties of individual learning styles. Additionally, as design is considered to be a combination of crafts, technologies and various disciplines, its education is likely to contain all dimensions of learning, while different phases or aspects of problem solving are likely to be guided by different learning styles (i.e. not only by 'either-or' extremities of cognitive styles).

3.1.2 Evaluation of Cognitive Abilities

Two decades ago, Carroll (1993) reviewed and reanalysed the world's literature on individual differences in cognitive abilities to reach an integrated picture and identify the structure of human ability factors. His work incorporates the results of a systematic exploratory factor analysis of over 460 human ability data sets, many of which were reported during the past 50 to 60 years. There also had been prior attempts to integrate a large body of theoretical and empirical research under a common theoretical umbrella, which makes it different from the situation with cognitive/learning styles domain, still awaiting its consensus taxonomy.

The most recent Cattell-Horn-Carroll (CHC) theory of intelligence is widely recognized as the most empirically validated theoretical structural model of human cognitive abilities. It integrates the Cattell-Horn theory of intelligence (Horn, 1991; Horn & Noll, 1997) and Carroll's three-stratum models of cognitive abilities (Carroll, 1993, 1997; Daniel, 1997, 2000; Snow, 1998; Sternberg & Kaufman, 1998). CHC is a psychometric theory since it is primarily based on procedures that assume that "the structure of intelligence can be discovered by analysing the interrelationship of scores on mental ability tests. To develop these models, large numbers of people are given many types of mental problems. The statistical technique of factor analysis is then applied to the test scores to identify the 'factors' or latent sources of individual differences in intelligence" (Davidson & Downing, 2000, p. 37). CHC theory is a hierarchical framework of human cognitive abilities that consists of three strata: (1) narrow cognitive abilities (stratum I); (2) broad cognitive abilities (stratum II); and (3) general intelligence or *g* (stratum III). The broad cognitive abilities include Fluid Reasoning (*Gf*), Comprehension-Knowledge (*Gc*), Short-

term Memory (*Gsm*), Visual Processing (*Gv*), Auditory Processing (*Ga*), Long-term Retrieval (*Glr*), Processing Speed (*Gs*), Decision/Reaction Time or Speed (*Gt*), Reading and Writing (*Grw*), and Quantitative Knowledge (*Gq*). The broad cognitive abilities subsume approximately 70 narrow cognitive abilities (McGrew & Flanagan, 1998). The primary architects of CHC theory do not agree on the third stratum – whereas Carroll’s model includes a higher-order general intelligence factor, Horn argues against the validity of *g*.

The present research is interested in two classes of stratum II cognitive abilities: *Visual Processing* and *Long-term Retrieval*. Visual Processing (*Gv*) is a group of eleven cognitive factors, listed in Table 2 below, each one emphasizing a different process involved in the generation, storage, retrieval and transformation of visual images (Lohman, 1994).

Table 2. Eleven *Gv* abilities as per the CHC theory of intelligence

Visual Processing Abilities (<i>Gv</i>)	
Visualization (<i>Vz</i>)	Serial Perceptual Integration (<i>PI</i>)
Spatial Relations (<i>SR</i>)	Length Estimation (<i>LE</i>)
Closure Speed (<i>CS</i>)	Perceptual Illusions (<i>IL</i>)
Flexibility of Closure (<i>CF</i>)	Perceptual Alternations (<i>PN</i>)
Visual Memory (<i>MV</i>)	Imagery (<i>IM</i>)
Spatial Scanning (<i>SS</i>)	

Accordingly, *Gv* abilities are measured by tasks (figural or geometric stimuli) which require the perception and transformation of visual shapes, forms, or images and/or tasks that require maintaining spatial orientation with regard to objects that may change or move through space.

Gv abilities have been linked to: (1) higher-order thinking in science, math, design, architecture and the achievement (Chronbach, 1970; Ghiselli, 1973; Alias, *et al.*, 2002); (2) incremental prediction of performance (above and beyond verbal and quantitative abilities) in gifted and talented populations (Shea, *et al.*, 2001); and (3) the observation of creative “insights by means of thought experiments on visualized systems of waves and physical bodies in states of relative motion” (Lohman, 1996, p. 99). Additionally, in line with the research confirming the importance of visual abilities in design and architecture (reviewed in Subsection 2.1.4), they are believed to be essential elements of the design ability (Bernstein, 1988; Schön, 1983, 1992; Bennet, 1996; Cross, 1992, 1995; Löwgren & Stolterman, 1998, reviewed in Subsection 2.1.3).

This study explores *Vz*, *SR*, *MV* and *SS* factors from the above list; it leaves out several others to remain within the limits of the specified research scope. That is, our primary concern remains discovering whether the proposed methodology ensures initial tentative links between different sets of information that would allow establishing how the chosen abilities account for the performance on design tasks. There are several reasons to choose these four factors from the *Gv* class of broad abilities. Firstly, only a handful of studies have explored the structural characteristics of the *Gv* domain during the past decade. Juhel (1991), using Carroll-based exploratory factor methods and procedures in a sample of college students, confirmed the existence of the well documented visualization (*Vz*), spatial relations (*SR*), and visual memory (*MV*) abilities (Carroll, 1993; Lohman, 1979; 1996). Similarly, results from the most recent research involving architects, who were administered nine spatial tests from different test batteries, identified three main factors: visualization, spatial relations, and dynamic spatial ability (D'Oliveira, 2004). Additionally, visualization and spatial relations are the two main factors that typically appear in factor-analytic studies (French, 1951; Ekstrom, *et al.*, 1976; Carroll, 1993; Lohman, 1987, 2000) and design research (summarised in Subsection 2.1.4).

There is another group of cognitive factors explored in this thesis that has been linked to imagery, creativity and design ability (Gonzales & Campos, 1997). It is called *Long-term Retrieval* (*Glr*) class of narrow abilities, as the factors within it embody the ability to store and consolidate new information in long-term memory and later fluently retrieve the stored information (e.g., concepts, ideas, items, names) through association. Horn (Horn & Masunaga,

2000) differentiates two major types of *Glr* – fluency of retrieval of information over minutes or a few hours (intermediate memory) and fluency of association in retrieval from storage over days, months or years. Ekstrom *et al.* (1979) distinguished two additional characteristic processes of *Glr*: (1) reproductive processes, which are concerned with retrieving stored facts, and (2) reconstructive processes, which involve the generation of material based on stored rules.

Table 3. Thirteen *Glr* abilities as per the CHC theory of intelligence

Long-term Retrieval Abilities (<i>Glr</i>)	
Associative Memory (<i>MA</i>)	Word Fluency (<i>FW</i>)
Meaningful Memory (<i>MM</i>)	Figural Fluency (<i>FF</i>)
Free Recall Memory (<i>M6</i>)	Figural Flexibility (<i>FX</i>)
Ideational Fluency (<i>FI</i>)	Sensitivity to Problems (<i>SP</i>)
Associational Fluency (<i>FA</i>)	Originality/Creativity (<i>FO</i>)
Expressional Fluency (<i>FE</i>)	Learning Abilities (<i>L1</i>)
Naming Facility (<i>NA</i>)	

Glr abilities, listed in Table 3, traditionally belong to the domain of creativity, where they have been referred to as idea production or ideation abilities (Torrance, 1962; Ekstrom, *et al.*, 1976; Williams, 1980). In cognitive studies, ideation factors have been linked to cognitive structures and processes supporting creativity and perception (Koestler, 1964; Simonton, 1988; Finke, *et al.*, 1992, 1995, 1999; Smith, 1995). Idea production abilities have also been related to intelligence, environment, psychological profiles, affective traits and cognitive styles (Guilford, 1956; Torrance, 1966; Guilford, 1967; Clark, 1989; Perkins, 1981; Nickerson, *et al.*, 1985; Sternberg, 1988, 1990; Sternberg & Lubart, 1991; Khatena, 1992; Colangelo & Davis, 1997). They have been argued to serve as predictors of creative achievement (Torrance, 1966, 1974) and academic performance (Sawyers & Canestero, 1989). Ideation has been linked to sketching performance and sketching abilities (Hocevar, 1979; Stroebe & Diehl, 1994; Amabile, 1996; Van der Lugt & Hemberg, 2002). Additionally, in line with the research confirming the significance of *Glr* factors in design and architecture, they are regarded as important constituents of the design ability (Bernstein, 1988; Schön, 1983, 1992; Bennet, 1996; Cross, 1992, 1995; Löwgren & Stolterman, 1998, reviewed in Subsections 2.1.3-4).

This study only explores *FA*, *FE*, *FF* and *FX* factors from the above list to remain within the limits of the research scope. It was expected for their measures to ensure enough data to establish initial links between the input, the process and the product. There are two main reasons to choose them from the *Glr* class of broad abilities in addition to their importance in designing. Firstly, their roles in problem solving can be relatively easily observed and analysed as many studies have judged ideation based on a number or/and quality of ideas generated (Szymansky & Harkins, 1992; Gallupe, *et al.*, 1994) reflected in visual (sketching) and verbal (retrospective reports) accounts. Also, *FA*, *FE*, *FF* and *FX* may be linked to another group of ability factors, explored in the present research – Verbal-Visual/(Imagery) and Wholistic-Analytic learning styles. It may be argued, for example, that students with preferred Verbal (or Wholistic-Verbal) style of would score higher on verbal forms of ideation tests, while Visual (or Wholistic-Visual) students may have a higher ability in figural ideation. While low ideation ability may be correlated with dominant Analytic learning style. Thus, the clearly verbal nature of *FA* and *FE* and the clearly visual-figural nature of *FE* and *FX* were additional considerations that influenced the selection of these particular factors³.

Related to the above two groups of abilities is *Imagery (IM)* which may seem the most apparent choice of the ability factor due to its role in design ability, creative reasoning, visualisation, etc. Yet, it is omitted from the study due to its exceeding complexity and a considerable number of associated with it theories (summarised by Kosslyn, 1994). There is still no consensus on

³ Same applies to the *Vz* abilities and their potential links to the measurements of W-A and V-I styles.

whether it represents a separate ability or a multidimensional construct, whether it could be defined/measured in terms of the underlying cognitive factors, or whether conventional cognitive tests require imagery in their performance (Di Vesta, *et al.*, 1971; Richardson, 1977, 1983; Kosslyn, *et al.*, 1984; Poltrock & Brown, 1984; Poltrock & Agnoli, 1986; Dean, 1994).

3.2 Design Process

Different methods of data collection and analysis have been employed in design science during the past three decades: thinking aloud (Ericsson & Simon, 1993), retrospection (Galle & Kovacs, 1992), introspection and interviews (Lawson, 1997) most frequently. With the advancement of domain research, protocol analysis has become the fundamental and most broadly applied technique for investigating design processes. It is characterised by a rigorous methodology for eliciting verbal reports of thought sequences used as a source of data on thinking and problem solving (Ericsson & Simon, 1993). It is based on the assumed possibility to instruct subjects to verbalize their thoughts in a manner that doesn't alter the succession of thoughts mediating the completion of a task, and can therefore be accepted as valid data on internal reasoning (Ericsson, 2001).

Generally, the views on the use of protocol studies range from identifying different modes in the design activity, to revealing how knowledge and actions are embedded in design. The earlier studies dealt mainly with protocols' verbal aspects, while the later studies acknowledge the importance of design drawings, interpreted through verbal descriptions. At the same time, the inference of context and intention from a design drawing is typically used to reveal the relationship of sketching to design thinking. As the technique advanced, there have been new approaches suggested, combining protocol analysis with introspection and questionnaires. Formerly, the techniques of introspection and questionnaires have often been utilised independently of protocols, as the primary means of discovering and elucidating cognitive processing taking place during sketching and thinking (Ericsson & Simon, 1980).

In this research, they are used in an integrated manner – with protocol analysis, which remains the primary data-collection method. Introspective self-reports and questionnaires ensured additional sources of information that helped interpreting the observed cognitive activities and connecting them to various characteristics of the design *product* and the *ability factors*. Thus, the motivation behind integrating qualitative and quantitative approaches is supplementing different data sets and yielding a richer and more meaningful account that reflects the situation being studied more accurately. The next two subsections discuss these methods in further detail to delineate the purpose of their use in the thesis, and to review a number of major issues associated with them.

3.2.1 Protocol Analysis

Protocol studies began in late sixties when Newell (1968) first applied the technique of protocol analysis to study human problem solving mechanisms. These early studies were based on the *information processing* outlook on designing. Later, Schön (1983/88) took a different approach to analysing protocol studies of practicing architects. He argued that design reasoning was a pattern of the use of design rules, where designers engage in *reflection-in-action*, as they 'see' and then 'move' the manipulated design objects. Similar views are shared by a considerable number of researchers, who also stress the importance of sketches in the analysis of protocols (Ullman, *et al.*, 1990; Goldschmidt, 1991; Akin & Lin, 1995; Suwa & Tversky, 1996). The method of protocol analysis has been improved over time through many studies from different design disciplines (Visser, 1989; Stauffer & Ullman, 1991; Cross, *et al.*, 1996; McNeill & Edmonds, 1998; etc). They added to developing several modern frameworks deriving both from the direct observation of the designer's interaction with the problem domain, and from the models of design reasoning projected onto the rich and unstructured protocol data.

Until lately, most protocol studies have been using concurrent protocols, during which subjects attempt verbalising their inner thoughts while reasoning and sketching on various design problems (Ericsson & Simon, 1993; Van Someren, *et al.*, 1994). Designers working on real or simulated problem situations are encouraged to ‘think aloud,’ thus, revealing details of the information processing sequence using their short-term memory. More recently, researchers started applying retrospective techniques to avoid some of the drawbacks of concurrent protocols, and to understand perceptual aspects of designing (Suwa & Tversky, 1997; Suwa, *et al.*, 1998; Suwa, *et al.*, 1999). Their subjects try recollecting the preceding cognitive processes by retrieving information stored mainly in long-term and partially short-term memory (Suwa & Tversky, 1997) typically assisted by video- and audio-tapes of the entire problem solving session (Cross, *et al.*, 1996; Cross, *et al.*, 1997). The documents collected usually include: alternative versions of produced plans, schemas and other external design representations, both the intermediate and the definitive design solutions, and both the versions for the client and those designers construct for themselves during problem solving.

There is another categorical distinction: between process- and content-oriented protocol studies (Dorst & Dijkhuis, 1995). Generally, studies employing concurrent protocols focus on the process-oriented aspects of designing and are based on the information processing view of design activity originally proposed by Simon (1992). They describe design processes in terms of a general taxonomy of problem-solving, i.e. problem-states, operators, plans, goals, strategies, and various issues deriving from the design process (Eastman, 1970; Akin, 1993; Eckersley, 1988; Chan, 1990; Gero & Mc Neill, 1998). Studies utilising retrospective protocols, on the other hand, are usually aimed at understanding cognitive aspects of designing; they are based on the idea of reflection-in-action introduced by Schön (1983). They focus on ‘internal’ cognitive processes to provide a better understanding of designers’ drawing, seeing, and other issues deriving from the design content (Suwa & Tversky, 1997; Suwa, Purcell, & Gero, 1998; Suwa, Gero, & Purcell, 1999). The content-oriented method is more suitable for examining the ways in which designers cognitively interact with their sketches.

Overall, the lack of a universal taxonomy of the contents of designers’ actions has made it difficult to compare results from different studies. There are many distinctions in approaches to coding schemes and methods, associated with different aspects of both content- and process-oriented protocol studies. And a need of methodological examination of the differences between the two different types of protocols, including their relative advantages, and dangers and limitations in revealing design processes.

In terms of the common drawbacks, several major issues have been raised regarding the technique. First, a design protocol can only reflect a certain part of the design process; it cannot capture everything. Ericsson and Simon (1993) also argued for the accuracy of the verbalisation in a protocol to be task-specific. When a task is responsive, involving only short-term memory, the verbal report is closer to the real mental process. But when a task is more retrospective – involving the use of long-term memory – then wrong or missing data may occur. A de-briefing interview or a questionnaire has been suggested after the protocol to reduce erroneous readings.

Another issue is that the think-aloud protocol might distort a real design process, or interfere with the act of designing (Lloyd, *et al.*, 1995). Concurrent introspective reports are assumed to provide information on the strategies subjects are using at the time of the report. However, the concentration put on thinking aloud might detract individuals from their ability to do the task efficiently, thus rendering the outcome of the report spurious and tentative (Wenden, 1998). Additionally, it is possible that concurrent protocols may only effectively reveal verbal aspects of problem solving in the design process (Lloyd, *et al.*, 1995).

There are also related concerns of the verbal protocols to impair reasoning. Schooler and Engstler-Schooler (1990) conducted experiments showing verbal reasoning interfering with visual reasoning in visual memory tests. Wilson (1994) in his experiments, argued that people often misstate what they are thinking about in talk-aloud protocol studies. Contrary to some of these observations, a more recent research by Gero and Tang (2001) presents arguments indicating that there is no associated interference with the ongoing design process when using concurrent protocols for exploring the process-oriented aspects of designing.

Finally, a real design process is usually ‘thought over’; designers have time to digest design briefs or architectural tasks. They would not normally be forced to work out a design during an artificially short period of time set by a protocol study. A real design process would be in a real setting (e.g. in a studio) instead of in isolation in a laboratory. Thus, an alternative to protocol analysis termed a ‘discourse analysis,’ has been suggested – it uses transcripts of actual interactions involving domain experts and their clients in a real setting (Belkin, *et al.*, 1987).

As there are several important concerns regarding the protocols, it is important for at least two aspects to be considered when performing analyses: (a) the coding scheme must adequately reflect the complexity of the protocol data without distorting it; and (b) the process of coding the protocol must be as objective as possible (Mc Neill, *et al.*, 1999). Typically, the first issue is addressed by a combination of coding categories that are derived from real data collected in earlier studies (Gero & Mc Neill, 1998) and categories that are derived from theories of design.

The second issue is usually addressed by the presence of two (or more) coders and a consensus approach to the final coding result. In this study, only one coder is used, but the objectivity of the coding process is supported by performing two codings of each individual protocol session accomplished at the rate of • 10 days apart, with the consensus results used for successive analyses. Much consideration was given to the selection/adaptation of the coding scheme, further explained in Section 6.3. Additionally, this research employs an integrative approach combining qualitative and quantitative techniques to help addressing some of the limitations of protocol studies, including facilitating more accurate readings.

3.2.2 Introspective, Retrospective Self-Reports and Questionnaires

These self-report methods of collecting data on problem-solving and raising personal awareness of reasoning strategies are similar to protocol studies in a number of ways. They also involve assigning tasks and collecting reports on thinking while, or after, performing them. They are called introspective as respondents are asked to self-reflect on their cognitive processing and verbalize their ‘stream of consciousness’ (Wenden, 1998). There are at least five approaches to introspection as listed by Wallendorf and Brucks (1993). They include: *researcher introspection*, where a researcher provides self-introspection and is the only subject of a study; *guided introspection*, where a group of subjects is asked to provide their reflections about a specific activity or event, usually verbally but also on paper via questionnaires. *Interactive introspection* is used when a researcher and a subject are going through the same life experience, thereby providing a connection that can result in richer, more in-depth descriptions and insights. *Syncretic combinations* of introspection utilise researcher’s introspective reports along with the introspections of other respondents. There is no interaction between them but the researcher’s data is added to the respondents’ and analysed accordingly. The fifth introspection method is called *reflexivity*. It combines participants’ observations with the use of written recordings of a researcher’s thoughts and experiences while s/he studies the respondents.

There is an alternative classification broadly applied in education and psychological studies, where self-reports are divided into *semi-structured interviews* and *structured questionnaires*. A semi-structured interview (also termed an ‘open questionnaire’, an ‘open interview’ or a ‘semi-directed interview’) may focus on a specific skill/ability or activity to extract information about respondents’ views of their skills, problems encountered, techniques or strategies applied to tackle these problems, and their ideas on optimal ways of acquiring specific skills or dealing with learning tasks. It is often the first approach to studying a new domain of research for it allows obtaining data on such aspects of the activity as – global description of the task, its major stages or phases, or the main information sources used. Semi-directed interviews may include or be a part of *retrospective self-reports*, during which participants are asked to think back or retrospect on their learning experience or task-related cognitive processing. These reports are usually open ended, since there are no restrictions applied to what people may say in response to a question or a statement that points to a topic in a general way. A *structured questionnaire*

aims at retrieving the same information, although via constructing explicit questions and statements, and then asking respondents to agree or disagree, write true or false, and so forth.

Similarly to other qualitative methods, intro-, retrospective self-reports and questionnaires are not devoid of dangers and limitations. The main objection is whether they ensure a reliable source of information as the ability of subjects to accurately remember and report their cognitive and emotional states is dubious (Nisbett & Wilson, 1977; Mannell & Iso-Ahola, 1987; Stewart & Hull, 1992). It is uncertain whether they can recall or identify the significant events or stimuli that may cause a change in cognitive or behavioural states, or whether they have access to their own cognitive processes. People may have little awareness or memory of actual events, their own behaviour, or the physical components of the environment (Nisbett & Wilson, 1977; Daniel and Ittelson, 1981; Ericsson & Simon, 1980; Bernard, *et al.*, 1984). Instead, subjects use easily observed or remembered cues to invoke broader cultural or environmental norms (Bradburn, *et al.*, 1987). Similarly, new experiences quickly get generalised, which is the basis for their interpreting, as well as for determining how the event is remembered. Frequent and alike events lead to developing constructed memories and expectations (an assimilation effect). It has been discovered that generic memories are formed which tend to blur together the specific time, location and context features (Strube, 1987; Jobe & Mingay, 1991; Jobe, *et al.*, 1993). Unless specifically probed for, respondents find it easier to skim over the details of an experience and instead rely upon the generic memory. Thus, as the more generic cognitive structures (memories, opinions, stereotypes, etc.) often provide the basis for post factum judgments, verbal reports may represent little more than constructed memories of reports. However, there is no proven method of controlling the boundaries of what is merged into the memory or judgment.

Additionally, earlier questions and answers in a questionnaire or an interview may also bias the recall and report of events and experiences (Bishop, 1987; Schwarz & Sudman, 1992). There is social pressure for one to be logical and consistent, and because of a search for structure many people interpret successive questions as logically connected or related (Clark & Schober, 1992). Thus, early options also set the tone for subsequent choices (Hippler & Schwarz, 1987). Wilson and Schooler (1991) combined questionnaires and introspective self-reports to ascertain whether respondents make decisions or form opinions based on reasons that are unknown to them, but feel compelled to create explanations that sound convincing. They discovered that as people create plausible reasons or focus on certain aspects of a situation, they may start convincing themselves that these were the real reasons that shaped their opinions or decisions. And when given the opportunity to form a new opinion, they may have a new attitude that is more in line with the reasons they constructed than with how they felt in the first place.

Among other concerns, it has also been argued for respondents to have an imperfect memory of memory, where the process of remembering may alter the recollection of events (Koriat, 1993). And for people to have idiosyncratic theories or limited observations of covariation that can both enhance or impair their reports (Wilson & Stone, 1985).

Finally, there is a danger that researchers' bias in some ways can be even greater than that of the respondents. Any researcher with preconceived notions of what respondents may say is likely to find exactly that, simply fulfilling his/her agenda. And while the intention is to look at the participants' perspectives; the questions are unavoidably and dangerously based on the researcher's views of what the subjects may find important in their experience. This 'filtering' of data limits the potential findings and prejudicially influences the insights participants offer.

This study employs this traditional approach of researching design thinking by the means of questionnaires, introspective statements and retrospective reports. Retrospective reports are the main source of data on internal problem solving represented by recorded verbalisations of cognitive processing that occurred during the preceding individual protocol session and served to reinstate the context in which the processing actually occurred (Cantor, *et al.*, 1985). Additional accounts on individual *ability factors* and the use of imagery (where appropriate) were obtained through intro- and retrospective verbalisations guided by a semi-directed interview (i.e. by asking specific, but mostly clarifying questions related to various aspects of design activity) and a questionnaire. Other relevant information, acquired through spontaneous

introspective statements, or introspective claims containing generalisations, was also taken into account. On the whole, it was expected for the reports of designers' activity to correspond reasonably well to other evidence of their activity, such as notes, sketches and observed actions and, where necessary, to help dealing with ambiguous or incomplete data.

There are two main dangers in dealing with introspection and questionnaires that this study tried minimising: (1) getting a pre-formed opinion which may or may not be true, and (2) influencing subjects' opinions and getting a distorted picture by compelling them to create reasons that sound plausible. The researcher was extremely cautious when dealing with peoples' perspectives as representations of reality. The qualitative forms of data collection and analysis were fully understood before being undertaken. Social research, such as in the fields of sociology, social psychology, and social work, provided a well-established tradition of methodology training and a strong literature outlining such procedures (i.e. Stake, 2000, etc).

3.3 Design Product

Section 3.3 is a continuation of the design product discussion pertaining to the final two experiments concerned with observing the process of sketches generation and analysing alternatives, as well as with the assessment of produced design solutions and academic performance. Its purpose is to bring together theoretical and empirical knowledge underpinning this study's method of: (1) identifying drawing strategies that are commonly used by individuals with similar learning styles and/or cognitive abilities, and (2) discovering and elucidating certain characteristics of design drawings that can be associated with individual differences in the ability factors. This section is organised into two subsections.

First subsection contains a summary of the theoretical arguments and experimental studies that became a foundation for an integrative schema of addressing relationships between the design ability and the design process, presented in Subsection 4.2.5. The approach outlined applies to both external and internal representations, since there are no principal differences among the types of data extracted (although via different methods and techniques) and many correspondences in underlying theories.

The second subsection contains a brief overview of the present situation in the domain of design product assessment, including elucidating a number of major evaluation methods and taxonomies that have been considered for application in this thesis (i.e. could enable correlations between the researched ability factors and various characteristics of produced design solutions).

3.3.1 Analysis of Design Drawings

There is almost an infinite amount of aspects to analyse in studies involving sketches. This is, above all, because sketching, unlike language, has no definite and standardised grammar or syntax. Almost any technique is allowed for conveying the intended message: symbols, schemas, perspectives, partial views, annotations, and so on, arranged freely in a two-dimensional setup. There is no universal rule or procedure to follow in designing any particular object and a great variety of patterns and strategies used to generate sketches. As a result, there is an ever proliferating number of research techniques and methodological approaches applied to investigate sketches, but no single general method or easy comparability among the results generated. Thus, this chapter does not attempt at presenting an overview of the empirical field of design drawings, but reviews a number of theories and approaches brought together based on their relevance to the purpose of the present research.

First of all, this thesis distinguishes between two classes of external representations, as it seeks to establish links between them and types of problem solving, as well as the ability factors supporting them. These classes are: (1) graphical representations, further divided into freehand sketches and diagrams, and (2) sentential representations – written ideas and annotations.

Diagrams and sketches

A diagram is a drawing that uses geometric elements to abstractly represent phenomena such as sound, light, heat, wind, and rain; building components such as walls, windows, doors and furniture; characteristics of human perception and behaviour such as sight lines, privacy and movement; and territorial boundaries of space or rooms. Thus, its symbols may represent either objects (e.g., a space or a piece of furniture) or concepts (e.g., service area, a buffer zone, accessibility or noise). A diagram may explore, explain, demonstrate, or clarify relationships among parts of a whole or illustrate how something works (a sequence of events, movement, or a process). It can also express functions, relationships between functions, and the hierarchy of those functions. It omits detailed scale or realistic pictorial representations; it indicates spatial relationships only approximately using indefinite shapes, such as functional spaces in a floor plan as 'bubbles', showing only sizes, adjacencies, containment, and connections (Lockard, 1973; Laseau, 1980; Do & Gross, 2001). Thus, a diagram is an expression in a graphic language that consists of grammatical rules and vocabulary, is made of symbols and is about concepts.

A sketch, in contrast, is about spatial form; it is executed with a finer resolution that indicates attributes of that form. It often comprises repetitive overtraced lines made to explore precise shapes, rather than the intentionally abstract shapes of a diagram, and it uses graphic modifiers such as tone and hatching to convey additional information. There are many kinds of drawings: softline (freehand) and hardline (drafted) schematic drawings, working drawings, as well as different projections (plans, sections, elevations, elevation oblique, axonometric). They can be two-dimensional, for example, a plan or an elevation exploring the proportions of a building. Or three-dimensional, such as a perspective providing information about a scene, specifying the shape of physical elements and visual appearance from some location. Although a sketch falls short of precisely determining positions, dimensions, and shapes, it usually provides a more detailed information than a diagram (Laseau, 1980; Do & Gross, 2001).

Further to this classification, this study distinguishes between four secondary object classes, which are: (1) *two-dimensional sketches* – building views, floor plans, elevations and sections, complete or partial, and (2) *three-dimensional sketches* – perspectives, isometric and axonometric views, complete or partial, (3) *object-diagrams* – diagrams illustrating spaces and relationships among them (i.e. sizes, adjacencies, containment, and connections), and (4) *concept-diagrams* – illustrating concepts (i.e. parts of the preliminary analysis, such as orientation and zoning, functions, and relationships between functions).

It is proposed that diagramming and sketching (their quantitative and qualitative characteristics) may be associated with different styles of problem solving underpinned by individual learning styles and cognitive abilities.

Annotations and written ideas

In addition to graphical representations, this study distinguishes between three types of sentential representations. They include words, phrases or sentences: (1) describing objects; (2) describing concepts; and (2) extending existing, or outlining new design ideas.

Sentential representations are used for different purposes and in different combinations. Among the types of writing that are commonly found in design are: annotations, lists of items (with numbers or bullets), diagram-like placements of keywords, and words that comprise complete sentences. Annotations usually have a function of clarifying or commenting on a sketch, image, or mark (Lawson & Loke, 1997). A list of items is used to record a number of attributes of a certain idea (usually graphical), while a diagram-like placement of keywords is often an abstraction. A statement consisting of complete sentences can either explain ideas more thoroughly or contain newly emerging ideas, though less often. This study suggests that as architects write in the act of designing, words should be considered as a part of the design process along with sketches and diagrams. This is supported by the research demonstrating that there is a relationship between the design quality and the use of words (Wong & Kvan, 1999).

An *object-annotation* is a written note, specifying, describing, or defining an object, a group of objects, relationships among objects, and physical properties of objects (including size, shape, materials, colours, etc). They can also be used to specify certain properties of a relation between two objects, such as a distance from A to B, proximity or alignment.

Concept-annotations are used to describe zones, functions, relationships between functions, or characteristics of an object that cannot be (easily) formulated graphically (such as ‘privacy’, ‘good view’, ‘noisy’, or affective comments – ‘gloomy’, ‘nice feel’, etc).

Idea-annotations are sentences used for (a) commenting on a sketch or a diagram, or (b) as a records of ideas that, for some reason, could not be expressed graphically. The first type can be associated with vertical progression of a design – as it further develops, or adds details, to the already existing idea or drawing (i.e. ‘studio needs more space’, or ‘trees can be planted along this road’). The second type is more independent as it is used for noting down newly emerging ideas which can be associated with lateral design (or sketch) development (i.e. ‘swimming pool somewhere here?’, or ‘more light upstairs, move study room ([there]’).

It is proposed that extensive/redundant annotating could be correlated with verbal and visual learning styles respectively, whereas its other characteristics could also be linked to the Wholist-Analytic dimension and individual cognitive abilities.

External and internal representations

It is known that processes involved in the reasoning include those that operate more or less exclusively within the realm of external representations (e.g. in diagrammatic reasoning systems), those that operate on mental representations (such as in mental image inspection), and those that involve both mental and external representations (e.g. when reading an information item from a sketch and then using it in mental reasoning). For the latter group of processes, two types of functions can be idealized, doubling in number by assuming internal and external perspectives: (1a) the external representations are constructed during the reasoning task and serve as externalizations to the mental reasoning processes. As such, they constitute a sort of graphical notes. (1b) the external representations provide information input to the construction of mental representations and to mental reasoning processes. (2a) the mental representations are constructed during reasoning on an external representation and they serve as temporary abstractions in extent, level of detail, or quality from the external. (2b) mental reasoning on these abstractions can lead to modifying the external representations (Goldschmidt, 1995; Purcell & Gero, 1998; Vertijnen, *et al.*, 1998).

Clearly, in order to explore the complexity of design thinking one shall focus on the above processes and interactions among them. However, researching the interplay between mental imagery, sketching and verbal reasoning is a demanding task to undertake, that exceeds the scope of the current research. Alternatively, this thesis concentrates only on those types and qualities of external and internal cognitive processing (occurring consecutively or simultaneously) and representations that allow establishing initial tentative links with underlying individual cognitive abilities and learning styles.

External and internal representations in design process

In recent years attempts have been made to capture and store certain elements of the sketching and thinking processes using a number of different methods and techniques (Lakin, 1989; Hwang & Ullman, 1990; Fergusson, 1992; Gross, 1996; Eisentraut & Günther, 1997). Below is an illustration of two principal approaches that are conceptually inter-related; they allow connecting the development of design ideas, expressed verbally in introspective reports, and graphically – by sketching, to individual differences in learning styles and cognitive abilities.

Vertical versus horizontal sketch development

One of the most detailed studies of the act of sketching was conducted by Goel (1995). He identified two types of operations occurring between successive sketches in the early stages of design, namely *lateral* transformations and *vertical* transformations. In a *lateral* (or horizontal) transformation, movement is from one idea to a slightly different idea. In a *vertical*

transformation, movement is from one idea to a more detailed and exacting version of the same idea. This study explores relationships and correlations between sketch transformations, the product, and the ability factors. This includes correlating the estimated number of horizontal transformations with ideation abilities and relevant measures of the product assessment, and the two types of sketch development – with individual learning styles. It also correlates it with various characteristics of design thinking reflected in verbal reports.

Divergent and convergent reasoning

According to creativity and design research (Osborn, 1963), design activities in conceptual design contain two kinds of steps – divergent and convergent. Divergent phase focuses on idea production; it is a phase where alternatives are generated and explored, i.e. it relies on lateral thinking characteristic of wholistic approach. Convergent phase focuses on idea evaluation; it is a refining and detailing phase, characteristic of analytical vertical approach. Linked to the two phases are two kinds of problem solving behaviour – divergent and convergent thinking. Divergent thinking is characterized by ideation and fluency with unusually associated ideas; it moves away from the known and predictable. Conversely, convergent thinking progress toward the production of a single, right answer to a problem, and is a style of thinking characterized by a logical, analytical approach to problem-solving. It moves toward the known and specified.

In addition to exploring design sketching and design thinking that manifest themselves in divergent and convergent problem solving, and vertical and horizontal transformations, this study utilises several other categories and approaches that can be linked in a similar conceptual manner. Their detailed scheme is presented in Section 6.1 of the empirical part of this study.

3.3.2 Design Product Assessment

The subject of design product assessment is complex. Numerous methods and taxonomies have been suggested in past for the use in different areas of professional design, architecture and engineering, for research purposes, and for the evaluation of student designs in education.

In the professional design industries, the dimensions of the design product assessment typically include three main parameters: originality (creativity and novelty), usefulness (appropriateness and usability), and customer appeal. Different techniques exist for evaluating products based upon these definitions; however, due to their subjective nature, many of these techniques suffer from a lack of discriminant validity among the attributes they propose to measure. Their poor ability to differentiate creative, useful and appealing products from the less creative, useful and appealing often undermines the results of their application (Miller, 1956; Getzels & Jackson, 1962). Additionally, the relative importance of each dimension changes depending on the domain and the context of use.

Creativity as an attribute of the product

The product perspective of the *Four P's* frames creativity as a property of products and examines what causes creative products to be different from more mundane products. Studies that develop and use lists of properties to separate creative from non-creative products represent an important step in the evolution of creative assessment, but they frequently offer different definitions. For example, creative products are novel and appropriate to an open ended task (Amabile, 1987), are adaptive to reality and serve to solve a problem, fit a situation, or accomplish some recognizable goal (MacKinnon, 1962), are uncommon (Barron, 1955), are unusual, appropriate to the situation, transform the constraints and boundaries of the situation, and have high condensation power (Jackson & Messick, 1965).

Usefulness and usability as an attribute of the product

Appropriateness or *usefulness* is another obvious criterion – it implies that the product must yield a workable solution to some relevant problem (Cooper & Kleinschmidt, 1987). Whilst the

quality that appears much less often in the assessment taxonomies is related to the user experience with the product. It is a function of the product usefulness or the value the product offers users, that is, its *usability* or the ease with which users are able to achieve their goals (Rosenbaum, *et al.*, 2000). As a result, many products that are today in the market (or systems that are in use) represent poor levels of usability or the lack of user-centred aspects in their designs (Bloomer & Wolf, 1999; Rosenbaum, *et al.*, 1999; Anderson, 2000).

Customer appeal as an attribute of the product

Another central goal of designing is to create products that appeal to the end user, showing how attractive or stimulating they are to use. The recent literature on the new product success suggests that two key drivers of customer appeal are, often, a combination of the above two dimensions, i.e. how useful and original it is perceived to be (Rosenbaum, *et al.*, 2000). Designs that are useful to the end user i.e. satisfy their needs, are more appealing (Cooper & Kleinschmidt, 1987; Pugh, 1996). Originality is also expected to influence customer appeal (Angelmar, 1990).

In the design research domain, there have been a number of attempts to create evaluation systems that could be adapted to different design disciplines (from interior and product design, to architecture and engineering) and education. One of the most recent multidimensional frameworks is the Consensual Assessment Technique (CAT, Amabile, 1996) developed to measure creativity, novelty and appropriateness of the design product. The artefacts are typically rated by several judges on up to twelve dimensions, including: creativity, novelty, originality, complexity, technical merit, functionality, craftsmanship, artistic merit, thematic expression, appropriateness of solution, aesthetic appeal and liking. A consensus of opinions is then achieved via the means of statistical analysis.

Design product assessment is the rather fragmented and underdeveloped area of quality learning in design, architecture, engineering, and technical graphics education. There, evaluation taxonomies are the most complex and diverse as they are subdivided into the cognitive, affective and psychomotor domains. They are typically created for particular fields of instruction in order to model the content and goals of that field (Imrie, 1995). The more detailed educational classification systems are hierarchical and reflect a great number of elements or aspects that students have to learn in a studio or a subject. Some of these taxonomies may offer a useful method for the future assessments of design products in relation to individual design abilities, as they (classification systems) are a reflection of cognitive abilities, styles, strategies, skills and knowledge students are expected to possess or learn.

This study integrates several dimensions from the assessment frameworks used in design research and quality learning into a single approach (further explained in Subsection 4.2.6). It aims at evaluating a number of characteristics of design drawings that seem to correspond well to the measured ability factors to, then, enable the exploration of relationships and correlations between the *input* and the *product*.

Chapter 4. Method & Experimental Design

Chapter 4 contains a synopsis of this study's methodological approach and experimental design. It elucidates its research plan, data-collection and assessment techniques and research method. The choice of *ability factors*, the selection and application of psychometric tools, assessment techniques, evaluation taxonomies and types of applied analyses are further explained.

Student samples and experimental structure

This thesis contains descriptions and analyses of the two student samples who have participated in two different sets of experiments. The first and the earliest sample consisted of 60 design and architecture students from years 1, 3 and 4-5 (20 in each respective subgroup) who were administered Experiment I/a (cognitive abilities assessment) in groups of around 10 people. Additionally, individual ratings/judgements of academic performance were obtained from their course supervisors via Experiment III/a.

The second student sample is the most recent. It contains 20 design and architecture students from the first and fourth-final years of study (10 in each respective subgroup). They have participated in the full set of six experiments which were administered individually in a sequence (I-II-IV-V). For the purpose of clarity and convenience, this second set of experiments corresponding to the second sample is marked by letter 'b' (i.e. Experiment I/b through to VI/b).

4.1 Cognitive Abilities Assessment

The first experiment is represented by a set of tests administered to two student samples and aimed at assessing a selected number of individual cognitive abilities chosen on the basis of: (a) their being relevant to the design ability as suggested by design research literature (Bernstein, 1988; Cross, 1992, 1995; Löwgren & Stolterman, 1998); (b) being associated with imagery's properties (Finke, *et al.*, 1992); (c) believed to have a significant influence on problem solving and domain performance, as reported by many authors from different research areas (Chronbach 1970; Ghiselli, 1973; Sawyers & Canestero, 1989; Alias, *et al.*, 2002; Shea, *et al.*, 2001, etc); and (d) present in the CHC taxonomy and being reliably quantifiable (Carroll, 1993).

Dimensions of assessment

Visualisation (Vz) or the ability to apprehend a spatial form, object, or scene and match it with another spatial object, form, or scene with the requirement to rotate it (one or more times) in two or three dimensions. Requires spatial thinking, comprehending the interior structure, recognizing how to combine parts together and the ability to mentally imagine, manipulate or transform objects or visual patterns and to predict how they would appear under altered conditions (e.g., parts moved or rearranged). It has also been described as "an ability to comprehend imaginary movements in three-dimensional space or the ability to manipulate objects in the imagination" (Michael, *et al.*, 1957, p.188). It differs from *Spatial Relations* primarily by a de-emphasis on fluency. In Carroll's (1993) analysis, more than 800 variables have salient loading on this factor. Most engineering, architectural and geometric problems involve visualisation. Usual marker tests for Vz are classified in six categories: Paper Form-board tasks, Block tasks, Block Rotation tasks, Paper Folding tasks, Surface Development tasks, and Perspective tasks (Eliot & Smith, 1983).

Spatial Relations (SR) requires speeded rotation or reflection of relatively simple spatial forms, and represents "the ability to solve simple rotation problems quickly, by whatever means" (Lohman, *et al.*, 1987, p.267). This factor has also been called spatial orientation (Carroll, 1993); it includes the ability to perceive spatial patterns accurately and to compare them to each other with regard to a speed of responding (McGee, 1979). SR may also require the identification of an object when viewed from different angles or positions. The best markers fall under the category of Figural Rotation tasks as described by Eliot and Smith (1983), and Spatial Orientation (SO) tests (French, 1951; Lohman, 1987).

Visual Memory (MV) is the ability to form and store a mental representation or image of a visual shape or configuration, to remember its location and orientation during a brief study period, and then recognize or recall it later, during the test phase. There are many studies that argue for visual memory to be more than a result of the pictorial test content but to involve cognitive processes different from those used in other memory factors (Ekstrom, *et al.*, 1976, Carroll, 1993). Other research suggests there may be sub-factors to visual memory (Ekstrom, *et al.*, 1976; Carroll, 1993; Rensink, 2000; Hollingworth & Henderson, 2002). Space limitations do not allow for the detailed description of *MV* theories, nor is such understanding necessary in the current context. In this study, visual memory is treated as an independent unidimensional phenomenon, without much concern given to its place within the CHC taxonomy or in relation to higher-order constructs. It will, though, be linked to other stratum II factors as it is possible for the more complex *Gv* abilities (such as *Vz* and *SR*) to be partially dependent on, and supported by, *MV* (Juhel, 1991). In architecture, visual memory is used in a wide range of tasks, including mental transformations of visual information based on visual image retention, such as the translation of measurements into plans, elevations and development from isometric or pictorial drawings. Usual marker tests for *MV* are classified in four categories: Shape Memory, Building Memory, Map Memory tasks (Ekstrom, *et al.*, 1976), and the Rey-Osterrieth Complex Figure test (Rey, 1941; Osterrieth, 1944).

Spatial Scanning (SS) requires the ability to quickly and accurately visually explore a wide or complicated spatial field/visual pattern and identify a particular configuration (path) through it, usually by visually following the indicated route. It is a much less developed area of research, as *SS* measures have mainly been used to determine the extent to which they predicted success in acquiring information from maps and graphs (Allen, *et al.*, 2000), wayfinding (Allen, 1999, 2003; Kirasic, 2000), and navigating through complex electronic information fields (Allen, 1998). This study is interested in spatial scanning largely because it is regarded as one of the elementary and purely spatial abilities, related to the ability of people to derive meaning from spatial representations. This is different from visualization or other more complex *Gv* abilities, which have salient loadings of a great number of variables, are interrelated and often show inconsistent results in the execution of different components (Carroll, 1993). Thus, the rationale for measuring *SS* is (a) test takers are less likely to utilise a number of different strategies for arriving at correct answers, and (b) spatial scanning has low factor loading. Correspondingly, establishing correlations between the measurements of spatial scanning, the process and the product, may prove more direct and accurate, and the interpretation of results more convincing. In architecture, spatial scanning is involved in a wide range of tasks, from reading maps and plans, to scanning printed material for comprehension, and to 'walking through' imagined or depicted constructions. The most popular *SS* markers fall under the category of Maze Tracing, Choosing a Path, and Map Planning tasks (Ekstrom, *et al.*, 1976).

Associational Fluency (FA) is a highly specific ability to rapidly produce a series of words or phrases associated in meaning (semantically) when given a word or concept with a restricted area of meaning. In contrast to *FI*, quality and speed rather than quantity of production is emphasized, which may be a more important ability for architects or designers to possess. Carroll (1974) points out that associational fluency entails search of a major portion of a long-term memory lexicosemantic store, with special attention to its semantic and associational aspects, i.e. there is a relationship between *FA* and memory factors. The best markers fall into three categories of tasks as described by Ekstrom *et al.*, (1976): Controlled Associations, Opposites and Figures of Speech.

Expressional Fluency (FE): is the ability to rapidly think of and organize words or phrases into meaningful complex ideas under general or more specific cued conditions. It requires the production of connected discourse in contrast to the production of isolated words (e.g., *FA*, *FW*). It differs from *FI* in the requirement to rephrase given ideas rather than generating new ideas, but may be a verbal version of *FO* factor. Like associational fluency, expressional fluency also involves a search of lexicosemantic memory, but with special attention to the grammatical features of lexical items and different syntactical patterns of phrases and sentences (Carroll, 1976). Usual marker tests for *FE* are classified in three categories: Making Sentences, Arranging Words, and Rewriting (Ekstrom, *et al.*, 1976).

Figural Fluency (FF) requires the ability to rapidly draw or sketch as many things (or elaborations) as possible when presented with a meaningful visual stimulus (e.g., set of unique visual elements). Quantity is emphasized over quality or uniqueness, that is speed and success in giving figural responses to specified tasks. Variables loaded on this ability are diverse, covering several other primary factors in the domain, including Vz (Carroll, 1993), and differentiated from FI, FW, FA, FE and FO factors. Usual marker tests are Ornamentation, Elaboration and Symbols tests (Ekstrom, *et al.*, 1976); Make a Figure, Make a Mark and Sketches tests (Guilford & Hoepfner, 1966); and Design Synthesis and Form Completion (Bereiter, 1960). Three FF tests are used in the present study, of which the symbols test could also be an originality factor (Ekstrom, *et al.*, 1976), or a figural form of associational fluency.

Figural Flexibility (FX) is an ability to rapidly change set and try-out a variety of approaches to solutions for figural problems that have several stated criteria. It requires fluency in successfully dealing with figural tasks via a search for relevant hypothesis in long-term memory and the performance of serial operations (Carroll, 1976). FX is well differentiated from FI, FW, FO and FF factors. It may have visual perception, visualisation and reasoning components, or may indicate an ability to be flexible in adopting and changing hypothesis and mental sets about figural and spatial problems. Usual marker tests for FX are classified in five categories: Mark Match Problems, Planning Air Manoeuvres (Guilford & Hoepfner, 1966); Toothpicks, Planning Patterns and Storage tests (Ekstrom, *et al.*, 1976).

Method of assessment

There is a significant number of psychometric tools developed for the assessment of different aspects of human cognition. Influential methods of ability factors tests for adults can be found in several editions: (1) in the early *Primary Mental Abilities Tests* (PMA; Thurstone, 1938; Thurstone & Thurstone, 1941) which does not include a general factor of intelligence but posits that the intellect is composed of seven primary mental abilities; (2) in the *IPAT Culture Fair Intelligence Scales* by Cattell and Cattell (1957) that contains *Comprehensive Ability Battery* (CAB) measuring 20 primary cognitive abilities, including general reasoning; (3) in Guilford's *Structure of Intellect Tests* (SOI) by Guilford's Laboratory (Guilford, 1967, 1981; Guilford & Hoepfner, 1971) assessing 120 different intellectual abilities, emphasizing cognitive processes and products of cognition, excluding *g* factor; (4) in the *Kit of Factor-Referenced Cognitive Tests* by Educational Testing Service (ETS kits; French, *et al.*, 1963; Ekstrom, *et al.*, 1976) containing 72 tests that have been demonstrated to be consistent markers in studies of 23 cognitive factors, including general reasoning; (5) in the *Differential Aptitude Test Battery* (DAT) measuring eight areas, including reasoning abilities and distinguishing between *Gf-Gc* factors (Bennett, *et al.*, 1975); (6) and in the most recent *Woodcock-Johnson (WJ) III Tests of Cognitive Abilities* (2001) based on the Cattell-Horn-Carroll (CHC) theory of cognitive abilities, containing 20 hierarchically organised tests, including *g* factor. There is literature concerning each of these assessment tools claiming it was possible to demonstrate the empirical validity of the measured factors by means of factor analysis (i.e. Meeker, 1969, 1975; Hakstain & Cattell, 1982; Sternberg & Bhana 1986; Nijenhuis, *et al.*, 2000, etc), along with studies that dispute their validity and reliability (for example, McGrew, 1986; Flanagan, 2000).

The major problem in the area of abilities assessment is the lack of evidence on the relation between factor-analytic models. Abilities have been defined and evaluated in such a variety of ways – it is difficult to be precise about the meanings of used concepts. New types of testing need being developed (Carroll, 1997). There are only a handful of studies that empirically explore the dimensionality of ability domains by comparing existing test batteries and performing cross-validation through a confirmatory factor analysis (CFA) to verify they measure common factors. There is no sufficient evidence regarding the levels of correspondence among the results (assessments) these tests generate. The most prominent study that establishes the concordance of cognitive factors present in several (1st, 2nd, 3rd and 4th from the above list) models remains Carroll's (1993) survey relating factorial findings to theories and findings of cognitive psychology. There is also a clear lack of research confirming or, even, positing which factor models or test batteries work best in predicting achievement in design or architecture or yield strong(er) correlations with the performance on design tasks.

Thus, our decision to employ the ETS kit of reference tests for factorial studies (Ekstrom, *et al.*, 1976) is based on three major considerations: (1) the *Kit* is, probably, the most empirically validated set of specific tests, intended primarily for research use (further explained in Section 5.1), (2) it contains tests of abilities equivalent to cognitive factors as described by the CHC theory of intelligence, and (3) it was profoundly analysed by Carroll (1993) in his survey of factor-analytic literature.

Method of analysis

Quantitative – represented by a series of statistical analyses following data extraction, then followed by the results interpretation.

4.2 Learning Styles Assessment

The second experiment is another set of tests administered to the second student sample only. It aims at assessing individual positions on two dimensions of individual learning styles – Wholistic-Analytic and Visual-Imagery, chosen on the basis of (a) their being relevant to the design ability as suggested by design research literature (Bernstein, 1988; Cross, 1992, 1995; Löwgren & Stolterman, 1998), and (b) believed to have a significant influence on general problem solving and domain performance, as reported by many authors from different research areas (Cross & Nathenson, 1981; Pask, 1988; Borg & Shapiro, 1996; Lawson, 1990, 1997; Sternberg & Grigorenko, 1997; Ziegert, 2000; Durling, 2001).

Dimensions of assessment

There are three interrelated research areas that informed the type and the range of investigation dimensions in this study of learning styles. Firstly, there is research by Riding (Riding & Cheema, 1991; Riding & Douglas, 1993), whose comparative analyses allowed to cluster many cognitive and learning styles into two principal families, or two groups of qualitatively different types of thinking (reviewed in Subsection 3.1.1).

The first cognitive style group is Wholist-Analytic (W-A). It determines two different types of thinking. Analytic thinking relies on logical sequences and vertical reasoning, structured approaches to decision-making, and systematic methods of investigation. Wholist thinking relies on impulsive synthesis and lateral reasoning; rapid, open-ended approaches to decision-making, and random methods of exploration (Zeleny, 1975; Lynch, 1986). The second group is Verbal-Imagery (V-I), thought to be independent of the superordinate Wholist-Analytic dimension (Riding *et al.*, 1993). It determines whether an individual is inclined to represent information during thinking verbally, or in mental images, which is supported by two distinct cognitive subsystems (Riding & Cheema, 1991). This dimension has two basic effects: (1) how information is represented, i.e. verbally or visually, and (b) internal/external focus of attention, related to sensory modalities.

Linked to the above is the brain lateralisation research and design studies. First argues that temporal, sequential, analytic and verbal functions are associated with the left hemisphere of the brain. While, spatial, wholistic and synthetic functions are thought to be associated with the right hemisphere of the brain (West, 1991). In other words, the theory suggests there may be a connection between visual and wholistic thinking, and between verbal and analytic thinking. Similarly in design studies, the designers' reasoning is thought to be right brain-hemisphere dominant characterised by a distinct wholistic, visual approach, which is high on imagery (Lawson, 1990, 1997; Durling, 2001), contrasting sharply with the more convergent, analytical approach which is typical of science and technology.

Finally, there is research by Pask (1988) demonstrating that there are fundamentally different ways in which complex learning situations are approached by students. There are several ways of learning the same material and reasoning on similar tasks, which can be broadly characterised in terms of whether the student treats the material as a whole, later filling out the

structure of the situation with detail, or whether the learner prefers to focus on the particulars of the presented material, and gradually building up an overall sense of the situation. Pask has also shown that an individual's learning style determines, for a given task, which approach will be taken towards the new learning or problem-solving situation. And, although approaches can vary according to the task, most students are fairly inflexible in dealing with novel problems, demonstrating learning deficiencies that limit strategy application. Thus, the learning style is a subject of fundamental importance in the process of problem solving.

Method of assessment

This study utilises a model (re)designed by Dunn and Prashnig in 1991-2001. The *Learning Style Analysis* (LSA, 2001) claims to accurately identify how the test-takers learn, how they think, concentrate, solve problems and can best master their learning activities; it advises senior students and adult workers how to utilize personal preferences for future studies, work or career planning. It is based on a well-known and complex model by Ken and Rita Dunn (1978) of St. John's University, New York, who have isolated five different factors in their pioneering work on learning styles: environmental, emotional, sociological, physiological and psychological. Their model traces its roots to two distinct theories – Cognitive Style Theory and Brain Lateralization Theory. It identifies conditions external to the learner as well as factors that affect a person's ability to manipulate information. The Dunn and Prashnig model evaluates a respondent's biophysical makeup and several learning style elements across six key areas: Brain Processing, Sensory Modalities, Physical Needs, Environmental Preferences, Social Aspects and Attitudes. The present study limits itself to researching two major groups of factors: Brain Processing (Wholistic-Analytic) and Sensory Modalities (Verbal-Imagery).

This particular instrument, however, hasn't been utilized extensively in the design research. The two models that have been popular for many years, and we considered using, are the Riding's Cognitive Styles Analysis Test (1991), and the Myers-Briggs Type Indicator (1975). The CSA assesses individual performance on two bipolar dimensions based on the ratios of reaction times in different conditions. Verbal-Imagery cognitive style, or the way in which an individual tends to represent knowledge – in mental pictures or words; and the Wholist-Analytic cognitive style, i.e. the way in which an individual tends to organise information – in parts or as a whole. It has been argued that the CSA is a better approach to measuring cognitive styles since it directly evaluates task performance, as opposed to questionnaire approaches that evaluate strategies manifested by the underlying style (Riding & Rayner, 1998; Riding & Sadler-Smith, 1992). The test is typically completed electronically, has been in use for a number of years and has accumulated considerable empirical support. Though there is little evidence of published literature in the field which demonstrates its reliability⁴. The authors of the instrument mainly provide references to numerous studies, supporting the construct validity of the four dimensions as assessed by the CSA (Riding & Rayner, 1998). There are studies, however, that suggest that the Group Embedded Figures Test (*GEFT*, used as a part of the geometrical component of CSA) is not particularly satisfactory as a measure of Wholist-Analytic dimension since it is related to spatial ability (Goldstein & Blackman, 1978; Mac Leod, *et al.*, 1986). This issue had to be avoided, as we were not interested in discovering correlations (between the measurements of cognitive styles and spatial abilities) that could be attributed to the type of psychometric instrument used. There are also concerns regarding the textual part of the instrument as well as the manner of presenting instructions⁵ (Bull & McCalla, 2002).

The main reason, though, for choosing a different assessment tool is because the construct of cognitive style or "individual's preferred and habitual approaches to organizing and representing information" (Riding & Rayner, 1998) can be rather limiting. As thinking styles in

⁴ Recent research argues CSA is not sufficiently reliable on both W-A and V-I dimensions (Peterson, *et al.*, 2003a; 2003b; Coffield, *et al.*, 2004).

⁵ They relate to the choice of some of the comparisons in true/false judgement of appearance and conceptual category statements. Test takers have reported assessments on individual items to be 'unfair' and some of the instructions for the geometrical section confusing (Bull & McCalla, 2002).

design are usually learned, socialized and developed in interaction with others, they are likely to be explained better by the properties of individual learning styles, which are at the median between studies of cognition and studies of practices. Also, as learning styles are not bipolar dimensions, unlike cognitive styles, entailing many elements that usually are not 'either-or' extremities, they provide a richer, and possibly, more relevant source of data for analyses. Thus, it was important to choose an instrument that could measure and distinguish between the levels of the learning styles' strengths or preferences – to enable a better accounting for the problem-solving behaviour on design tasks.

One of the most popular models of learning styles has been the Myers-Briggs Type Indicator (MBTI). It is based on Jung's theory of psychological types (Jung, 1923). Preferences in the four dimensions of: extraversion-introversion, sensing-intuition, thinking-feeling, and judging-perceiving, are used to characterise people according to sixteen types. There have been numerous correlational studies that demonstrated the behaviours and attitudes which the MBTI appears to tap, suggesting a strong argument for construct validity (Myers & McCaulley, 1985). However, this tool examines personality types rather than learning styles. Although certain dimensions of this model have been linked to particular learning styles, its primary use is not in that area. More importantly, though there is a way of connecting MBTI types to Wholistic-Analytic cognitive family, the instrument does not provide any information on the Verbal-Imagery mode. There are hardly any empirically validated learning style models that integrate all four modes in one assessment tool, but mostly short self-report inventories, criticised for being highly subjective reflecting nothing but a test-taker's self-image (Coffield, *et al.*, 2004).

There is also a proliferation of other instruments, as the field of learning styles research is characterised by a very large amount of small-scale applications of particular models to small samples of students in specific contexts. There are more than 100 presently known labels, 13 of which can be categorised as major. This has proved especially problematic in our search for the evidence of the impact of learning styles on academic performance and problem solving, since there are very few robust studies which offer reliable and valid empirical support and clear implications, based on large-scale samples. At the same time, even the most prominent instruments have been criticized not only for their lack of adequate empirical validation but for weak theoretical foundations and contradictory approaches. Conflicting assumptions about learning underpin mainstream ideas about learning and the best-known models of learning styles (Coffield, *et al.*, 2004).

Considering these issues, the Dunn & Dunn model (LSI) redeveloped by Prashnig and Dunn (LSA), appeared as one of the most suitable in terms of meeting the research objectives and matching against the minimal criteria of internal consistency and predictive validity (Coffield, *et al.*, 2004). As this study is only concerned with the four dimensions as assessed by the CSA, the construct validity of the chosen model is a subject of the extensive study by Riding & Rayner (1998). There is still a lack of research concerning the Dunn and Prashnig instrument's reliability but a lot of accumulated empirical support covering many fields. This contrasts the situation with the earlier Dunn & Dunn model which has received extensive scientific validation (Dunn, *et al.*, 1989, 1995). There are, however, no principal differences between the two labels (i.e. LSA and LSI) both in terms of their theoretical underpinning and the type and structure of psychometric measures, with LSA claiming to avoid making simplistic connections formerly criticized in the Dunn & Dunn model. The final decision upon choosing LSA was influenced by the fact that its' results (indicating strong preferences) did not disagree with the CSA scores on all four dimensions reported by several independent test-takers who had taken both tests.

Method of analysis

Quantitative – represented by a series of statistical analyses following data extraction, then followed by the results interpretation.

4.3 Analysis of Protocol Sessions

Experiment IV/b is individual design sessions concerned with the conceptual phase of solution development. The method of protocol analysis is used as a means of revealing and elucidating cognitive processing that takes place during sketching and thinking. It examines how design contexts and intentions are embedded in design drawings along with analysing designers' reasoning reflected in retrospective verbalizations. And, as neither internal reasoning nor mental images could be observed directly, and the acquired data is either inferred or (re)constructed in retrospect, in this study, they are not entirely separated from the external representations and their functions in problem solving. Rather, all sources of information are adjusted to supplement each other to facilitate interpretations or help in dealing with ambiguous or incomplete data.

Dimensions of analysis

Table 4 contains a summary of the issues tackled by protocol analysis and the types of data extracted from internal and external representations.

Table 4. Summary of the areas of applied analysis

External representations				Internal representations			
(I) Analysis of external and internal representations as an <i>object</i>							
Analysis of Design Drawings and Annotations							
Sketches		Diagrams		Ideas		Words	
Observable characteristics associated with learning styles & cognitive abilities							
2D	3D	Co	Ob	IA(v)	IA(h)	Co	Ob
Complexity				Ideas versus words			
Visual-spatial & Ideational abilities							
Analysis of external and internal representations as a <i>process</i>							
Analysis of Design Drawings and Annotations				Analysis of Retrospective Reports			
Sketches & Diagrams		Idea-annotations		Visual processing		Verbal processing	
Problem solving associated with learning styles & cognitive abilities							
Preferred mode/s of designing							
Graphic		Sentential		Imagery		Verbal	
Imagery-Verbal		Imagery-Graphic		Imagery-Sentential		Verbal-Graphic	
Verbal-Sentential							
Initial approach / macro level							
Wholistic		Analytic		Imagery		Verbal	
Prevailing approach / macro level							
Wholistic		Analytic		Imagery		Verbal	
Structure of design processes / macro level							
Wholistic		Analytic		Imagery		Verbal	
Strategies in problem-solving / second grade level							
Development of external representations				Development of internal representations			
H / V		IA(v) / IA(h)		Wholistic, Analytic, Imagery, Verbal, visual-spatial and ideation abilities			

Co – concept-diagrams / annotations; Ob – object-diagrams / annotations; IA(v) – idea-annotation vertical; IA(h) – idea-annotation horizontal; W-A – Wholistic-Analytic; V-I – Visual-Imagery; H – Horizontal sketch development; V – vertical sketch development;

The applied approach is further explained in Sections 6.1, 6.2 and 6.3 of the empirical study. Section 6.1 explains the protocol analysis progression according to the issues addressed. Section 6.2 explores qualitative and quantitative characteristics of *generated* diagrams, sketches and annotations, as well as of *proto-/metacognitive statements* from introspective reports and questionnaires in relation to individual learning styles and cognitive abilities. Section 6.3

addresses qualitative and quantitative characteristics of diagrams, sketches and annotations *being generated*, as well as of retrospective reports and questionnaires denoting the *progression* of problem solving, in relation to ability factors. It contains a description of the applied coding scheme, supported by examples from protocol materials.

Method of analysis

In accordance with the protocol study guidelines, i.e. after administering experiments and collecting data, the analysis was performed in four steps: (1) transcribing protocols, (2) parsing segments, (3) encoding raw protocols using the suggested coding scheme (Section 6.3), and (4) analysing encoded protocols. The analyses were then followed by the data interpretation.

4.4 Analysis of Introspective Reports and Questionnaires

Experiment V/b involves collecting introspective statements (spontaneous, as well as acquired via semi-directed interviews) and questionnaires from the participants of the preceding protocol studies. It is, primarily, a supplementary source of data, helping to (a) clarify ambiguous processes and actions from the records of administered design sessions, and to (b) provide additional accounts of the student's design abilities and problem-solving strategies. It is, thus, analysed in association with other datasets.

Dimensions of analysis

The major function of introspection and questionnaires in the present research concerns the distinction between task-specific strategies (revealed by retrospective reports) and higher-order strategies. Cognitive, or preferred learning, styles have been argued to be more strongly associated with the latter than the former (Martinsen, 1995; Sternberg, 1997). That is, styles should be more consistent across tasks and over time than task-specific learning strategies, as they are associated with metacognitive reasoning executed in planning, monitoring or global approaches to problem-solving situations. It was, therefore, expected for the information on learning styles to be obtained through introspective reports and questionnaires as well as spontaneous introspective claims containing students' generalisations describing their habitual ways of designing. Generally, they are statements of metacognitive theories – beliefs that people have about their cognitive processes, rather than memories of specific cognitive activities revealed by other, more spontaneous, aspects of retrospective reports. Their role is in providing the basis for the strategic choices that people make when undertaking complex cognitive tasks such as design. A more conscious choice of strategy is, evidently, a significant factor that shall be separated from other aspects of retrospection, concerned with particular cognitive events.

In addition to the information on individual learning styles and strategies, it may be possible to extract information on students' cognitive abilities, which may, in turn, be correlated with the data on lower-order task-specific cognitive strategies and the *input*. It is, though, understood that a large body of empirical research that has relied on introspective reports of imagery ability, has failed to find any consistent relationship between visual imagery and spatial abilities (Richardson, 1977; 1983). And that factorial studies of imagery ability claim for the subjective qualities of imagery as measured by self-report techniques to be unrelated to spatial test performance (Di Vesta, *et al.*, 1971; Kosslyn, *et al.*, 1984; Brown, 1984; Poltrock & Agnoli, 1986; Burton, 2003; Burton & Fogarty, 2003) and, therefore, to many of the cognitive abilities researched in the present study. However, the present study is not concerned with direct comparability – it illustrates aspects of the association between self-reports and spatial and ideation abilities that help establishing the grounds for finding some commonality. It only considers those reported items that are similar to the ones involved in the 'objective' psychometric tests; they describe/refer to the students' concrete cognitive abilities and not their metacognitive beliefs concerning personal aptitudes (further explained in Subsection 6.2.4).

Thus, the overall purpose of introspection in this study is to: (1) ascertain whether the behaviour of participants' observed during protocol sessions could be regarded as typical or habitual, (2) enable the distinction between task-specific aspects of problem-solving and the

global approaches to problem situations, (3) provide supplementary accounts of the students' learning styles and abilities, and (4) explore relationships and correlations among them.

Introspective statements and questionnaires also play a part in the design product assessment – they provide information on the participants' experiences and capabilities to facilitate better judgements on the evaluation parameters. For example, self-reports were examined prior to evaluating creativity of design solutions to help understanding whether they involved a retrieval or an adaptation of the formerly seen cases, whether they emerged as complex transformations or a synthesis of remote ideas, involving associative thinking, or other. Finally, there is also a potential academic role in using introspection. It has been argued for self-reports to be a means of raising awareness of individual strategies, and the need for constant evaluation of techniques, goals, and outcomes to result in the improvement of problem solving and academic performance (Wenden, 1998). This study discovered no evidence of the students' former purposeful exposure to these techniques. However, the degrees of self-awareness of cognitive processing and the use of imagery varied considerably, as well as resulting from it quality and quantity of introspective claims made. Thus, the role of introspection as a personal skill, innate or developed, was also taken into account.

Overall, as the data extracted from introspective reports and questionnaires is aimed at providing additional accounts concerning individual learning styles and cognitive abilities, reported in the form of metacognitive and other statements, separate and as a part of problem solving, analysis dimensions correspond to *ability factors*.

Method of analysis

Method of analysis combines qualitative and quantitative techniques. The qualitative part involves acquiring an understanding and an insight into the participants' thinking. It is followed by data extraction, which is then converted into the quantifiable format and analysed.

In the quantitative part, four principal types of data are identified. The first two include students' proto-metacognitive statements of their habitual approaches to problem situations, revealed in, or made in relation to, design sessions, and describing (1) individual learning styles, and (2) cognitive abilities. The last two are also concerned with the ability factors, but show evidence of a higher level of cognitive control, they are referred to as metacognitive statements. Table 5 outlines this study's method of data extraction, while the more detailed account of the adopted approach is presented in Section 6.2.4.

Table 5. Approach to the analysis of introspective statements (example)

Individual characteristics associated with different learning styles (LSA definitions)	Exemplar (1) metacognitive and (2) proto-metacognitive statements
S/he prefers following the same procedure/routine	<i>Over the years, I have came up with a few strategies that work well for me, I prefer trying them up first</i>
S/he needs visual stimulation when acquiring new knowledge	<i>I prefer to learn from drawing or illustrating material instead of listening to lectures or tutorials</i>
Individual characteristics associated with different cognitive abilities	Exemplar metacognitive (1) and proto-metacognitive (2) statements
Visualisation	<i>I usually try to imagine the whole thing in 3D... how I walk around inside... and sometimes I look at it from above...</i>
Ideational Fluency Figural	<i>... like today, I often have lots of ideas popping up in my head all at once... yeah, usually like pictures...</i>

Questionnaires

A post session questionnaire consisting of twelve questions was used to acquire information on differences in professional experience, interest, satisfaction, performance, perceived task difficulty and creativity of the outcome. It contained personal assessments of the students' performance and produced design solutions, e.g. answers to questions such as "How would you rate the difficulty of this assignment?", "How would you rate your performance in this design task?" and "How would you rate the creativity of your design ideas, solutions" (see Appendix B). Responses were recorded on a 10-point scale (1 = definitely dissatisfied, 10 = very satisfied). The grades students assign to their design solutions and performance are used for

correlating with academic achievement and the judges' assessments. The purpose is to discover how the capacity of the students to design relates to their capacity to understand and evaluate design, as well as what this capacity may depend upon or is related to. Additionally, questionnaires collected summaries of individual processes utilised during design tasks, as reported by the participants. They provided extra accounts of the overall structure and global approaches to problem solving that could be then linked to individual differences in design abilities (as measured by psychometric tests). Finally, questions such as, "Did you have any problems expressing your ideas by freehand sketching?" and "What kind of tools/techniques do you generally use to support the expression of your ideas?" were also included.

Method of analysis

Qualitative for the purpose of data extraction. Quantitative – represented by a series of statistical analyses, then followed by the results interpretation.

4.5 Assessment of Academic Performance and Design Solutions

Judgements of academic performance: Experiment III

For most design education disciplines, students' grading is based upon tools like regular assignments, individual or group projects, studio work, online or in-class quizzes, and take-home exams. All of these types of tests must have maximum validity, feasibility, and objectivity in order to meet the characteristics of all students and provide a comprehensive picture of their performance (Jegede, *et al.*, 1991). Ideally, the content of the assessment tool should cover the entire course, including the following six aspects: (a) knowledge, (b) comprehension, (c) application, (d) analysis, (e) synthesis, and (f) evaluation (Bloom, *et al.*, 1956). Creativity aspect may be added to match the specifics of the architectural domain. This type of assessment is especially helpful in dealing with students with different learning styles. Additionally, scales or taxonomies need being developed to apply a degree of uniformity to the graded data, and to delineate major principles evaluators use or need to use in their assessments. Matching different measurements of individual design abilities against the relevant scales would be a productive way of conducting this research. However, information on students' problem-solving styles, visual-spatial and ideation abilities, or creativity was not available, readily or in any workable form. There was no combined dataset that would rank a student on either of these dimensions in relation to his/her peers.

Thus, this thesis applies a simple and straightforward approach to collecting data on its participants' academic performance. Four course supervisors (one rated first year students in both samples, one – third year students from the first sample, and two rated the fourth-final year students from both samples) were approached in order to get the information on (a) creativity and (b) academic achievement (on design projects only). Creativity assessments were a matter of the raters' subjective opinions. The judgements of academic performance were based on the supervisors' knowledge of their students and were referenced against the list of grades brought in by the researcher (no significant discrepancies were detected). A 4-point scale (i.e. 'very good', 'good', 'average-good' and 'average') was used when obtaining supervisors' reports. The course supervisors avoided using 'poor' in their grading. This is because the first year students were evaluated largely in terms of their potential, and it was not entirely evident how it would develop into the achievement, whereas the older students had already proven their ability to meet basic course requirements (i.e. succeeded academically).

Method of analysis

Qualitative and quantitative. It involves gaining insight and understanding of the overall situation, based on the judges' grading and their written observations plus personal opinions shared verbally. It is followed by a series of statistical analyses and data interpretation.

Design solutions assessment: Experiment VI

The main purpose of the design drawings assessment is providing data for the exploration of the links between the *product*, the *process* and the *input*. It was expected, for example, from

designers with wholistic approach, they are also viewed as individuals with innovator traits, to produce designs, which would be assessed as original, attractive and transformational. While analytic individuals, often seen as adaptors, were expected to produce designs which would be more logical, functional and useful. Similarly, the data from this experiment allows determining whether students' ideational and spatial abilities could be related to the quality and quantity of ideas present in individual design drawings, spatial characteristics of generated sketches, etc.

Method of assessment

Professional architects assisted with the final experiment – they were asked to evaluate students' design solutions according to the taxonomy specified by the researcher. The judges were provided with rating sheets, containing descriptions of the assessment dimensions, and received verbal and written instructions to get accustomed with prior to commencing the rating process.

Dimensions of assessment

Four types of criteria have been developed to assess the quality of the students' designs. The first has three components and is a measure of whether the final design meets a number of constraints specified in the problem statement. The first component is the *client*, it contains 2 constraints. The second component is the *site*, containing 2 constraints, and the third component is the *house* containing 12 constraints. The final design may score from 1 to 16 based on the number of constraints met, subsequently converted into a 4-point scale used across all other experiments and assessment dimensions.

As design solutions (in this study – sketches) are considered artefacts or creative products, the second measure contains a number of parameters typically used for the evaluation of creativity. The ratings are also done according to a 4-point scale.

Creativity/Originality. The degree to which the design is creative is measured using the judges' own subjective definitions of creativity. It refers to producing unusual, uncommon and novel ideas, questions, suggestions or solutions, ways of doing things as a result of seeing new relationships among ideas, combining remote ideas, improving things on new lines, etc.

Complexity and Elaboration. Refers to the ability of participants to articulate ideas in terms of related and composite parts; developing the basic idea, figure, object, insight, into details looking into the implications of ideas.

Flexibility and Fluency. Refers to producing a variety of ideas, solutions, possibilities, interpretations, by shifting perspectives, methods, designs, approaches in the direction of thinking and valuing multiple viewpoints and possibilities.

Functionality and General Knowledge of Design Process. It is the third measure evaluating the degree to which the designed space is functional. It also refers to displaying the design process knowledge and skills, including skill in task clarification, concept generation, evaluation and refinement, and overall skill displayed in the execution of design process.

Technical Merit of Design Drawings. It is the fourth and final measure evaluating the degree to which the project, overall, is good technically. Analysing the levels of students' graphical proficiency allowed understanding better the role of sketching ability in individual problem solving – i.e. whether it served as a good/bad interactive thinking tool, a means of the imagery externalisation, or both. Whilst speed and accuracy in design drawing were considered as they could facilitate or impede the process of ideation.

The design product was rated with the help of transcripts and video recordings provided by the researcher, as the students' design ideas and intentions were made clearer via gaining access to their verbal reports. The final score of the first criteria was obtained by weighting its parts equally to obtain an average score ranging from 1 to 4 (corresponding to 'very good', 'good', 'average-good' and 'average') to enable comparisons with other assessments and experiments utilising 4-point scales. The consensus score (counted as a mean for each student on the basis of the three judges assessments) was prepared for the use in subsequent analyses. All notes and observations produced by the judges were treated separately to help with data interpretations.

Chapter 5. Experiments I-III. Evaluation of Cognitive Abilities, Learning Styles and Academic Performance

Chapter 5 presents three experiments supplemented by data extraction, analyses and discussions. Experiments I and II are psychometric studies concerned with two major groups of ability factors – cognitive abilities and learning styles. Experiment III contains assessments of the students' academic achievement and creativity on design projects – as reported by their course supervisors. It is grouped with two other experiments for the reasons explained below.

Experiment I involves administering visual-spatial (visualisation, orientation and scanning), visual memory, and ideation (verbal and figural) tests. Its objectives are to (1) provide an estimate of the students' cognitive abilities and general cognitive development; (2) look into the issue of cognitive improvement, including the trainability of measured abilities; (3) explore connections and correlations among them, years of study and selected demographic factors; (4) offer an alternative frame of reference for interpreting academic achievement; and (5) determine which factors can be regarded as predictors of the domain performance.

Experiment II assesses individual positions on two dichotomies of learning styles – Wholistic-Analytic and Verbal-Imagery. The purpose of this experiment is similar to the study of cognitive abilities. It is aimed at (1) assessing the participants' learning styles – repertoires, strengths and weaknesses; (2) exploring the issue of cognitive development, including the trainability of W-A and V-I learning styles; (3) explore connections and correlations among them, years of study and several chosen demographic parameters; (4) offering an additional frame of reference for interpreting academic performance; and (5) discovering which of the measured learning styles may be regarded as predictors of academic achievement and creativity.

Following these experiments is the correlation analysis concerned with the range of links between the four learning styles, creativity, academic performance and cognitive abilities. It is aimed at determining (1) which learning styles are likely to affect performance on ability tasks, and which cognitive abilities may underlie the learning styles' preferences; and (2) which styles and/or abilities may have a strong(er) predictive power in education.

5.1 Cognitive Abilities

The cognitive abilities section contains two major parts referred to as Experiment I/a and Experiment I/b as it describes two different sets of tests administered to 80 (60+20) subjects at two separate stages of this research development. The following subsection begins a discussion of the earlier empirical study, while Subsections 5.1.3 and 5.1.4 contain results of the most recent research.

5.1.1 Experiments I/a & III/a: Assessment, Analyses and Findings

The first series of cognitive tests were accomplished in 2000 in order to (a) obtain a general picture and an initial understanding of the aptitudes of pre-architecture and architecture students, and (b) explore relationships and correlations between the measured ability factors and academic performance. It was aimed at determining which abilities may become a fruitful research matter in terms of their predictive powers; and learning whether additional experiments with different cognitive factors would be necessary for arriving at meaningful conclusions.

Participants

The participants were 60 students completing their courses of study at the University of Sydney, Faculty of Architecture. 20 participants were (at the time of experiment) first year students, 20 were doing their third year, while the remaining 20 (16 + 4) were students from the fourth and fifth (final) years respectively. Fourth and final year students were grouped together based of the similarities in their levels of expertise, knowledge, skills and, possibly, abilities.

Table 6. Participants by year and gender: Experiment I/a

Year 1		Year 3		Years 4 & 5	
Females	Males	Females	Males	Females	Males
10	10	10	10	10	10

Sampling

Random sampling technique was applied in data collection. Design and architecture students from the first, third, fourth and final years of study were approached in their studios or classrooms with the invitation to take part in this study, and with explanations concerning the research objectives, as well as the nature and purpose of the psychometric testing. Typically, 6-10 students (from 15-30 present in a studio/classroom) would volunteer themselves to participate in the experiment. Same procedure had been repeated several times till the total number of 60 students, equalized in terms of gender and age (within each group), underwent testing. Cultural backgrounds were not intended as a variable for analyses in Experiment I/a, and, therefore, were not considered in the sampling process. It was, however, made sure for each participant to exhibit a high degree of English proficiency.

Procedure

The participants were tested in groups of 10-16 students. They were first administered figural fluency and flexibility tests (4-5 minutes per each test); followed by four measures of visual-spatial abilities in succession (each 4-8 minutes long). Testing was preceded by the standard instructions specific for each test. The experimenter read instructions aloud while the participants could accustom themselves with test requirements from the previously distributed materials. Total experiment duration was 40 ± 5 minutes long depending on time spent on the instructions comprehension.

Materials

All test materials can be found in the *Kit of Factor-Referenced Cognitive Tests* by Ekstrom, French & Harman (1976). The kit contains 72 cognitive tests that have been demonstrated to be consistent markers in studies of 23 aptitude factors, including: perception, verbal ability, visual-spatial ability, memory, and other. Each test has two parallel parts. Detailed information about the factors and the tests, as well as scoring keys, is contained in the *Manual* (1976). It includes representative data (mean, standard deviation, reliability, etc.) for each test. Additional information about the research for the 1976 version of the kit is contained in *Cognitive Factors: Their Identification and Replication* by R. B. Ekstrom, J. W. French, and H. H. Harman (1976). Seven tests were selected from the kit on the basis of their expected roles in the domains of design and architecture. They are listed in the order they were administered to the participants:

Ornamentation Test (Figural Fluency, FF) is used to assess a subject's ability to think of as many different ways as possible to decorate an object. It is regarded to be a figural form of the ideational fluency factor and requires the ability to draw quickly a number of examples based on a given visual stimulus. It has also been used extensively as a tool assessing visual creativity.

Elaboration Test (Figural Fluency, FF) evaluates another aspect of the figural fluency factor. Subjects' ability to draw quickly a number of elaborations based on a given visual stimulus is measured. Test takers are requested to think of a number of different ways to add details to a design. Similarly to ornamentation and storage tests, it has been broadly used as an instrument measuring creativity.

Storage Test (Figural Flexibility, FF) is intended at assessing the ability to change a set of elements in order to generate new and different solutions to figural problems. Subjects are asked to show the different ways small boxes could be arranged inside of a large container. This test also draws on the ability to visualise and mentally transform three-dimensional objects.

Building Memory Test (Visual Memory, MV) was designed to evaluate levels of visual memory. It requires the ability to keep several components of a composite picture (12 different

buildings placed on a map) and their spatial characteristics in mind at a time. This test assesses the ability of visual imagery for retention of visual material, such as: scenic or situational objects, their characteristics, and relationships among them.

Card Rotations Test (Spatial Orientation, SO) evaluates the ability to perceive spatial patterns, or to maintain orientation with respect to objects in space. Each item of the card rotation test requires participants to view a two-dimensional target figure and judge which of the five alternative test figures were planar rotations of the target figure (as opposed to its mirror image) as quickly and as accurately as possible.

Paper Folding Test (Spatial Visualisation, Vz) measures the ability to manipulate or transform the image of spatial patterns into other arrangements. Each item in this test shows successive drawings of two or three folds made in a square sheet of paper. The final drawing shows a hole being punched in the folded paper. The subject is to imagine and articulate how the punched sheet would appear when fully opened.

Maze Tracing Test (Spatial Scanning, SS) assesses the speed of exploring visually a wide and complicated spatial field. It involves finding and marking a path through a series of printed mazes. This test requires an ability to scan the field quickly for openings, follow paths visually (i.e. prior to marking the paper), and reject false leads. Royce (1973) has suggested that perceptual speed may be a subfactor of this ability.

Scoring

Scoring was done manually in accordance with instructions and right response tables (scoring procedures varied) from the *Kit*. It required approximately 5 minutes per each test. A correction for guessing was used for scoring: the total test score is calculated according to the formula $R - W/(n-1)$, where R is the number of correct responses, W is the number of wrong responses, and n is the number of response options for each item. Results are presented in three tables, Appendix A, grouped by the year of study. The scoring procedure was followed by a series of statistical analyses discussed below.

Internal consistency analysis

For all psychometric test results it was possible to compute a reliability coefficient known as Cronbach's alpha to prove their internal consistency. A score was calculated from each test item (responses were standardised to a standard deviation of 1) and the overall rating (scale) was defined by the sum of these scores over all test items. Then reliability was calculated as the square of the correlation between the measured scale and the underlying factor the scale was supposed to measure. Cronbach's alpha values for all administered tests ranged from 0.85 to 0.96 for the first year students, from 0.83 to 0.94 for the third year students, and from 0.82 to 0.92 for the fourth and final year students – reflecting good internal reliability.

Demographic analysis

Demographic analysis was performed to ensure there was no significant disparity between the chosen parameters (Table 7). The age variable was included as it is a factor loading on ability scores (Carroll, 1993). The age differences of students attending the same course were not significant. The social-economic backgrounds of the participants varied, but not greatly. Another aspect which was likely to influence the test performance is ethnicity or cultural differences. Experiment I/a did not consider this issue although the relevant information had been collected (approximately 40% of test-takes were of Australasian origin, 55% were White Australians, and 5% White Europeans, rather evenly distributed across the test groups). Approximately 15% of test-takers were born outside of Australia, but spent the last 15+ years in Australia which enabled their trouble-free understanding of oral and written instructions.

Table 7. Demographic analysis of the age groups, Experiment I/a

Year 1		Year 3		Years 4 & 5	
Mean	SD	Mean	SD	Mean	SD
19.17	0.71	22.35	0.69	23.57	0.81

Previous education in design-related areas (or extensive professional experience), as well as the former exposure to cognitive tests similar to the ones used in the present study, were also considered. The two volunteers who reported either were not included in the sample.

Distribution

The test scores were jointly analysed for a multivariate normal distribution and homogeneity of variance-covariance matrices for each year separately. No violations of assumptions were detected. Significant multivariate differences ($p \leq 0.05$) were followed up with an analysis of variance utilizing Student-Neuman-Keuls (SNK) post hoc comparisons to determine which groups were significantly different. Effect size (n^2) was also calculated to indicate the relative strength of significant group differences. The results of these tests are discussed below.

Descriptive statistics

Descriptive statistics for all variables measured in this experiment is presented in Table 8.

Table 8. Distribution characteristics for cognitive factors by year and gender, Experiment I/a

Test*	Year 1				Year 3				Year 4&5			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
O	9.00	21.00	16.40	3.66	9.00	22.00	14.80	3.39	9.00	24.00	17.30	6.09
	8.00	22.00	14.00	4.19	11.00	24.00	16.40	4.03	6.00	24.00	14.40	4.74
E	12.00	17.00	14.00	2.05	8.00	12.00	10.00	1.63	9.00	18.00	13.30	3.05
	8.00	18.00	11.50	3.27	11.00	20.00	14.70	3.56	6.00	20.00	12.50	4.03
S	5.00	10.00	7.80	1.55	4.00	10.00	7.60	1.90	5.00	11.00	7.50	1.90
	4.00	12.00	8.50	2.42	6.00	11.00	8.60	1.90	7.00	13.00	9.20	2.04
CR	32.00	76.00	54.20	17.31	30.00	74.00	53.10	14.52	32.00	80.00	58.30	19.04
	32.00	80.00	52.70	15.20	42.00	80.00	67.60	12.69	35.00	78.00	64.40	16.94
PF	2.75	9.00	5.93	2.25	3.00	9.00	7.10	1.96	5.50	7.75	6.67	0.83
	4.75	8.75	6.68	1.46	4.25	10.00	7.10	1.66	3.50	10.00	7.67	1.74
MT	9.00	20.00	13.20	3.36	8.00	19.00	13.40	3.65	8.00	23.00	15.30	4.42
	7.00	18.00	13.30	3.65	10.00	20.00	15.10	2.99	9.00	20.00	14.30	3.13
BM	5.50	12.00	9.10	2.39	4.25	12.00	9.90	2.49	8.25	12.00	10.50	1.29
	5.25	12.00	9.00	2.30	4.25	12.00	9.63	2.42	5.75	12.00	10.37	2.57

 Females  Males

*O – Ornamentation; E – Elaboration; S – Storage; CR – Card Rotations; PF – Paper Folding; MT – Maze Tracing; BM – Building memory

Effects of gender of participants

The collected data suggests there are marginal gender differences in the scores of abilities, as men have higher collective Means on spatial tests (males: Mean=23.15; SD=23.55; females: Mean=21.39; SD=20.61), and females tend to do better in ideation (females: Mean=14.3; SD=2.57; males: Mean=13.9; SD=1.72⁶). However, the MANOVA analysis has not revealed a significant main effect or interaction for gender. The differences may be attributed to higher maximal visual-spatial ability scores attained by 7% of men, and lower minimal scores that belong to 3% of women. Similarly, there were 5% more of women than men (across the sample) among the top scorers on ideation tasks. Comparisons of male and female participants clustered by ability levels attest to much similarity in the score fluctuations for both genders – for the exception of the above scorers, there are no significant differences in ability results.

Characteristics of sample and comparative analyses

Aptitude profiles were obtained from the performance scores. Group differences on the test battery were analysed by performing *t* tests on each of the ability scores. A continuing increase

⁶ This excludes the *Storage* test, as it belongs to both visual and idea-production domains having salient loadings of both *Gv* and *Glr* abilities (Carroll, 1993).

in scores from year 1 to years 4&5 was observed on visual-spatial and ideational tasks (excluding *Elaboration* scores discussed below).

Table 9. Distribution characteristics for cognitive factors by year, Experiment I/a

Tests	Year 1		Year 3		Years 4 & 5	
	M	SD	M	SD	M	SD
Ornamentation	15.20	4.00	15.60	3.71	15.85	5.50
Elaboration	12.75	2.95	12.35	3.61	12.90	3.50
Storage	8.10	2.00	8.30	1.91	8.35	2.10
Card Rotation	53.45	15.85	60.35	15.21	61.35	17.20
Paper Folding	6.30	1.88	7.13	1.77	7.17	1.42
Maze Tracing	13.25	3.41	14.25	3.37	14.80	3.70
Building Memory	9.06	2.28	9.76	2.39	10.44	2.00

As Table 9 indicates, the growth was generally more significant between the first and the second group (years 1 and 3), than between the second and the third group (years 3 and 4&5), although it varied for different abilities. The only test that did not fit with the trend was *Elaboration*, where the first year students were marginally better on the task, compared to the third year students. This may be attributed to the effect of 2% less top scorers ('high' in our classification) in the third year, whereas other groups (i.e. 'medium-high', 'medium-low' and 'low') indicate a steady growth of the ability level. Additionally, there are issues related to ideation measures that may have caused a distortion in the test results. Elaboration task requires quick adding of different details to 20 identical objects. The final score is calculated based on the number of objects completed. However, many test takers (especially in the second and third groups) were inclined towards completing fewer objects but producing more complex and/or original elaborations. Thus, if complexity or originality were the two other aspects measured by this test, the overall picture may have been different (this data is included in Appendix A tables).

Pre-architecture, architecture students and lay people

There are studies showing that architects are consistently more accurate at tasks involving spatial visualisation (Salthouse, 1991) and score higher than the general public on visual-spatial tests of mental rotations, mental scanning, constructing spatial analogues, and several other (Ghiselli, 1966; Smith, 1964; Chase and Chi, 1981). There have also been many predictive studies that defined occupations with a strong correlation with spatial visualisation, they include: architecture (Smith, 1964; Chronbach, 1970; Ghiselli, 1973), structural design (Alias, *et al.*, 2002, 2003), and computer aided design (Sorby, 1999).

Table 10. Cognitive testing results among different groups of population. Experiment I/a

Tests	General population				Year 1		Year 3		Years 4&5	
	group I*		group II**							
	M	SD	M	SD	M	SD	M	SD	M	SD
Ornamentation	11.50	4.45	12.10	4.50	15.20	4.00	15.60	3.71	15.85	5.50
Elaboration	10.25	4.20	10.95	5.00	12.75	2.95	12.35	3.61	12.90	3.50
Storage	6.20	2.60	5.30	1.70	8.10	2.00	8.30	1.91	8.35	2.10
Card Rotation	47.57	13.3	44.00	12.30	53.45	15.85	60.35	15.21	61.35	17.2
Paper Folding	6.04	2.25	5.47	1.85	6.30	1.88	7.13	1.77	7.17	1.42
Maze Tracing	11.20	3.15	13.20	3.56	13.25	3.41	14.25	3.37	14.80	3.70
Building Memory	6.35	2.44	5.45	2.35	9.06	2.28	9.76	2.39	10.44	2.00

* Group I is represented by 191 (46+145) college students.

Source: *Kit of Factor-Referenced Cognitive Tests* (1976; pp. 4-12)

** Group II are 11th and 12th graders, 288-300 males, and 317-329 females.

Source: *Kit of Factor-Referenced Cognitive Tests* (1976; pp. 4-12)

Another traditionally important for design area is idea production, it belongs to the domain of creativity (Torrance, 1966; Ekstrom, 1976; Amabile, 1996). Design methodologists usually suggest that, to be successful, productive as well as creative, the process of designing should be characterized by ideation and fluency with unusually associated ideas. And that this kind of thinking is natural to designers (Kimbell, *et al.*, 1991; McCormick, *et al.*, 1993; NEAB, 1993; Atkinson, 1997, 1998). There is also research arguing for individuals to choose creative fields of work and study (Yamada & Tam, 1996; Plucker, 1999).

In agreement with these studies Table 10 present further evidence confirming that architects and designers are among the people possessing high/higher visual-spatial and ideation abilities. Additionally, as most students of architecture enter higher education with little experience in architecture as a discipline, a large part of architectural education is concerned with the development of new skills and aptitudes, of which spatial and ideational abilities have always been considered as of primary importance. It is possible, therefore, that the gradual acquisition of these skills is reflected in the test results presented above. How and whether students' abilities improve during the course of design education is the next point of discussion.

Effects of preserved differentiation, training & attrition

This issue is equally relevant to Experiments I/a and I/b as it applies to both samples of students for there are no principal differences in the character of results of cognitive abilities tests. To avoid repetition, it is being addressed in detail only in this subsection.

It appears that design students tested in this study generally possess better abilities in ideation and visualisation than the lay public. It is not clear, though, whether the developed aptitudes were present in designers and architects before the extensive occupational training took place – by the time of experiment, the group one participants were already finishing their first year of study. Salthouse defines this problem as *differential preservation* versus *preserved differentiation* (Salthouse, *et al.*, 1990; Salthouse, 1991). Whereas the first term implies that people's experience in architecture leads to the enhancement of their spatial abilities; the second means that the developed spatial abilities architects possess have always existed. What is more likely is that both stipulations are equally plausible. The high level of ability of the first group perhaps attests to *preserved differentiation* (as one year of design education may not be enough to achieve significant improvements in the aptitude measures, especially, in cases of no earlier exposure to visualisation enhancing activities), while the gradual increase in the ability scores of the third and fourth-final years students may attest to *differential preservation*. More evidence in support of or in refutation of these claims is needed before any conclusions are drawn.

Additionally, as students develop strategies in the use of abilities, they may significantly alter their performance on ability tests. In this case, what we regard as advanced abilities of the third and more so fourth and fifth years, may, in fact, be improved (or more appropriately chosen) task-specific problem solving strategies. They are equally likely to alter the performance on design tasks but, rather possible, in a similar manner. This, therefore, will not necessarily lead to the inconclusiveness of linear correlations between the *input*, the *process* and the *product*, but will mean that the subject of ability trainability is a complex issue that needs being researched from a variety of angles, and with a more specific methodological focus.

It has also been argued there may be a *transfer-of-training* effect involved, which shows that training a particular skill may transfer to another skill, presumably within the same group of broad abilities (Carroll, 1993). Pellegrino (1984) for example, has obtained some results suggesting that training transfers across certain measures of spatial visualisation ability. It is not surprising, therefore, that some of the students' visual and ideation abilities are consistently interrelated in all three test groups (see Table 11).

Another relevant issue is *attrition*. If a developed spatial ability was indeed a prerequisite to achievement in design and architecture, as can be inferred from the vast literature (Smith, 1964; Ghiselli, 1966, 1973; Chronbach, 1970; Taylor, 1980; Visser, 1981; Millroy, 1985; Sorby, 1999; Alias, *et al.*, 2002, 2003), then students who do not possess it initially and fail to develop it via the course of education are at risk of dropping out or choosing a different field of study. The

lack of ability growth could be due to it being hardly malleable or trainable, ineffective instructional methods poor in adapting to or stimulating students aptitudes (or learning styles), or else. In this case, the effect of gradual improvement of spatial skills from group one to group three can be attributed to the effect of attrition. The number of students who continue to pursue their study decreases with each year of education. It is possible, therefore, that there are mostly low spatial individuals among the drop-outs. The remaining higher ability students are accountable for the observable improvement in the ability levels. Overall, only a longitudinal study may help resolving this issue; testing all, or most, students across all years of study could be another demanding process of getting an answer to this question.

Correlation analysis (a)

Several analyses were performed with the purpose of (a) establishing which abilities were correlated among each other and what were the implications of these correlations; (b) how visual-spatial and ideation factors were related to the assessments of academic performance and creativity; and (c) which abilities (if any) could serve as a predictor of academic performance and creativity.

Table 11. Pearson product-moment correlation coefficients: Years 1, 3, 4&5, Experiment I/a

Test	O	E	S	CR	PF	MT	BM
Year 1							
Ornamentation	1						
Elaboration	0.603**	1					
Storage	0.426	-0.038	1				
Card Rotation	0.374	0.072	0.218	1			
Paper Folding	-0.064	-0.187	0.221	0.492*	1		
Maze Tracing	-0.199	0.100	0.017	-0.215	0.045	1	
Building Memory	0.355	0.189	0.399	0.441	0.463*	-0.214	1
Year 3							
Ornamentation	1						
Elaboration	0.688**	1					
Storage	0.139	0.329	1				
Card Rotation	0.072	0.316	0.125	1			
Paper Folding	-0.032	0.110	0.333	0.710**	1		
Maze Tracing	0.357	0.325	0.379	0.055	0.063	1	
Building Memory	0.247	0.287	0.232	0.255	0.631**	0.244	1
Years 4&5							
Ornamentation	1						
Elaboration	0.486*	1					
Storage	0.172	-0.151	1				
Card Rotation	-0.296	0.008	0.218	1			
Paper Folding	-0.107	-0.070	0.429	0.468*	1		
Maze Tracing	0.406	0.054	0.135	0.166	0.242	1	
Building Memory	-0.119	-0.194	0.153	0.216	0.538*	0.432	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table 11 indicates that there are similar correlations observed in all three test groups, though the magnitudes of correlation coefficients vary. They include:

1. *Ornamentation* is correlated with *Elaboration*
2. *Card Rotations* is correlated with *Paper Folding*
3. *Building Memory* is correlated with *Paper Folding*

Ornamentation (Figural Fluency, *FF*) and *Elaboration* (Figural Fluency, *FF*) are correlated with each other because they evaluate different aspects of the same ability – figural form of the ideational fluency factor (initially, both measures were included to help with results validity). And there is consistency across the sample. The tests, though, show differences in relation to

other factors. This may be due to some students' concentration on originality and complexity in one of these tasks, instead of fluency in adding elaborations to pictorial objects.

Figural fluency tests are among the measures of creativity, which is believed to consist of a number of independent psychological factors (Guilford, 1959, 1962). Torrance (1966, 1974) suggested the use of composite scales, while other studies indicated that the latent structure of TTCT and other creativity assessment instruments show different results (Dixon, 1979; Hocevar, 1979; Hocevar & Michael, 1979; Chase, 1985; Treffinger, 1985; Heausler, & Thompson, 1988; Runco & Marz, 1992; Clapham, 1998). That is, while *Ornamentation*, *Elaboration*, *Storage* and other ideation tests measure factors contributing to creativity, they are not equivalent in terms of their properties.

Storage measures an independent aspect of figural ideation – Figural Flexibility (FX), which loads on both *Glr* (Figural Fluency, FF) and *Gv* (Visualisation, Vz, and Visual Memory, MV) groups of broad abilities. This may be a reason why it is not correlated with other figural ideation factors – test takers utilise a broad range of strategies to fulfil test requirements. It may also have visual perception and reasoning components, or may indicate an ability to be flexible in adopting and changing hypothesis and mental sets about figural and spatial problems (Ekstrom, *et al.*, 1976; Carroll, 1993). In this study it appears to be associated with *Gv* abilities.

Card Rotations (Spatial Relations, SR) is correlated with *Paper Folding* (Spatial Visualisation, Vz), which is an expected result. There may be two main reasons for the observed relationship. Firstly, a transfer-of-training effect may be involved, showing that training a particular skill (SR) may transfer to another skill (Vz) within the same group of broad abilities (Pellegrino, *et al.*, 1984). Also, visualisation requires spatial thinking, and the ability to mentally imagine, manipulate or transform objects or visual patterns, while spatial relations requires speeded rotation or reflection of the relatively simple spatial forms, and has been considered as one of the many subfactors to visualisation. Whereas other researchers consider visualisation as a more complex and less speeded form of spatial relations, as both require the mental rotation of a spatial configuration in a short term visual memory (Ekstrom, *et al.*, 1976).

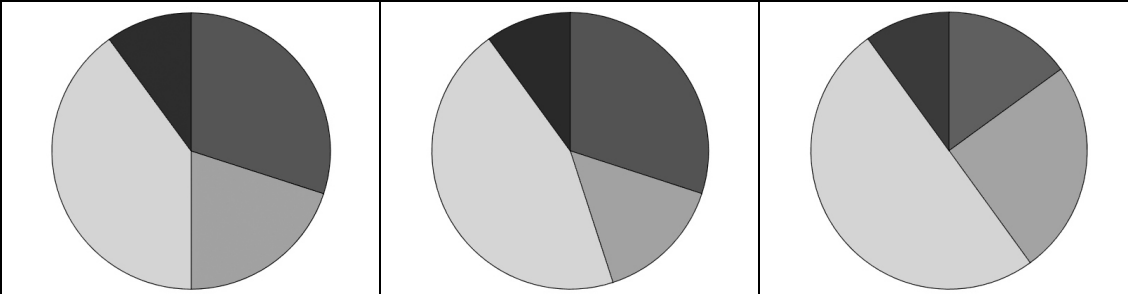
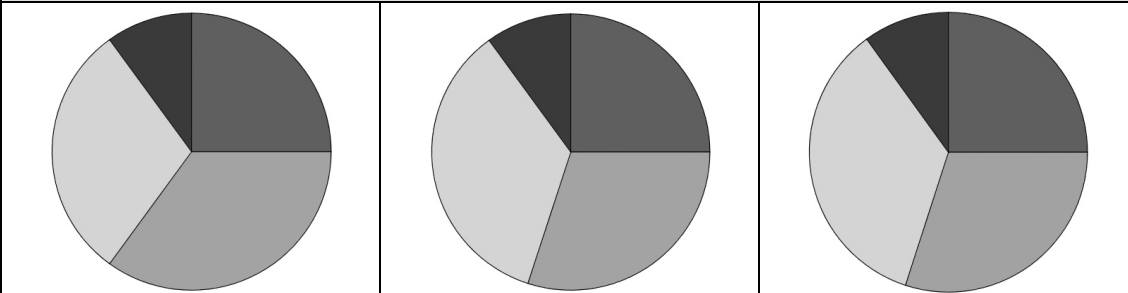
Paper Folding (Spatial Visualisation, Vz) is correlated with *Building Memory* (Visual Memory, MV). This result was also anticipated. Vz abilities were reported to require the most complex cognitive processing; i.e. greater complex mental manipulations and transformations, loading highest on *Gv*. MV was found, in a relative sense, to be a lower level less complex factor in the domain of visual-spatial abilities supporting higher level abilities (Miyake, *et al.*, 2001; Lohman, 2002). That is, it has been argued for the more complex *Gv* abilities (such as Vz and SR) to be partially dependent on, and supported by, MV (Juhel, 1991). In this study, SR shows only low correlations with MV, the reason for this could be the lesser dependence of spatial relations on high visual memory. The majority of test participants scored remarkably higher on MV than did the lay people – even the lowest scores are typically above the Mean for general public. Correspondingly, even the relatively 'low' visual memory of some design and architecture students may provide enough support for their spatial relations ability.

Cognitive abilities, creativity & judgements of academic performance

For most design education disciplines, students' grading is based upon tools like regular assignments, individual or group projects, studio work, online or in-class quizzes, and take-home exams. Ideally, all of these types of tests must have maximum validity, feasibility, and objectivity in order to meet the characteristics of all students and provide a comprehensive picture of their performance (Jegede, *et al.*, 1991). Additionally, scales and taxonomies need being developed to apply a degree of uniformity to the graded data, and to delineate major principles the evaluators need to use in their assessments.

Thus, as this information is not yet readily available, a simplified straightforward approach to data collecting was utilised in this thesis. Three course supervisors were approached in order to get the information on their students' (a) creativity and (b) academic performance on design projects only. A 4-point scale (i.e. 'very good', 'good', 'average-good' and 'average') was applied when obtaining evaluation reports. The reports were cross-referenced with the records of students' grades (the resulting data is included in Appendix A tables).

Table 12. Assessments of creativity and academic performance, Experiment III/a: frequencies by gender

	Year 1				Year 3				Years 4&5			
	Creativity		Performance		Creativity		Performance		Creativity		Performance	
	Fem %	Male %	Fem %	Male %	Fem %	Male %	Fem %	Male %	Fem %	Male %	Fem %	Male %
Average	15	15	15	10	15	15	15	10	5	10	10	15
Average-Good	5	15	10	25	10	5	10	20	15	10	15	15
Good	25	15	20	10	25	20	20	15	30	20	20	15
Very Good	5	5	5	5	0	10	5	5	0	10	5	5
Creativity												
												
Academic performance												
												
Year 1				Year 3				Years 4&5				
Very Good		Good		Average		Average-Good						

As it is clear from Table 12, there are approximately equal amounts of very creative, creative, moderately creative and not-so-creative students in the first and second groups, with a 5% shift from the average-good into the good sector (provided it was a longitudinal study). Then, there is a bigger change, as 15% of average students move into the average-good and good sectors. In terms of gender differences, males tend to outperform females as there are more of them at the upper end of scales (i.e. very good), but there are notably more females among the good group (across the sample). These results, may only be viewed as an indication of a trend until a longitudinal study is conducted, especially because of the supervisors' subjectivity of creativity assessments. Also, creativity of design projects of the first year freshmen is different from creativity of the final year learners as the latter have to apply domain knowledge to accommodate a broader range of technical and other constraints. A further series of multivariate analyses with additional variables (i.e. visual-spatial and ideation abilities, general achievement, etc.) may provide a better understanding of the above results.

The situation with academic performance is similar; there is almost no disparity in the percentages of people with different academic achievements in all three groups. It shows gradual improvement in good – average-good sectors, whereas the amount of average and very good students remains the same (provided it was a longitudinal study). Yet again, these results are mostly indicative of similar distributions close to normal (as the Chi-square histograms showed), which may add to the credibility of the analysed statistical data. It is hard to compare academic performance across the sample as (a) the requirements to design projects for the first

year freshmen are different from the requirements to the final year learners, and (b) first year students are often evaluated in terms of their potential, while the final year students are assessed on the basis of what they have already achieved.

General cognitive ability

Levels of cognitive development of each student were also determined to address the broad variability of visual-spatial and ideation abilities test results. That is, with over 70% of the sample scoring unevenly – high on one test of spatial or ideation ability and low or average on another, it was difficult to distinguish between high, low or medium ability individuals. There were also different score fluctuations between tests, with visual memory scores having the lowest fluctuation and most students scoring much above the Mean for general public, and maze tracing being the closest to general public and high on score variability. The range of reasons for this is not fully evident, some will be discussed later. A general intelligence theory could, potentially, explain the observed phenomenon. However, as this study is only concerned with a limited number of cognitive factors, it does not apply any of the human ability theories.

A series of clustering using partitional (k-means) and hierarchical (sample average and median) methods were performed to identify levels of cognitive development or *general cognitive ability* groups of the sample, then split by the year of study. General ability incorporates both visual-spatial and ideation abilities scores; it received its name for convenience and is not related to the general intelligence factor *g* from the CHC theory. After clustering, a four-measure scale was applied to 12 (4 in each) identified groups of general abilities, as they were divided into ‘high’, ‘medium-high’, ‘medium-low’ and ‘low’⁷ levels.

Correlation analysis (b)

The above data on students’ abilities, academic performance and creativity was correlated with the ability scores to determine whether certain abilities or the general cognitive development could serve as predictors of academic performance and creativity on design projects (the lowest or the poorest ability / level of creativity / performance was ascribed a numeric value - 1 and the highest - 4).

Table 13 indicates that there are many similar correlations observed in all three test groups, though the magnitudes of correlation coefficients vary. While some correlations are only present in one or two groups of subjects. For the first year they include:

1. *Creativity* is correlated with *Ornamentation*, *Storage*, *Card Rotations*, *Building Memory*, and *General Ability* tests,
2. *Academic performance* is correlated with *Ornamentation*, *Card Rotations*, *Paper Folding*, *Building Memory*, *Creativity* and *General Ability*, and
3. *General Ability* is correlated with *Storage*, *Card Rotation*, *Paper Folding*, *Building Memory*, *Creativity* and *Academic Performance*.

Thus, both ideational and visual-spatial abilities predict creativity in the first year students. Assessments of academic performance are also correlated with visual-spatial and ideational abilities and creativity. Whereas general ability is dependent on visual-spatial abilities that show high correlations among each other (i.e. spatial visualisation, spatial relations and visual memory) and ideation test (i.e. figural flexibility) which also has a visual component. General ability predicts both academic performance and creativity. And, finally, academic assessment is correlated with creativity, which is an expected outcome.

⁷ ‘Low’ in this study is relative of other architecture and design students, as less than 10% of participants in Experiment I/a scored below the Mean for general public

Table 13. Pearson product-moment correlation coefficients: Years 1, 3, 4&5, Experiment I/a

Test	O	E	S	CR	PF	MT	BM	C	AP	GA
Year 1										
Ornamentation	1									
Elaboration	0.603**	1								
Storage	0.426	-0.038	1							
Card Rotation	0.374	0.072	0.218	1						
Paper Folding	-0.064	-0.187	0.221	0.492*	1					
Maze Tracing	-0.199	0.100	0.017	-0.215	0.045	1				
Building Memory	0.355	0.189	0.399	0.441	0.463*	-0.214	1			
Creativity	0.618**	0.341	0.446*	0.658**	0.437	-0.133	0.770**	1		
Acad. Performance	0.542*	0.134	0.332	0.662**	0.499*	-0.020	0.630**	0.833**	1	
General Ability	0.283	-0.093	0.579**	0.685**	0.727**	-0.071	0.766**	0.755**	0.754**	1
Year 3										
Ornamentation	1									
Elaboration	0.688**	1								
Storage	0.139	0.329	1							
Card Rotation	0.072	0.316	0.125	1						
Paper Folding	-0.032	0.110	0.333	0.710**	1					
Maze Tracing	0.357	0.325	0.379	0.055	0.063	1				
Building Memory	0.247	0.287	0.232	0.255	0.631**	0.244	1			
Creativity	0.671**	0.537*	0.454*	0.446*	0.608**	0.248	0.687**	1		
Acad. Performance	0.396	0.296	0.488*	0.378	0.691**	0.279	0.751**	0.842**	1	
General Ability	0.279	0.234	0.465*	0.654**	0.779**	0.095	0.653**	0.746**	0.826**	1
Years 4&5										
Ornamentation	1									
Elaboration	0.486*	1								
Storage	0.172	-0.151	1							
Card Rotation	-0.296	0.008	0.218	1						
Paper Folding	-0.107	-0.070	0.429	0.468*	1					
Maze Tracing	0.406	0.054	0.135	0.166	0.242	1				
Building Memory	-0.119	-0.194	0.153	0.216	0.538*	0.432	1			
Creativity	-0.326	-0.083	0.426	0.563**	0.326	0.098	0.477*	1		
Acad. Performance	0.038	0.071	0.303	0.072	0.577**	0.260	0.560*	0.649**	1	
General Ability	-0.202	-0.054	0.468*	0.755**	0.770**	0.304	0.582**	0.681**	0.655**	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

These correlations were observed in the third year:

1. *Creativity* is correlated with *Ornamentation*, *Elaboration*, *Storage*, *Paper Folding* and *Building Memory* tests,
2. *Academic performance* is correlated with *Storage*, *Paper Folding*, *Building Memory*, *Creativity* and *General Ability*, and
3. *General Ability* is correlated with *Card Rotation*, *Paper Folding*, *Building Memory*, *Creativity* and *Academic Performance*.

This means that both ideational and spatial abilities predict creativity in the third year students. Assessments of academic performance are correlated with visual-spatial abilities and creativity, and only one component of ideational abilities – figural flexibility. Whereas general ability has a stronger component of visual-spatial abilities that show high correlations among each other (i.e. spatial visualisation, spatial relations and visual memory), than it has of ideation abilities. General ability predicts both academic performance and creativity. And, finally, academic assessment is correlated with creativity, which is an expected outcome.

And, lastly, correlations observed in the fourth and final years:

1. *Creativity* is correlated with *Card Rotations* and *Building Memory* tests,

2. *Academic performance* is correlated with *Building Memory*, *Creativity* and *General Ability*, and
3. *General Ability* is correlated with *Storage*, *Card Rotation*, *Paper Folding*, *Building Memory* and *Academic Performance*.

These correlations suggest that only visual-spatial abilities predict creativity in the fourth and final year students. Similarly, assessments of academic performance are correlated with visual-spatial abilities only. They are also correlated with creativity. The general ability is dependent on visual-spatial abilities that show high correlations among each other (i.e. spatial visualisation, spatial relations and visual memory); and one component of ideation abilities – figural flexibility (*Storage* test). This test has a strong visual-spatial component, as participants generate new and different solutions to figural problems supported by visualisation, where abilities for manipulating three-dimensional objects and mental synthesis are essential.

Among the reasons for the decrease of predictive effect of ideation abilities – in the third year only figural flexibility is correlated with creativity and academic performance, while in the fourth and final years it does not correlate with neither academic performance nor creativity – is, perhaps, the growing complexity of design tasks. That is, tasks used in ability tests are simple cognitive tasks, possibly loading on doodling ability, or speed and control in sketching (Carroll, 1993). Whereas most projects in architecture are multifaceted complex activities.

Additionally, creativity in architecture is more than ability; creative personality includes psychological and affective traits, knowledge of creative processes, former experience with a wide scope of tasks, styles of thinking, and so on. Whereas, the design and architecture products have to meet an extensive range of specifications, in addition to being creative and novel, they have to be usable, appealing, practical, feasible, and so on. Thus, to establish reliable correlations between ideation factors and creativity or academic performance in architecture, a measurement for creativity beyond the measurement of the quantity of ideas generated needs being used. In this respect, visualisation abilities are better predictors of academic performance as they involve the more complex cognitive processing characteristic of design tasks.

Finally, complex design exercises may be less likely to have linear correlations with figural fluency ability (or any other ability emphasizing high speed over quality) as they are typically not a subject of time constraints, unlike the cognitive tests. That is probably why maze tracing has no observable correlations with any other spatial test, creativity or academic performance. Though measuring an essential ability for spatial scanning, it is mostly a time- rather than a quality of execution-dependent measure – its scores indicate how much rather than how well one can trace a maze, because false leads are obvious to the subject.

5.1.2 Conclusions

Experiments I/a and III/a attempted to establish statistical causal relationships between education, acquiring spatial and idea production skills, and spatial visualisation and ideation abilities. It sought to determine whether students' aptitudes in spatial visualisation and ideation could be enhanced via teaching and learning activities. The data showed that the improvement is likely, but its magnitude in the components of *Gv* and *Glr* abilities would vary. According to these experiments, the largest gain was on visual memory, and the least on spatial scanning task. It is possible for visual memory to be highly developed among architects due to a wide range of tasks and activities that (a) improve the quality of visual memory and (b) depend on its use. The transfer-of-training effect between visualisation and visual memory may also be present. Advanced spatial scanning ability, on the other hand, may not be so important, or not in the form it is measured by the ability tests – with the speed of performance emphasized. Not many architectural tasks would require time-constrained scanning of complex visual material, hence the lowest gain on this factor. The idea of ability trainability is in conformity with the previous research by Piaget (1971) Sorby and Baartmans (1996) and a vast number of other studies. Although a longitudinal study is necessary to ensure the adequately supported conclusions.

Many of our deductions are founded on the analysis that the aptitude scores increasing gradually and steadily from year one through to the fourth and final years, suggesting that idea production and spatial reasoning are not fixed abilities, but involve processes that may be changeable in adulthood. The results indicate that aptitude enhancements have occurred within all test groups and that the instruction received may influence cognitive abilities in a positive way. Another observation concerns general cognitive ability; it may serve as a predictor of academic performance and creativity for all test groups. While visual-spatial and ideation abilities of the fourth and final year students have the lowest correlations with academic performance, which may mean that other factors relating to teaching, previous instruction and complexity of design tasks, thinking styles, knowledge and experience, may be of equal (or higher) importance.

On a more detailed level the results indicated:

- no significant gender-related differences in the ability levels observed;
- spatial ability scores are generally higher among the tested architecture and design students when compared to lay people, and this observation is valid for all years;
- around 10% of students from the first year are ‘objectively’ low ability individuals, that is not only within their respective groups but compared to other samples from the general population (i.e. their combined Means are marginally lower);
- spatial ability scores of the 1st year students are generally lower when compared to the 3rd year, whereas years 4 and 5 demonstrate the highest levels of aptitude. This leads to three possible implications (1) the ability is also a skill which can be developed and/or there are learnt strategies that allow achieving higher results on cognitive tests; (2) high spatial individuals have better prospects of fulfilling course requirements and, therefore, to continue education through to the final year; or (3) a combination of both. Longitudinal research with a bigger sample is necessary to understand this issue better;
- there are no consistent correlations between and within the visual-spatial and ideation groups of abilities. Some abilities within each respective group are inter-related (i.e. visual memory, spatial relations and visualisation), while others are not;
- approximately 25% of high spatial and low spatial individuals were identified in all three groups; all of their scores were significantly higher or lower than the group Mean. However, the other 75% of students show uneven ability profiles. That is, scoring high on one/several tests and below average of low on another/others, even within the same group of factors. There may be different explanations to this observation, including some of the abilities to be more trainable or more likely to be improved via the course of education, the transfer-of-training effect, the more efficient use of compensatory strategies on cognitive testing, and so on;
- figural fluency scores are highly correlated with each other as they measure different aspects of the same factor, while figural flexibility is unrelated to other ideation factors and may have a component of visual-spatial abilities;
- visual-spatial abilities of the 1st year students are correlated with their academic achievement and creativity; their ideation abilities are also correlated with academic achievement and creativity;
- visual-spatial abilities of the 3rd year students are correlated with their academic achievement and creativity; ideation abilities are only correlated with creativity and are not related to academic performance;
- visual-spatial abilities of the 4th and final year students are correlated with creativity and only visual memory is correlated with academic achievement, ideation abilities are not correlated with either;
- there is a general trend for high spatial students (or individuals with a developed general ability) to be reported as very good or good students while low ability students are often described as average. However, 10% of the test participants (predominantly in the 4th and final years) do not fall into these categories.

5.1.3 Experiments I/b-III/b: Assessment, Analyses and Findings

A more recent series of cognitive tests were conducted with a different group of participants, they are involved in all six experiments of the current thesis. There are several differences between the current and the earlier sets of tests. One of the figural fluency measures administered earlier – *Elaboration*, was correlated with *Ornamentation* in each of the three test groups, which suggested they measured different aspects of the same factor, yet the latter one had no predictive effect in terms of academic performance, and no relation to creativity. Thus, it was replaced by the *Symbols* test as potentially more useful. Two verbal ideation factors were added to the list on the basis of their expected relationship with academic performance and cognitive styles. The testing was accomplished in year 2002 to (a) obtain a general picture of the aptitudes pre-architecture and architecture students possess, and (b) explore relationships and correlations between the measured ability factors and academic performance. It was aimed at gaining an insight into which types of abilities may become a fruitful research issue in terms of their predictive powers; and establishing which additional experiments or research methods are necessary for validating this study's initial tentative conclusions.

Participants

The participants were 20 students completing their courses of study at the University of Sydney, Faculty of Architecture. 10 participants were (at the time of experiment) first year students, and 10(6 + 4) were students from the fourth and fifth (final) years respectively. Students from the fourth and final years are treated conjointly, as one group, as there are strong similarities in the levels of expertise related to academic knowledge, skills and abilities.

Table 14. Participants by year and gender: Experiment I/b

Year 1		Years 4 & 5	
Females	Males	Females	Males
5	5	5	5

Sampling

Stratified random sampling technique was applied in data collection. Over than 200 students from first, fourth and final years of study were approached via e-mail with the invitation to take part in this research, and explanations concerning its objectives, nature and purpose of the psychometric testing. 49 students (19 from fourth and final, and 30 first years) exhibited initial degree of interest. Of those 30 were chosen randomly by taking into account a number of parameters, including gender, cultural backgrounds, age, former architecture or design education/experience, and the earlier exposure to cognitive testing. 25 of them agreed to participate in our study. The final 20 students were selected as the most balanced sample.

Procedure

The participants were tested on an individual basis. They were first administered figural and verbal fluency tests (4-5 minutes per test); followed by four tests of visual-spatial abilities in succession (4-8 minutes long). Testing was preceded by the standard instructions specific for each test. The experimenter read instructions aloud while the participants could accustom themselves with test requirements from the previously distributed materials. Total experiment duration was 50±5 minutes long depending on the time spent on the instructions comprehension.

Materials

All test materials were obtained from the same *Kit of Factor-Referenced Cognitive Tests* by Ekstrom, French & Harman (1976). Nine tests were selected on the basis of their expected functions as the design ability constituents. They are listed in order of administration:

Ornamentation Test (Figural Fluency, FF) is used to assess a subject's ability to think of as many different ways as possible to decorate an object. It is regarded to be a figural form of the

ideational fluency factor and requires the ability to draw quickly a number of examples based on a given visual stimulus. It has also been used extensively as a tool assessing visual creativity.

Symbols Test (Figural Fluency, FF) evaluates another aspect of the figural fluency factor. Subjects' ability to draw quickly a number of different symbols that could be used to stand for certain words or ideas is measured. Symbols test may also be an originality factor (Ekstrom, *et al.*, 1976), and a figural form of associational fluency. Variables loaded on this ability are diverse, covering several other primary factors in the domain, including Vz (Carroll, 1993). Similarly to ornamentation and storage, it has been used as an instrument measuring creativity.

Storage Test (Figural Flexibility, FF) is intended at assessing the ability to change a set of elements in order to generate new and different solutions to figural problems. Subjects are asked to show the different ways small boxes could be arranged inside of a large container. This test also draws on the ability to visualise and mentally transform three-dimensional objects.

Arranging Words Test (Fluency Expressional, FE) measures the ability to rapidly produce a connected discourse that fits restrictions in terms of words and ideas. Participants are requested to write up to twenty different sentences using the same four words. The test contrasts with associational fluency which focuses on the production of single words. It requires rephrasing given ideas rather than generating new ideas, and may be a verbal version of the ideation factor.

Controlled Associations Test (Fluency Associational, FA) measures the ability to produce words which share a given area of meaning or some other common semantic property. The task is to write as many synonyms (up to 12) as possible for each of 4 words. In contrast to ideational fluency, quality and speed rather than quantity of production is emphasized.

Building Memory Test (Visual Memory, MV) was designed to evaluate levels of visual memory. It requires the ability to keep several components of a composite picture (12 different buildings placed on a map) and their spatial characteristics in mind at a time. This test assesses the ability of visual imagery for retention of visual material such as scenic or situational objects, their characteristics, and relationships among them.

Card Rotations Test (Spatial Orientation, SO) evaluates the ability to perceive spatial patterns, or to maintain orientation with respect to objects in space. Each item of the card rotation test requires participants to view a two-dimensional target figure and judge which of the five alternative test figures were planar rotations of the target figure (as opposed to its mirror image) as quickly and as accurately as possible.

Paper Folding Test (Spatial Visualisation, Vz) measures the ability to manipulate or transform the image of spatial patterns into other arrangements. Each item in this test shows successive drawings of two or three folds made in a square sheet of paper. The final drawing shows a hole being punched in the folded paper. The subject is to imagine and articulate how the punched sheet would appear when fully opened.

Maze Tracing Test (Spatial Scanning, SS) assesses the speed of exploring visually a wide and complicated spatial field. It involves finding and marking a path through a series of printed mazes. This test requires an ability to scan the field quickly for openings, follow paths visually (i.e. prior to marking the paper), and reject false leads. Royce (1973) has suggested that perceptual speed may be a subfactor of this ability.

Scoring

Scoring was done manually in accordance with instructions and right response tables (scoring procedures varied) from the *Kit*. It required approximately 5 minutes per each test. A correction for guessing was used for scoring: the total test score is calculated according to the formula $R - W/(n-1)$, where R is the number of correct responses, W is the number of wrong responses, and n is the number of response options for each item. Results are presented in two tables, Appendix A, grouped by the year of study.

Internal consistency analysis

For all psychometric test results it was possible to compute Cronbach's alpha to prove their internal consistency. A score was calculated from each test item (responses were standardised to

a standard deviation of 1) and the overall rating/scale was defined by the sum of these scores over all test items. Then reliability was defined as the square of the correlation between the measured scale and the underlying factor the scale was supposed to measure. Cronbach's alpha values for all administered tests ranged from 0.84 to 0.95 for the first year students and from 0.81 to 0.92 for the fourth and final year students. These values reflect good internal reliability.

Demographic analysis

Demographic analysis was performed to further validate the tested data. The age variable was included in Table 15 to ensure there was no significant disparity between the test-takers on the relevant dimension, as age is a factor loading on ability scores (Carroll, 1993). The age differences of students attending the same course are usually not significant, which is also clear from the table below. Another issue was the cultural spectrum that, in this sample, pertained to ethnicity⁸. While all sample members were Australian (Australian-Asian (Chinese) and Australian-Caucasian), 15% of the students, were born in Asia (China), but spent the last 15+ years living in Australia. In this study, they are grouped with Australian-Asian students as ethnic influences are very strong in Australasian communities. Both test groups (i.e. first year and fourth and final years) have 50% Australian and 50% Australasian representatives. It was made sure for all subjects to exhibit very high degrees of English proficiency, to enable not only trouble-free understanding of oral and written instructions, but efficient processing of the verbally based tests. Seven measures from the administered set of tests are not related to verbal ability; they are visually oriented and require reading only for instructions; whereas the other two require verbal processing.

Table 15. Demographic analysis, Experiment I/b

	Year 1		Years 4 & 5	
	Mean	SD	Mean	SD
Age	19.50	0.85	23.00	0.94
Ethnicity	1.50	0.53	1.50	0.53

The social-economic backgrounds of the participants varied, but not greatly. Previous education in design-related areas (or extensive professional experience), as well as the former exposure to cognitive tests similar to the ones used in the present study, were also considered. The subjects who reported them, were not included in the sample and are not mentioned in the present experiment. Table 15 demonstrates sufficient consistency of the demographic parameters.

Distribution

The test scores were jointly analysed for a multivariate normal distribution and homogeneity of variance-covariance matrices for each year separately. No violations of assumptions were detected. Significant multivariate differences ($p \leq .05$) were followed up with an analysis of variance utilizing Student-Neuman-Keuls (SNK) post hoc comparisons to determine which groups were significantly different. Effect size (n^2) was also calculated to indicate the relative strength of any significant group differences. The results of these and other explorative analyses are discussed below.

Descriptive statistics

Descriptive statistics for all variables measured in this experiment is presented in Table 16. It shows distribution characteristics of different cognitive abilities separated by demographic factors, including the participants' gender and years of study.

⁸ It is understood that 20 participants do not make a representative sample; however, gender and ethnicity have been the major sources of ability variance as indicated by many former factor-analytical studies (Carroll, 1993). We observed differences pertaining to ethnicity, and, therefore included this aspect in our thesis. Conclusions are considered tentative and indicative of the future research interests.

Table 16. Distribution characteristics for cognitive factors by year and gender, Experiment I/b

Test*	Year 1						Years 4&5					
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
O	10.00	23.00	15.00	5.24	13.30	4.52	10.00	19.00	13.00	3.75	13.70	3.09
	8.00	17.00	11.60	3.36			12.00	18.00	14.40	2.51		
Sy	5.00	8.00	6.20	1.30	6.80	1.75	5.00	12.00	9.20	2.77	9.60	2.46
	4.00	9.00	7.40	2.07			8.00	14.00	10.00	2.35		
S	5.00	10.00	7.60	1.95	8.30	2.00	7.00	10.00	8.40	1.14	8.40	0.97
	7.00	12.00	9.00	2.00			7.00	9.00	8.40	0.89		
AW	3.00	5.00	4.20	1.10	4.40	0.84	3.00	5.00	4.20	0.84	4.20	0.79
	4.00	5.00	4.60	0.55			3.00	5.00	4.20	0.84		
CA	7.00	12.00	10.20	2.49	10.40	2.17	6.00	15.00	9.60	3.78	10.40	2.84
	7.00	12.00	10.60	2.07			9.00	13.00	11.20	1.48		
CR	30.00	66.00	52.00	16.78	56.50	13.95	47.00	80.00	62.60	14.5	65.40	11.75
	47.00	76.00	61.00	10.27			55.00	78.00	68.20	8.98		
PF	4.75	8.75	6.85	1.94	7.38	1.49	6.00	9.00	7.70	1.56	7.58	1.45
	7.00	9.00	7.90	0.74			5.75	9.00	7.45	1.52		
MT	9.00	15.00	12.20	2.39	12.40	2.27	11.00	19.00	14.60	3.05	15.30	2.83
	10.00	16.00	12.60	2.40			12.00	19.00	16.00	2.74		
BM	8.00	12.00	10.30	1.71	10.28	1.71	9.50	12.00	10.50	1.37	10.58	1.48
	8.00	12.00	10.25	1.90			7.75	12.00	10.65	1.74		

Females
 Males
 Group results

*O – Ornamentation; Sy – Symbols; S-Storage; AW – Arranging Words; CA – Controlled Associations; CR - Card Rotations; PF – Paper Folding; MT- Maze Tracing; BM – Building memory

Effects of gender and ethnicity of participants

Data in Table 16 and Figure 2 (below) suggest there are marginal gender differences in the scores of aptitudes as men have higher means on most visual-spatial tests (*Card Rotation*: males, Mean=64.60; females, Mean=57.30; *Paper Folding*: males, Mean=7.67; females, Mean=7.28; *Maze Tracing*: males, Mean=14.30; females, Mean=13.40; *Building Memory*: males, Mean=10.45; females, Mean=10.40).

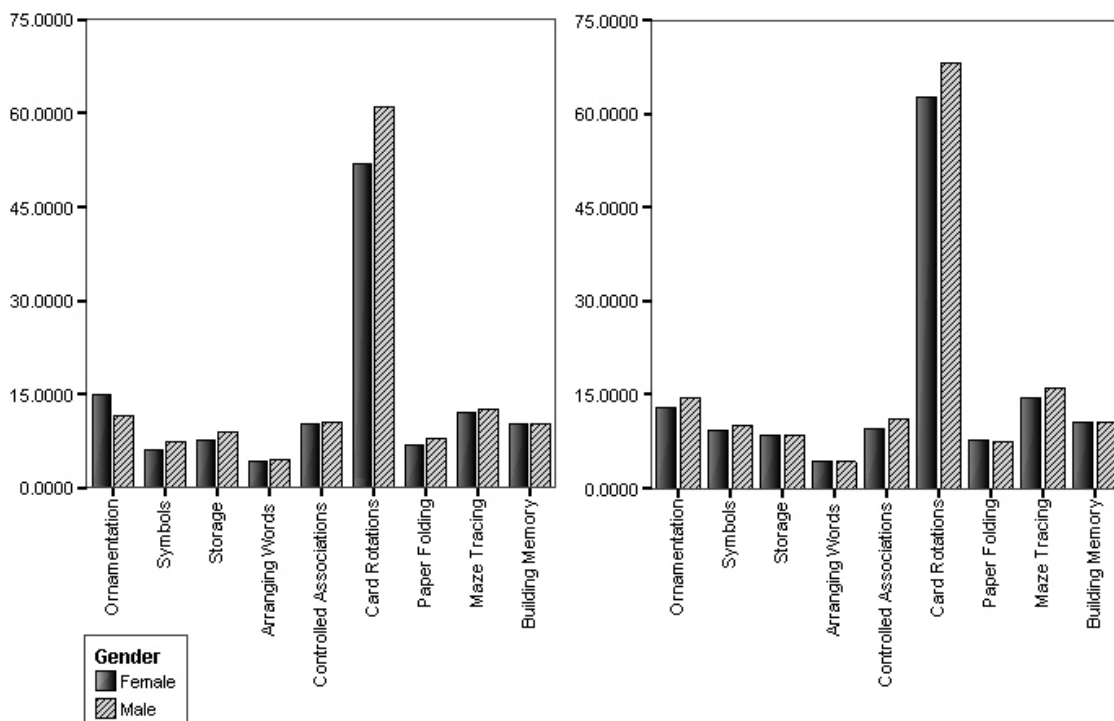


Figure 2. Comparison of ability scores (Means) by year and gender: Year 1(left), Years 4&5 (right)

The collective means are equal on ideation, with females scoring marginally higher on figural fluency and marginally lower on figural flexibility tests (*Ornamentation*: males, Mean=13.00; females, Mean=14.00; *Symbols*: males, Mean=8.70; females, Mean=7.70; *Storage*: males, Mean=8.70; females, Mean=8.00), and males tend to do slightly better on one of the verbal ideation measures (*Arranging Words*: males, Mean=4.40; females, Mean=4.20; *Controlled Associations*: males, Mean=10.90; females, Mean=9.90).

Gender differences in spatial ability, favouring males, are well established. The largest gender difference have been found in tests of the SR factor (marker test - *Card Rotations*), but in tests of the Vz factor (marker test – *Paper Folding*) the differences have been small or null (Linn & Petersen, 1985; Voyer, *et al.*, 1995). This research confirms the earlier findings. On other tests, the MANOVA analysis has not revealed a significant main effect or interaction for gender. The differences may be attributed to the higher maximal visual-spatial ability scores, taken over by 5% of men, and the lower minimal scores that belong to 5% of women. Series of comparisons of male and female participants clustered by ability levels (elicited below), also attest to much similarity in the score fluctuations for each gender.

Similarly, the MANOVA and Pearson product-moment analyses have not revealed any significant main effect or interaction for ethnicity.

Characteristics of sample & comparative analyses

Aptitude profiles were obtained from the performance scores. Group differences on the test battery were analysed by performing *t* tests on each of the ability scores. A score increase between year 1 and years 4&5 was observed on visual-spatial and ideational tasks, Figure 3. Both groups consisted of high-ability individuals as indicated by their scores, but were different in aptitude profiles. Fourth-final year students performed better on visual-spatial and ideation tasks, whereas first year students did marginally better on the verbal aptitude measure, both groups did better than the general public, suggesting they have definite aptitude strengths.

There could be a number of reasons for the first year students' more advanced verbal abilities. Traditional teaching techniques are designed for verbal sequential learners, where concepts are introduced in a step-by-step fashion, assessed under timed conditions, and then reviewed. Thus, students verbal abilities tend to advance in secondary and high school education, as their aptitudes and instruction treatment variables interact (Cronbach & Snow, 1977; Snow, 1977). They may also be more used to working under time constraints, including cognitive testing. It has also been argued for students' aptitudes to change due to the more visual-based instructional treatment in design and architecture, to the marginal detriment of verbal reasoning as the newly learnt strategies tend to overshadow the formerly learnt ones (Carroll, 1993). The effect of attrition is possible but less likely with our sample, as the majority of high verbal individuals also score reasonably high on visual-spatial and ideation tests.

The improvement in the components of *Gv* and *Glr* abilities varied; the largest gain was on card rotations, and the least on figural flexibility (*Storage*) task. The reasons and implications of these occurrences are discussed below.

Pre-architecture, architecture students and lay people

The results of Experiments I/a and I/b are very similar and have been previously discussed in Subsection 5.1.1. They are in conformity with the literature indicating for architects to score higher than the general public on visual-spatial tests of mental rotations, mental scanning, constructing spatial analogues, and so on (Ghiselli, 1966; Smith, 1964; Chase and Chi, 1981). And with other research, indicating that they are consistently more accurate at tasks involving spatial visualisation (Salthouse, 1991), and are better than the lay people at ideation and other creativity-related tasks (Yamada & Tam, 1996; De Bono, 1996; Lawson, 1997; Birkhofer, *et al.*, 1998; Plucker, 1999). Test results presented in Table 17 contain more evidence confirming the common view of architects and designers as people possessing high ideation and visual-spatial abilities, essential in their fields of work.

Table 17. Cognitive testing results among different groups of population, Experiment I/b

Test	General population				Year 1		Years 4&5	
	group I*		group II**					
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Ornamentation	11.50	4.45	12.10	4.50	13.30	4.52	13.70	3.09
Symbols	5.20	2.40	6.20	2.50	6.80	1.75	9.60	2.46
Storage	6.20	2.60	5.30	1.70	8.30	2.01	8.40	0.97
Arranging Words	3.90	1.50	3.50	1.70	4.40	0.84	4.20	0.79
Controlled Associations	6.80	2.50	7.20	2.20	10.40	2.17	10.40	2.84
Card Rotation	47.57	13.30	44.00	12.30	56.50	13.95	65.40	11.75
Paper Folding	6.04	2.25	5.47	1.85	7.38	1.49	7.56	1.45
Maze Tracing	11.20	3.15	13.20	3.56	12.40	2.27	15.30	2.83
Building Memory	6.35	2.44	5.45	2.35	10.28	1.71	10.58	1.48

* Group I is represented by 191 (46+145) college students.

Source: *Kit of Factor-Referenced Cognitive Tests* (1976; pp. 4-12)

** Group II are 11th and 12th graders, 288-300 males, and 317-329 females.

Source: *Kit of Factor-Referenced Cognitive Tests* (1976; pp. 4-12)

The education of an architect is a complex process which encourages students to develop new ways of seeing, thinking and doing, as most students enter higher education with little experience in architecture as a discipline. The above data indicates a possibility for the gradual improvement in aptitudes acquired during the course of study, as ability scores increase from year one to the fourth-final years. How/whether students' abilities improve is discussed below.

Effects of preserved differentiation, training & attrition

This issue has already been addressed in Subsection 5.1.1 in relation to Experiment I/a. There are no principal differences in the character of the samples' ability scores that can be attributed to the effect of training. Without repeating the discussion, several major points will be listed.

Firstly, it appears that design students tested in this study generally possess better abilities in ideation and visualisation than the lay public. What is not clear is whether the developed aptitudes were present in designers and architects before the extensive occupational training took place or they were enhanced by design education. Or whether it is an issue of *differential preservation* or *preserved differentiation* (Salthouse *et al.*, 1990, 1991). There are studies, defending either or both of these viewpoints (Smith, 1964; Ghiselli, 1966; Eisenberg & McGinty, 1977; Pellegrino, 1984, 1988; Hishitani, 1990; Braukmann, 1991; Sternberg & Lubart, 1991; Sexton, 1992; Gillespie, 1995; Scarr 1996; Plucker, 1999). In this study, the high level of ability of the first group perhaps attests to *preserved differentiation* (as one year in design may not be enough to achieve significant improvements in the aptitude measures), while the increase in the ability scores in group two may attest to *differential preservation*.

Another issue, equally related to the effect of training versus innate potential is *attrition*. If developed visual-spatial and creativity-related abilities were a prerequisite to achievement in design and architecture, as suggested by the vast literature (Smith, 1964; Ghiselli, 1966, 1973; Chronbach, 1970; Taylor, 1980; Visser, 1981; Millroy, 1985; Sorby, 1999; Alias, *et al.*, 2001), then students who do not possess or fail to develop them via the course of education would be at risk of dropping out or changing to a different field of study. The lack of ability growth could be due to it being non-malleable, ineffective instructional methods unable to adapt to students aptitudes or learning styles, or else. In this case, the effect of gradual advancement of spatial skills from group one to group two may be attributed to the effect of attrition. The amount of students who continue to pursue their study decreases with each year of education. It is possible, therefore, that there are mostly low spatial individuals⁹ among the drop-outs. The remaining higher ability students are accountable for the 'improvement' in the ability levels.

⁹ We consider 'Low' relative of other architecture and design students, not necessarily general public.

On the whole, only a large longitudinal study may be able to provide sufficient evidence in support of or in refutation of the above claims. Testing all, or most, students across all years of study could be another demanding process of acquiring the answer to these questions.

Comparison of means

Table 18 presents a comparison of test results of the two experiments. Finding differences and similarities could help establishing whether this study's samples were characteristic of the population they drew from – 1st year designers, and 4th and 5th year architects. The independent samples *t* test and a *t* test for paired samples were performed; both showed the diversity for samples was not significant (two-sample *t* test, $P > 0.05$). However, the efficiency of both tests could be undermined as they assume normal distributions, roughly equal variances and sample sizes. This condition is only partially fulfilled as the multivariate distributions are similar for both samples, but on several single tests the two samples come from fairly different shaped distributions, with the first sample being closer to normal (probably due to its larger size). The variances of the two samples are approximately equal, whereas the sizes of samples are not.

Table 18. Means and Standard Deviations in Experiments I/a & I/b

Test	Experiment I/a				Experiment I/b			
	Year 1		Years 4&5		Year 1		Years 4&5	
	M	SD	M	SD	M	SD	M	SD
Ornamentation	15.20	4.00	15.85	5.50	13.30	4.52	13.70	3.09
Storage	8.10	2.00	8.35	2.10	8.30	2.01	8.40	0.97
Card rotation	53.45	15.85	61.35	17.20	56.50	13.95	65.40	11.75
Paper folding	6.30	1.88	7.17	1.42	7.38	1.49	7.56	1.45
Maze tracing	13.25	3.41	14.80	3.70	12.40	2.27	15.30	2.83
Building memory	9.06	2.28	10.44	2.00	10.28	1.71	10.58	1.48

The similarities include scores on *Storage* and *Maze Tracing* tests, whereas marginal differences in the *Ornamentation* measure can be attributed to the students' concentration on complexity and originality more than fluency in decorating objects (data included in Appendix A tables). Also, the goals and the setup of individual sessions may have directed them towards being more meticulous when completing tasks. Being more careful with what they were doing combined with better test conditions, may have caused differences on other ability tests as they are marginally higher with Experiment I/b participants. Better conditions included students being well-rested coming in the morning for testing in quiet airy rooms, which is different from the earlier study when students were approached in their studios after classes. It is also possible that predominantly curious resourceful students secure about their potential volunteered themselves for a 5-hour long mentally demanding study. Then the second sample is less representative of the population they drew from (i.e. the University of Sydney architecture and design students) than the first (hence different shaped distributions, with some of the Experiment I/b test results deviating from normal). If this is the case, then it may explain differences in tests scores between first and fourth-final years in Experiment I/b, which are smaller than in Experiment I/a. The second sample has more high ability individuals in both assessment groups.

Correlation analyses (a)

Several analyses were conducted with the purpose of (a) establishing which abilities were inter-related and what were the implications of these correlations; (b) how visual-spatial and ideation factors were related to the assessments of academic performance and creativity; and (c) which abilities (if any) could serve as a predictor of academic performance and creativity.

Table 19 indicates that there are similar correlations observed in both test groups, though the magnitudes of correlation coefficients vary. And some correlations are only present in one group of subjects.

Table 19. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiment I/b

Test	O	Sy	S	AW	CA	CR	PF	MT	BM
Year 1									
Ornamentation	1								
Symbols	0.261	1							
Storage	0.394	0.589	1						
Arranging Words	0.052	0.135	0.382	1					
Controlled Associations	0.269	0.637*	0.404	0.571	1				
Card Rotation	0.147	0.505	0.320	0.246	0.169	1			
Paper Folding	0.385	0.574	0.479	0.508	0.395	0.824**	1		
Maze Tracing	0.268	0.302	0.020	-0.557	-0.149	0.081	-0.049	1	
Building Memory	0.462	0.475	0.541	0.532	0.514	0.249	0.641*	-0.461	1
Years 4&5									
Ornamentation	1								
Symbols	0.012	1							
Storage	0.119	0.777**	1						
Arranging Words	-0.291	0.561	0.321	1					
Controlled Associations	0.104	0.105	0.178	0.308	1				
Card Rotation	0.530	0.464	0.425	0.314	-0.025	1			
Paper Folding	0.500	0.173	0.095	0.107	-0.251	0.634*	1		
Maze Tracing	0.532	-0.236	0.073	-0.478	0.565	0.053	0.075	1	
Building Memory	0.528	-0.159	0.016	-0.253	0.171	0.345	0.667*	0.552	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

For the first year they include:

1. *Controlled Associations* is correlated with *Symbols*
2. *Card Rotations* is correlated with *Paper Folding*
3. *Building Memory* is correlated with *Paper Folding*

The following correlations were observed in the fourth and final years:

1. *Storage* is correlated with *Symbols*
2. *Card Rotations* is correlated with *Paper Folding*
3. *Building Memory* is correlated with *Paper Folding*

It is hard to be certain about the meaning of the above inter-relations due to the size of the sample; we need assuming that correlations are not randomly occurring in this study's data. Since most of them (correlations) are similar and are present in both samples (i.e. Experiments I/a and I/b), it is rather possible for this assumption to be true.

Symbols test (Figural Fluency, *FF*) is correlated with *Controlled Associations* test (Associational Fluency, *FA*) in the first year; and with *Storage* test (Figural Flexibility, *FX*) in the fifth-final years. There could be several reasons for this. Different individuals and skill groups have been shown to use alternative strategies for solving spatial or figural problems. Some individuals compensated for deficits in visualisation with verbal-analytic strategies and vice versa. Strategies for solving spatial items can shift from visual to verbal modes as a result of minor variations in tasks (Glushko & Cooper, 1978; Hunt & MacLeod, 1979; Sternberg & Weil, 1980). Flexibility of strategy use, or strategy shifting, reflects an individual's adaptation to changes in task difficulty. As verbal is presumed to be a more habitual way of problem solving for the first year students (due to their previous learning experiences), they apply it with ease to visual tasks, especially when they are not very familiar with the graphical language and design conventions. Additional evidence for this interpretation was observed. When clearly asked to draw different symbols for each of several words or phrases, majority of the first year students incorporated words and short phrases in their responses (data is included in Appendix

A tables). Additionally, *Symbols* test could also be a figural form of associational fluency (Ekstrom, *et al.*, 1976). Thus, if these tasks are similar in some key aspects, students may apply their knowledge of the stimulus and task constraints to reduce their processing burden and the complexity of this figural-spatial task by using their prior verbal knowledge.

If the above is true, then it is not surprising why the figural fluency measure is correlated with the visual-figural ideation test – figural flexibility, among the fourth and final year students. These test subjects are more familiar with design and drawing conventions and are more experienced in visual reasoning, they seldom resort to verbal strategies as can be observed from the final results (i.e. produced symbols are purely figural). Also, both *Symbols* and *Storage* measures belong to the same group of ideation factors related to creativity (i.e. *Glr* group of broad abilities). A study by Chase (1985) suggested that the correlation coefficients among figural fluency and flexibility were often so high (0.74 to 0.80) that one single score could be appropriate. Additionally, they may involve similar processes. Both measures require fluency in successfully dealing with figural tasks via a search for relevant knowledge in long-term memory. And an ability to rapidly change set and try-out a variety of approaches to solutions for figural problems that have several stated criteria (Carroll, 1976). They may have visualisation and reasoning components, or may indicate an ability to be flexible in adopting and changing hypothesis and mental sets about figural problems.

Card Rotations (Spatial Relations, *SR*) is correlated with *Paper Folding* (Spatial Visualisation, *Vz*). There may be two main reasons for the observed relationship. Firstly, a transfer-of-training effect may be involved, showing that training a particular skill (*SR*) may transfer to another skill (*Vz*) within the same group of broad abilities (Pellegrino, *et al.*, 1984). Also, visualisation requires spatial thinking, and the ability to mentally imagine, manipulate or transform objects or visual patterns, while spatial relations requires speeded rotation or reflection of the relatively simple spatial forms, and has been considered as one of the many subfactors to visualisation. Whereas other researchers consider visualisation as a more complex and less speeded form of spatial relations, as both require the mental rotation of a spatial configuration in a short term visual memory (Ekstrom, *et al.*, 1976).

Paper Folding (Spatial Visualisation, *Vz*) is correlated with *Building Memory* (Visual Memory, *MV*). This result is also not unexpected. *Vz* abilities were reported to require the most complex cognitive processing; i.e. greater complex mental manipulations and transformations, loading highest on *Gv*. *MV* was found, in a relative sense, to be a lower level less complex factor in the domain of visual-spatial abilities supporting higher level abilities (Miyake, *et al.*, 2001; Lohman, 2002). That is, it has been argued for the more complex *Gv* abilities (such as *Vz* and *SR*) to be partially dependent on, and supported by, *MV* (Juhel, 1991). In this study, *SR* shows low correlations with *MV*, possibly due to the lesser dependence of the relatively cognitively undemanding spatial relations on high visual memory. Most of the test subjects scored remarkably higher on *MV* than did the lay people – even the lowest scores are typically above the Mean for general public.

Additionally, similarly to the *Symbols* test, many first year students applied verbal reasoning in the *Building Memory* task. Being intuitively aware that recall is enhanced by storing information in both visual and verbal form, many of them applied several verbal compensatory strategies (numbering or naming buildings, etc). While visual-haptic (drawing invisible and thin lines, retracing, etc) compensatory strategies were observed among the fourth and final year students. Somewhat expected, more often than not, these strategies proved efficient in both groups of subjects. And, as the participants knew their visual memory was being tested they may have employed strategies that called into play processes and mechanisms not typical of normal memory operating (e.g. storing visual information as verbal descriptions).

Cognitive abilities, creativity & judgements of academic performance

As per discussed earlier, there have been many predictive studies conducted to assess the role of visual-spatial and ideation abilities and visual memory in forecasting job success and academic performance (Smith, 1964; Ghiselli, 1966; Hays & Pereira, 1972; Ekstrom, *et al.*, 1976; Hulme,

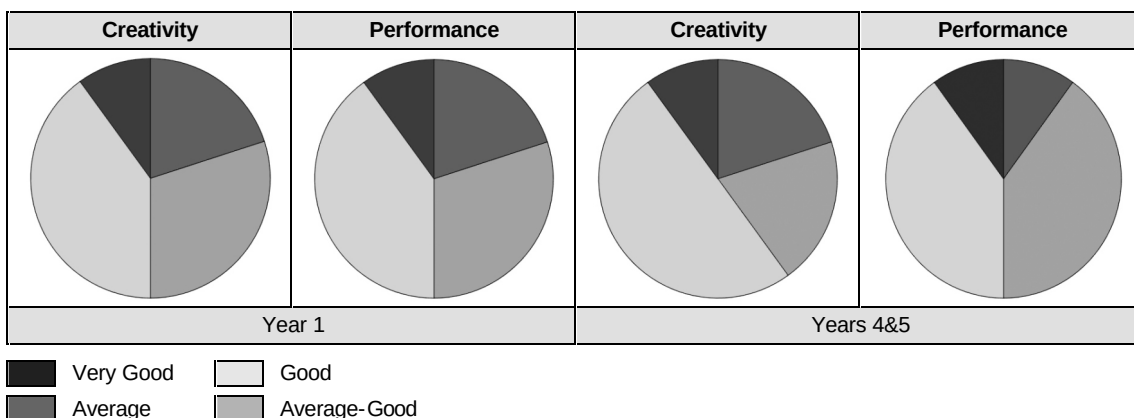
1979; Taylor, 1980, 1981; Torrance, 1981; Torrance & Wu, 1981; Visser, 1981; Millroy, 1985; Sternberg, 1988; Sawyers & Canestero, 1989; Kolb & Whishaw, 1990; Sternberg & Lubart, 1991; Amabile, 1996; Yamada & Tam, 1996; Kosslyn, 1999; Plucker, 1999; Goldberg, 2000; Greenfield, 2001; Klatzky & Lederman, 2002; Miller, 2002; Taylor, *et al.*, 2002; Knipp, 2003; Aronen, *et al.*, 2004). Generally, positive correlations have been observed, though more empirical support is needed before any compelling conclusions are reported.

Similarly to Experiment III/a a simplified straightforward approach to data collecting was utilised in Experiment III/b. Two course supervisors were approached in order to get the information on their students' (a) creativity and (b) academic performance on design projects. A 4-point scale (i.e. 'very good', 'good', 'average-good' and 'average') was applied when obtaining evaluation reports. The reports were referenced against the records of students' grades, no major discrepancies were detected (the resulting data is included in Appendix A).

As Table 20 shows, there are approximately equal amounts of very creative, creative, moderately creative and not-so-creative students in the first and second groups, with a 10% shift from the average-good into the good sectors (provided it was a longitudinal study). In terms of gender differences, males tend to outperform females as there are more of them at the upper end of scales (i.e. very good), but there are more females among the good group (as a summary for both test years). The sample size, however, permits only tentative conclusions. The results may not be indicative of some trend or underlying rule because there were two different supervisors who attested to what they thought was good or bad creativity of their students. Additionally, perceptions of creativity of the first year design projects are likely to be different from the perceptions of creativity of the final year design projects, where students have to accommodate a greater number of constraints, meet more domain requirements, etc. Thus, a subsequent series of multivariate analyses with additional variables (i.e. visual-spatial and ideation abilities, general achievement, etc.) may provide with a better idea of what the results indicate.

Table 20. Assessments of creativity and academic performance: Frequencies by gender, Experiment III/b

	Year 1				Years 4&5			
	Creativity		Performance		Creativity		Performance	
	Females %	Males %	Females %	Males %	Females %	Males %	Females %	Males %
Average	10	10	20	0	10	10	0	10
Average-Good	20	10	10	20	10	10	30	10
Good	20	20	10	30	30	20	20	20
Very Good	0	10	10	0	0	10	0	10



The situation with academic performance on design tasks is much similar; there is almost no disparity in percentages of students with different levels of achievement in both groups. It shows a 10% improvement in average – average-good sectors, whereas the amount of good and very good students remains the same (provided it was a longitudinal study). These results are only indicative of similar distributions (as the Chi-square histograms showed), which may add

to the credibility of the analysed statistical data. However, it is hard to compare academic performance across the sample for the same reasons as with creativity assessments, that is (a) the requirements to design projects for the first year freshmen are different from the requirements for the final year learners, (b) different supervisors may have different views of the good/bad performance, and also (c) first year students are commonly evaluated in terms of a potential, which they may or may not fulfil later, while the final year students are assessed on the basis of what they have already learned/achieved. A further series of correlation analyses presented below elicit what these results may indicate.

General cognitive ability

Individual levels of general cognitive development were identified as there were no consistent correlations within visual-spatial or ideation groups of abilities, or between them, for many test takers. With some participants scoring high on one test of spatial or ideation ability and low or average on another, it was often hard to distinguish between clearly high, low or medium spatial or ideational ability individuals. There were also different score fluctuations for group results on different tests, with visual memory scores having the lowest fluctuation and most students scoring considerably above the mean for general public, and maze tracing being the closest to general public and high on score variability.

A series of clustering using partitional (k-means) and hierarchical (sample average and median) methods were performed to identify general ability groups within the sample, then split by two groups of subjects (4 in the first year and 4 in the fourth and final years respectively). The general ability variable has been previously described in Experiment I/a. It includes visual-spatial and ideation abilities scores analysed jointly to identify four principal ability levels ('high', 'medium-high', 'medium-low' and 'low'¹⁰) further ascribed numeric values of 4-1.

The above data on students' abilities, academic performance and creativity was correlated with the ability scores to determine whether individual aptitudes and/or the general cognitive development could serve as predictors of academic performance and creativity on design projects (the lowest or the poorest ability / level of creativity / performance were ascribed a numeric value - 1 and the highest - 4).

Cognitive abilities, creativity and academic performance

Table 21 indicates that similar correlations can be observed in all three test groups, though the magnitudes of correlation coefficients vary, with some correlations only present in either group.

For the first year they include:

1. *Creativity* is correlated with *Symbols*, *Controlled Associations*, *Academic Performance* and *General Ability* measures,
2. *Academic performance* is correlated with *Symbols*, *Storage*, *Controlled Associations*, *Paper Folding*, *Building Memory*, *Creativity* and *General Ability*, and
3. *General Ability* is correlated with *Controlled Associations*, *Card Rotations*, *Paper Folding*, *Building Memory*, *Creativity* and *Academic Performance*.

In other words, ideational abilities and general ability predict creativity in the first year students. This set of ideation tests correlates stronger with creativity than *Elaboration* and *Ornamentation* in the former experiment, because they tap complex creative abilities, more typical of design tasks. It is clear how figural ideation abilities are related to visual creativity, yet, verbal ideation may be as important. There are studies suggesting that a process of 'verbal punning' involving translation between visual and verbal forms of expression constitute a catalyst of creativity. It is frequently employed to generate solutions with both visual and verbal resonance (Tomes, *et al.*, 1998). Assessments of academic performance are correlated with visual-spatial and ideational abilities, general ability and creativity, which may mean that developed visualisation and

¹⁰ Relative of other participants in Exp. I/b, as only 10% scored marginally below the mean for lay people

ideation are essential for the first year. Whereas general ability is dependent on verbal ideation (i.e. associative fluency) and visual-spatial abilities (i.e. spatial visualisation, spatial relations and visual memory), which are strongly correlated among each other. General ability predicts both academic performance and creativity. Single visual-spatial abilities do not have a predictive effect on creativity, though are correlated with them as a group (also illustrated by Table 29). And, finally, academic assessment is correlated with creativity.

Table 21. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiments I/b & III/b

Test	O	Sy	S	AW	CA	CR	PF	MT	BM	C	AP	AL
Year 1												
Ornamentation	1											
Symbols	0.261	1										
Storage	0.394	0.589	1									
Arrang. Words	0.052	0.135	0.382	1								
Contr. Assoc.	0.269	0.637*	0.404	0.571	1							
Card Rotation	0.147	0.505	0.320	0.246	0.169	1						
Paper Folding	0.385	0.574	0.479	0.508	0.395	0.824**	1					
Maze Tracing	0.268	0.302	0.020	-0.557	-0.149	0.081	-0.049	1				
Building Mem.	0.462	0.475	0.541	0.532	0.514	0.249	0.641*	-0.461	1			
Creativity	0.325	0.906**	0.620	0.191	0.720*	0.577	0.520	0.274	0.346	1		
Acad. Perform.	0.376	0.644*	0.792**	0.600	0.710*	0.462	0.677*	0.020	0.695*	0.762*	1	
General Ability	0.304	0.597	0.490	0.620	0.663*	0.727*	0.844**	-0.230	0.660*	0.677*	0.812**	1
Years 4&5												
Ornamentation	1											
Symbols	0.012	1										
Storage	0.119	0.777**	1									
Arrang. Words	-0.291	0.561	0.321	1								
Contr. Assoc.	0.104	0.105	0.178	0.308	1							
Card Rotation	0.530	0.464	0.425	0.314	-0.025	1						
Paper Folding	0.500	0.173	0.095	0.107	-0.251	0.634*	1					
Maze Tracing	0.532	-0.236	0.073	-0.478	0.565	0.053	0.075	1				
Building Mem.	0.528	-0.159	0.016	-0.253	0.171	0.345	0.667*	0.552	1			
Creativity	0.499	0.233	0.118	0.290	-0.202	0.778**	0.777**	-0.182	0.552	1		
Acad. Perform.	0.571	-0.160	0.535	0.000	0.184	0.445	0.664*	0.346	0.896**	0.740*	1	
General Ability	0.595	0.321	0.667*	0.125	-0.046	0.745*	0.903**	0.227	0.694*	0.762*	0.678*	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

The correlations observed in the fourth and final years are:

1. *Creativity* is correlated with *Card Rotations* and *Paper Folding* tests
2. *Academic performance* is correlated with *Paper Folding*, *Building Memory* and *Creativity*
3. *General Ability* is correlated with *Storage*, *Card Rotations*, *Paper Folding*, *Building Memory*, *Creativity* and *Academic Performance*

These correlations suggest that only spatial abilities predict creativity in the fourth and final year students. Assessments of academic performance are correlated with visual-spatial abilities and creativity. Whereas general ability has a stronger component of visual-spatial abilities (i.e. spatial visualisation, spatial relations and visual memory indicating high correlations among each other), than it has of ideation abilities. It is correlated with figural flexibility (*Storage* test), but on this test, participants generate new and different solutions to figural problems supported by visualisation – an ability for manipulating three-dimensional objects and mental synthesis. The reason for low predictive effect of ideation may be the growing complexity of design tasks.

That is, tasks used in ability tests are relatively simple, related to visual/verbal creativity more characteristic of the first year design education (i.e. where, often, form is emphasized over function). Whereas most projects in architecture are multifaceted complex activities, dealing with a large number of constraints to accommodate diverse specifications.

Thus, to establish reliable correlations between ideation factors and creativity or academic performance in architecture, a creativity measurement beyond the measurement of the quantity of ideas generated shall be used. In this sense visualisation abilities are better predictors of academic performance as they involve more complex cognitive processing characteristic of design tasks. Additionally, complex design exercises may be less likely to rely upon abilities emphasizing high speed, as they are usually not a subject to time constraints characteristic of cognitive tests. That is why, perhaps, maze tracing has no observable correlations with any other spatial test, creativity or academic performance. Though measuring an essential ability for spatial scanning, it is mostly a time- rather than a quality of execution-dependent measure – its scores indicate how much rather than how well one can trace a maze because false leads are obvious to the subject. Finally, complex design exercises may be less likely to have linear correlations with figural fluency ability (or any other ability emphasizing high speed over quality) as they are typically not a subject of time constraints, unlike the cognitive tests.

Finally, general ability predicts both academic performance and creativity in the fourth and final year students, where the latter are only correlated with visual-spatial abilities. Possibly due to the above reasons, that is creativity in architecture is much more than the ideation ability. Whereas cognitive psychologists consider fluency and novelty as the primary measures of ability to generate ideas (Torrance, 1962, 1964), architectural design must also satisfy intended functions to pre-defined set of specifications. Thus, idea generation abilities in design may need to be evaluated by metrics different from the commonly used in the creativity research, i.e. intended to assess non-utilitarian artefacts (Shah, *et al.*, 2002). Additionally, creativity is much more than ideation abilities; it includes psychological and affective traits, knowledge of creative processes, environmental and cultural influences, former experience with a wide scope of tasks, styles of thinking, and so on. In this case, the more complex and essential visual-spatial abilities may serve as a better predictor of creativity. And, lastly, academic performance is correlated with creativity, which is an expected outcome, as creativity in architecture is crucial.

5.1.4 Conclusions

Experiments I/b & III/b explored relationships and correlations between education and design abilities. It sought to determine whether spatial visualisation and ideation skills could be enhanced via teaching and learning activities. The data showed it may be possible, though the improvement in the components of *Gv* and *Glr* abilities vary. According to this experiment, the largest gain was on visual memory, and the least on spatial scanning. It is possible for *MV* to be highly developed among architects due to a wide range of tasks and activities that both improve the quality of visual memory and depend on its use. Spatial learning strategies have also been found to be the cause of superior memory (Maguire, *et al.*, 2002). The transfer-of-training effect between visualisation and visual memory may also be present. Advanced spatial scanning ability, on the other hand, may not be as important in the form it is measured by ability tests – when the speed of performance is emphasized. Not many architectural tasks depend on time-constrained scanning of complex visual material, hence the lowest gain on this factor.

The idea of ability trainability is in conformity with the previous research by Piaget (1971), Sorby and Baartmans (1996) and a vast number of other studies. While our deductions are mainly founded on the observation that all aptitude scores are higher in the fourth and final years, suggesting that idea production and spatial abilities are not fixed, but involve processes that may be changeable in adulthood. It is though understood that a longitudinal study and a larger sample are necessary to ensure the adequately supported conclusions.

Another observation concerns general cognitive development, which may serve as a predictor of academic performance and creativity in both groups of students, though with unequal strengths.

As ideation abilities of the fourth and final year students do not show significant correlations with academic performance, it is likely that other factors relating to teaching, previous instruction and complexity of design tasks, thinking styles, problem-solving strategies, knowledge, experience, and so on may, be of equal or higher importance.

Finally, as there is much resemblance in the test results and outcomes of analyses between Experiments I/a and I/b, it is likely that the second sample (i.e. 20 people) is as, or similarly, representative of the student population it draws from as the first sample (60 people), and it is possible that it is representative of the population in general (i.e. Australian architecture and design students only). We do not wish to construct any arguments based on this observation, as this study only seeks to establish tentative links and avoids generalisations and extrapolations to other contexts, but expect it to add to the validity and reliability of the inferences made.

On a more detailed level the results indicated:

- no significant gender or ethnicity-related differences in the ability levels;
- spatial ability scores are generally higher among the tested architecture and design students when compared to lay people, and this observation is valid for each year;
- 10% of students from both years are ‘objectively’ low ability individuals, that is not only within their respective groups but compared to other samples from the general population (i.e. their combined means are marginally lower);
- spatial ability scores of the 1st year students are generally lower when compared to years 4 & 5. This leads to three possible implications (1) the ability is also a skill which can be developed and/or there are learnt strategies that allow achieving higher results on cognitive tests; (2) high spatial individuals have a better prospects of fulfilling course requirements and, therefore, to continue education through to the final year; or (3) a combination of both. Longitudinal research with a bigger sample is necessary to understand this issue better;
- 30% of high spatial and low spatial individuals were identified in both groups; all of their scores were significantly higher or lower than the group Mean. However, the other 70% of students show uneven ability profiles. That is, scoring high on one/several tests and below average of low on another/others, even within the same group of cognitive factors. There may be different explanations to this observation, including some of the abilities to be more trainable or more likely to be improved via the course of education, the transfer-of-training effect, the more efficient uses of compensatory strategies during cognitive testing, and so on;
- there are no consistent correlations between and within the visual-spatial and ideation groups of abilities. Some abilities within each respective group are inter-related (i.e. visual memory, spatial relations and visualisation), while others are not;
- visual-spatial abilities of the 1st year students are correlated with academic achievement and creativity; their ideation abilities are also correlated with the same parameters;
- visual-spatial abilities of the fourth and final year students are correlated with creativity and academic achievement, ideation abilities are not correlated with either;
- there is a general tendency for the high spatial and high general ability individuals to be reported as very good or good students, while the low ability students are mostly described as average. However, 10% of the test participants (predominantly of the fourth and final years) do not fall into these categories;
- more abilities predict academic performance and creativity of the first year designers, suggesting their higher importance, possibly due to the fact that the 4th and final year students (a) have succeeded in developing a range of aptitudes necessary for the domain performance, or (b) acquired certain ways of compensating for ability limitations; and
- there are no major differences in the character of test results of Experiments I/a and I/b.

Finally, the influence of g needs to be understood before the psychological and performance related significance of specific cognitive abilities can reveal themselves, because assessment instruments designed to measure these abilities typically carry large components of general intelligence, along with their own uniqueness (Lohman, 2002). There are many modern researchers who have conceptualized and appraised this construct. Kuncel, Hezlett, and Ones's (2004) meta-analytic work documents that general cognitive ability plays a role in determining graduate training and work outcomes even within the top third of the range of g . Their research has revealed how the same source of individual differences cuts across the school to work transition. Schmidt and Hunter (2004) added to their massive amount of work in occupational psychology by explicating the role that general intelligence plays in identification, performance, and self-selection in the world of work. Among the tests used by these researchers are visualization, spatial relations, visual memory, and spatial scanning. Finally, in addition to g , one needs to look further into other sources of individual differences influencing the performance on cognitive tests, or affecting the use of abilities in concrete problem solving situations, which may include individual cognitive or learning styles, strategies, and more.

5.2 Learning Styles

The second set of tests administered in this study was aimed at assessing individual positions on two dimensions of learning styles – Wholistic-Analytic and Visual-Imagery, chosen on the basis of (a) their relevance to the design ability as suggested by the design research literature (Bernstein, 1988; Cross, 1992, 1995; Löwgren & Stolterman, 1998), and (b) believed to have a significant influence on problem solving and domain performance, as reported by many authors from different research areas (Cross & Nathenson, 1981; Pask, 1988; Borg & Shapiro, 1996; Lawson, 1990, 1997; Sternberg & Grigorenko, 1997; Ziegert, 2000, Durling, 2001, etc). The following subsections describe the process and the outcome of the psychometric testing conducted; and present series of statistical analyses of the acquired data.

5.2.1 Experiments II/b-III/b: Assessment, Analyses and Findings

This part of the empirical study seeks to determine (1) whether designers and architects involved in Experiment II/b have predominantly wholistic and visual learning styles (2) whether they are flexible and efficient in adapting their styles to the needs of education and design practice, (3) whether learning styles can change as a result of a new and different learning environment, (4) whether there are differences in learning styles related to gender and ethnic origins, (5) whether there are significant differences in the learning styles of the first and fourth-final years students, and (6) whether there are significant correlations between the measures of academic performance, creativity and learning styles. The ultimate purpose of this experiment is to provide the basis for inter-relations and correlations between the analysed data concerning students' learning styles, and the *process* and the *product* of design problem solving.

Participants

Are the same 20 students from the University of Sydney, Faculty of Architecture, who had been administered a set of cognitive tests in Experiment I/b. 10 participants were the first year design students, 10 (4+6) were architecture students doing their fourth and final years respectively.

Procedure

The participants were tested on an individual basis. At each of the instrument administration sessions exact procedures were followed. Subjects were read, verbatim, the instructions provided by the instrument manuals, as they could accustom themselves with the goals and structure of testing outlined in previously distributed materials. The testing procedure involved students responding to a number of statements by marking them as 'true', 'false' or 'undecided'

(a sample questionnaire can be found in Appendix B). Total experiment duration was 35±5 minutes long depending on the fluency of individual responses.

Materials

All test materials are available online; tests can be completed electronically at the Creative Learning Company website¹¹, or downloaded as test sheets for manual completion and subsequent scoring with LSA software (also downloadable). The Learning Style Analysis assesses 49 individual elements in the six basic areas, represented as layers of a pyramid. The first four of these layers are believed to be biologically or genetically determined and the last two conditioned or learned. This study is only interested in two main layers. That is, *left/right brain dominance* describing (1) sequential or simultaneous brain processing strategies; (2) reflective or impulsive thinking styles; and providing an overall view of analytic and wholistic learning styles. And *sensory modalities* describing (1) verbal – reading, writing, talking and inner dialogue, and (2) visual – seeing and visualising, preferences in problem solving and approaching problem situations, as well as the strengths and weaknesses in dealing with them. The model treats each dimension as a continuum representing different combinations of the bipolar adjectives at each end of the continuum, i.e. the learner may use both wholistic and analytic processes but have a strength towards the wholistic end of the continuum.

Scoring

The results from collected test forms were scored by a four-measure scale, and transferred into the LSA Response Sheet. The rest of the scoring was done electronically via entering the data into the LSA-Adult Software in accordance with the instructions provided. Data entry was • 10 minutes per test. The results were then revealed in a form of composite scales reporting participants' *strong preferences*, *non-preferences* (inclinations to avoid if possible), *flexibilities* (situation or task-dependent factors that come with ease) and *strong adaptabilities* (situation or task-dependent factors that come with effort) for each of the four dimensions. The instrument provided interpretations of each individual test (see sample account in Appendix F). It reported invalid scores in case of contradictory responses for the purpose of reliability. The scoring procedure was followed by a series of statistical analyses discussed below.

Test results

The scoring results of Experiment II/b are presented in Tables 22-23, for the first and fourth-final years separately. Each table includes several dimensions arranged in three categories. The first two categories are further divided into analytic and wholistic components. The first category is *brain processing*, consisting of sequential (analytic) and simultaneous (wholistic) aspects. The second category is *thinking style*, containing reflective (analytic) and impulsive (wholistic) elements. A preference or strong preference in any of these elements indicates the natural ability of using different thought processes and/or a particular, natural style of thinking.

Brain processing: Sequential-Simultaneous. Students with sequential-analytic preferences learn step-by-step, prefer logical and analytic processing, focus on details. Learners with simultaneous-wholistic preferences need the big picture, may jump from task to task, and use creative right brain skills. Students with analytic and wholistic flexibilities have the ability to switch between left and right brain processing but tend to use the preferred mode. And students with dual preferences are capable of integrating left and right brain activities in one task.

Thinking style: Reflective-Impulsive. Students with reflective-analytic preferences do not act before considering all options, tend to ponder on problems, need time to think things over. Learners with impulsive-wholistic preferences are quick thinkers or risk takers, they have a tendency toward disorganised thinking patterns, and are spontaneous in their decision making. Students with these flexibilities can utilise both styles easily, they switch between quick reaction and contemplation but tend to use the preferred style more.

¹¹ <http://www.creativelearningcentre.com/>

*Sensory modalities: Verbal Internal and Verbal External*¹². Students with verbal-internal (self-talk) preferences talk to themselves when dealing with something difficult, have ongoing inner dialogue which helps them remember and understand new concepts. Learners with these flexibilities may have inner talk going on but do not always need it for better understanding. Students with verbal-external (words, reading) preferences remember much of what they read, prefer written information and communication (notes, instructions). Students with these flexibilities, if interested, can memorise a lot of what they read, they need written information to help them remember.

Sensory modalities: Visual Internal and Visual External. Students with visual-external (observing) preferences remember and understand best through watching, need visual stimulation. To words and written text, they prefer using pictures, mind maps, diagrams, etc. Students with these flexibilities, if interested, can retain a lot of what they see, they need visually-based tasks and study materials to enhance their understanding. Students with visual-internal (visualisation, imagery) preferences usually have a strong imagination, remember through visualising and see information internally. Students with these flexibilities, will use visualisation to remember, understand, or reason according to the situation.

High scores in both wholistic and analytic dimensions indicate that this person is highly integrated in using mental techniques, utilising both brain hemispheres equally strongly at any given time. Similarly, the more preferences and strong preferences someone has in sensory modalities, the easier it is for this person to absorb new information and apply it in problem solving. People with preferences and/or strong preferences in all areas, are called *brain-gifted*. When the result shows mainly flexibilities and/or adaptabilities in the wholistic-analytic mode, the person might find it hard to concentrate and follow through with problem solving (relying upon either style or strategy) when not interested or when dealing with difficult or unfamiliar tasks. In such cases, s/he needs being motivated to absorb and retain new information. Overall flexibility in the sensory areas means that these students can learn and reason through either mode, but mainly if their other preferences are matched in a learning situation, or a ‘multi-sensory’ approach is used, as learning through one modality may not be sufficient. If the learners do not have non-preferences (i.e. learning styles which they cannot utilise efficiently or prefer to never use), they are called *versatile*.

As it is clear from Table 22, four first year designers have preferences in simultaneous, right-brain processing. They are multi-task learners who need a general overview of the problem and being explained task motivation before they are ready to start. They prefer concepts to facts and apply random, rapid, open-ended approaches to problem solving. Three of them are also visual learners. Preferences in external visual mode mean that these students remember and understand new and difficult concepts best when visual sources like diagrams and pictures are included in a learning experience and instructional methods. Preferences in internal visual mode show that these learners are likely to have a developed imagery and visualisation ability and will rely on visualising in dealing with new or difficult study content and design tasks. One of wholistic students is a verbal learner. This means that he favours verbal and written instructions (over visual and figural), though prefers them abstract and general. He relies on verbal processing when dealing with a wide range of tasks and situations and has an ongoing inner dialogue.

Three first year designers have preferences in sequential, left-brain processing. They have an inclination towards structured exploration, prefer facts to concepts, learn more easily when they can study rules sequentially and apply a step-by-step approach to problem solving. These students feel most comfortable when they don’t have to risk error as they learn or resolve problems. Two of them have strong preferences for visual processing and one – for verbal.

¹² *Sensory modalities* describe through which *senses* a person prefers/dislikes to take in and process new and difficult information. We replaced LSA’s *auditory-internal*, i.e. inner dialogue, and *visual-words*, i.e. reading and writing, modes with *verbal internal* and *verbal external* modes (names only), as these LSA descriptions correspond well to the Verbal learning style dimension this study is interested in.

Table 22. Learning styles as assessed by LSA: Year 1, Experiment II/b

Student / Year / Gender	Brain Processing		Thinking Style		Sensory Modalities			
	Wholistic Simultan.	Analytic Sequent.	Wholistic Impulsive	Analytic Reflective	Visual External	Visual Internal	Verbal External	Verbal Internal
01/I/fem								
02/I/male								
03/I/male								
04/I/male								
05/I/male								
06/I/fem								
07/I/fem								
08/I/male								
09/I/fem								
10/I/fem								

	Strong preference (always needed, corresponds to primary learning style)
	Preference (needed most of the time)
	Flexibility (adjustable to situations, comes natural)
	Strong adaptability (comes with effort, influenced by situation/context)
	Non-preference (avoid if possible)

Six students have preferences and flexibilities in wholistic and analytic brain processing; this means they can view concrete situations from many different perspectives and are good (or reasonable, depending on the preference strength) at understanding a wide range of information and putting it into concise logical forms. Most of the students are also hardly ever impulsive in their thinking style, as they generally prefer to reflect on things, analysing and contemplating all aspects of a learning assignment. Wholistic-simultaneous reflective learners combine reflective observation with abstract conceptualisation. Analytic-sequential reflective students combine concrete logical thinking with reflective observation. Two learners have preferences/flexibilities in impulsive thinking and adaptabilities in reflective thinking which means they may have difficulties in adjusting to adverse learning situations and may lack in concentration. Majority has quite considerable flexibility in sensory modalities. This means they are good at verbal as well as visual reasoning and must use multi-sensory techniques when learning something new and difficult or engaging in problem solving. That is, they have to combine talking, watching, reading, writing, drawing, modelling, and other activities to achieve better academic results.

Overall, no learner fits neatly into one particular style, but rather is inclined towards one area more than another. The results suggest that consideration should be given to both the type of learning style preference and the degree of that preference. There are more first year students with flexibilities than with preferences or strong preferences, which means there are less students with the natural well-developed ability for using different thought processes, and more students that may switch between different modes if necessary. There is one important aspect to style flexibility, these students may find it hard to concentrate on one activity for a long time. They may lose interest in a topic, project or an assignment, because they would find it more difficult than versatile students. It may happen during a prolonged instruction, or, equally, during intense or/and extensive reasoning on design tasks.

Summarising the above, half of the first year designers would prefer teaching and learning which begins with the big picture and concepts, and then proceeds to details. Whereas the other half is more comfortable with a structured instruction, which introduces new information in a step-by-step ‘facts first – concepts next’ fashion. Majority being sufficiently flexible in both styles would also like teaching/learning that is focused toward future possibilities and gives alternative viewpoints. At the same time, it has to show objective data, that is logical and analytical. It has to be based on exemplars showing concrete things, containing visually-based material, and must also involve verbal instructions and written assignments.

These results are, in many ways, similar to the finding of Cross, Durling and Johnson (1996a; 1996b) despite of their use of a different instrument – the Myers-Briggs Type Indicator (*MBTI*, 1975). However, contrasting to their observations, half of this study’s designers prefer teaching which begins with details and facts, and then progresses to generalisations. They are more comfortable with initial guided instruction that adopts a step-by-step approach. Yet, as the above researchers also suggest, while there are styles characteristic of occupational groups, there is no universal schema of design learning that can accommodate all designers.

Similarly, in their more recent studies of architecture students, Demirbas and Demirkan (2003), and Kvan and Yunyan (2005), who employed yet another assessment instrument (Kolb’s *LSI*, 1976), discovered that learning styles of designers varied within an education major, indicating that inside the seemingly homogeneous groups such as design or architecture courses, differences in learning styles do exist.

One of the reasons for a high percentage of analytical and verbal learners has been the argument of many learning style developers, claiming that traditional, formal schooling (and higher education even more so) are too biased towards students who are verbal analytics in their approach, that teachers themselves tend to be verbal analytic learners, and that the longer people stay in the education system, the more analytic they become (Coffield, *et al.*, 2004). This may well be true, provided that prior achievement at school is a prerequisite to enrolment in architecture courses. However, as the amount of verbal learners is lower than of visual learners (and majority is flexible in both modes) to making claims regarding the enduring strength of the influence of previous education requires more support. Similarly, many analytical learners have been reported by LSA as fairly flexible in applying wholistic approaches to learning or dealing with problem situations.

These results suggest that more attention should be given to the direction of learning style preferences and the strength of these preferences in relation to academic performance and reasoning on design tasks. In architecture, being a versatile learner with a strong preference for analytical thinking may prove more beneficial in terms of general achievement than being a wholist with a lack of ability for analysis. The idea gains more credibility as this study looks into the test results of the fourth-final year students.

Table 23. Learning styles as assessed by LSA: Years 4&5, Experiment II/b

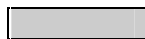
Student / Year / Gender	Brain Processing		Thinking Style		Sensory Modalities			
	Wholistic Simultan.	Analytic Sequent.	Wholistic Impulsive	Analytic Reflective	Visual External	Visual Internal	Verbal External	Verbal Internal
11/IV/male								
12/IV/male								
13/V/fem								
14/V/fem								
15/V/male								
16/IV/fem								
17/IV/fem								
18/IV/fem								
19/IV/male								
20/V/male								



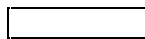
Strong preference (always needed, corresponds to primary learning style)



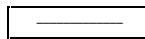
Preference (needed most of the time)



Flexibility (adjustable to situations, comes natural)



Strong adaptability (comes with effort, influenced by situation/context)



Non-preference (avoid if possible)

As Table 23 indicates, four fourth and final year designers have preferences in simultaneous, right-brain processing. They would require to be explained the big picture first, and then the

particulars of a design course assignment. Similarly, when reasoning on design tasks, these students would approach a problem situation with a general overarching idea and are more inclined towards adopting top-down processing. They are multi-task learners who are capable of doing things simultaneously, and may omit details whilst keeping an overview of the entire task. They are perceived as creative but may become quite random in thought processing. All four are also visual learners. Preferences in external visual mode – one student, mean that he remembers and understands new and difficult concepts best when visual sources like diagrams and pictures are included in a learning experience and instructional methods. Strong preferences in internal visual mode of all four students, show they are likely to have a highly developed imagery and visualisation ability and will rely on visualising in dealing with new or difficult study content and design tasks. Three of these students are also verbal learners. This means they are comfortable with verbal and written instructions and assignments, though would prefer them rather abstract and general. They are highly flexible in both modes, suggesting that they rely on both verbal and visual processing when dealing with a wide range of tasks and situations.

Seven architects have preferences in sequential, left-brain processing. Six of them have an inclination towards structured exploration, prefer facts to concepts, learn more easily when they can study rules sequentially, and apply a step-by-step approach to problem solving. These students are more comfortable when they do not have to risk error as they learn or solve problems. They are likely to start with a detailed analysis of the different components of a situation to proceed to a more general idea. Thus, when dealing with problem situations these learners are inclined to adopting a bottom-up approach. One of the seven analytics is a brain-gifted learner who is naturally strong in both styles of thinking. Preferences or strong preferences on both wholistic and analytic modes indicate that this person is highly integrated in using mental techniques, utilising both brain hemispheres equally efficiently at any given time.

Three of the seven analytics have strong preferences for visual processing and three – for verbal. All of the fourth and final year students have considerable flexibility in sensory modalities. This means they are good at verbal as well as visual reasoning and can apply either, depending on the specifics of a design project or the type of an assignment.

Nine students have preferences and flexibilities in wholistic and analytic brain processing; indicating that they can view concrete situations from many different angles and are good (or reasonable, depending on the strength of preference) at understanding a wide range of information and putting it into concise logical structure. Most of the students are also hardly ever impulsive in their thinking style, as they generally prefer to reflect on things, analysing and contemplating all aspects of a learning assignment. Wholistic-simultaneous reflective learners combine reflective observation with abstract conceptualisation. Analytic-sequential reflective students combine concrete logical thinking with reflective observation. Two learners have flexibilities in impulsive thinking and preferences/flexibilities in reflective thinking which means they have no difficulties in adjusting to adverse learning situations and, though find it easy to reason or act quickly or spontaneously, are also capable of slowly thinking things over before they respond or make a decision.

In summary, 30% of the fourth-final year designers may prefer teaching and learning which begins with the big picture and concepts, and then proceeds to details. Whereas fifty percent are inclined towards having a structured instruction, which introduces new information in a step-by-step and/or bottom-up ‘details first – overview next’ fashion. The remaining 10% are brain-gifted students equally comfortable with either style. However, as 90% of the fourth and final year students are flexible or highly flexible in both styles, both types of instructions shall be appropriate. Similarly, as the majority is versatile in all modes, they shall benefit from teaching/learning focusing toward future possibilities and giving alternative viewpoints, and, at the same time, showing objective data, that is logical and analytical. Both instruction and learning, or problem solving, have to be supported by exemplars showing concrete things, containing visually-based material, and must also involve verbal and written assignments.

The above suggests that, when the direction of learning style preferences is considered, the situation with both groups of students is rather similar. But there are considerable differences in

the strength of preferences. As is it clear from Tables 22 and 23, there are many versatile learners among the first and the fourth and final year students. Yet, there are more students with preferences and strong preferences in years 4 and 5, whereas the first year students have flexibilities mainly. Similarly, there are 10% of brain-gifted students among the first year students, in Visual-Verbal mode only, and 30% of brain-gifted students from years four and five, both in Wholistic-Analytic and Visual-Verbal dimensions. There are also 20% of learners in the second group who are highly versatile in brain processing and thinking styles (Table 25).

A strong flexibility between simultaneous, more right-brain style, and reflective, more sequential style of brain processing and thinking is a definite strength in complex learning and problem solving situations. The advantage of the students' versatility is in being able to adjust one's thinking style to match the situation. Given the complexity of design- and architecture-related exercises, it is almost necessary to be highly flexible in thinking styles. Being strictly wholistic or strictly analytic, only reflective or always spontaneous is not sufficient for achieving good academic results in a range of architecture-related courses. Similarly, it is important to be flexible in both visual and verbal modalities to fulfil a variety of requirements architectural educations sets for its students. It is not surprising, therefore, that no learner fits neatly into one particular style, but, rather, has a range of styles, although may be inclined towards one area more than another.

Effects of gender of participants

The MANOVA analysis of the learning style scores, gender, year of study, and ethnic origin, has not revealed a significant main effect or interaction for gender (Figure 3, Tables 26, 27). The data suggests there could be marginal gender differences in the strengths of learning preferences on both dimensions, with females in the sample more inclined towards the verbal mode (females Mean=3.40, SD=0.84; males Mean=3.30, SD=0.70) and wholistic simultaneous thinking (females Mean=3.6, SD=0.84; males Mean=3.30, SD=1.16) and males – towards the visual internal mode (females Mean=3.70, SD=1.16; males Mean=4.00, SD=0.81) and analytic sequential thinking (females Mean=3.50, SD=0.85, males Mean=3.70, SD=0.07).

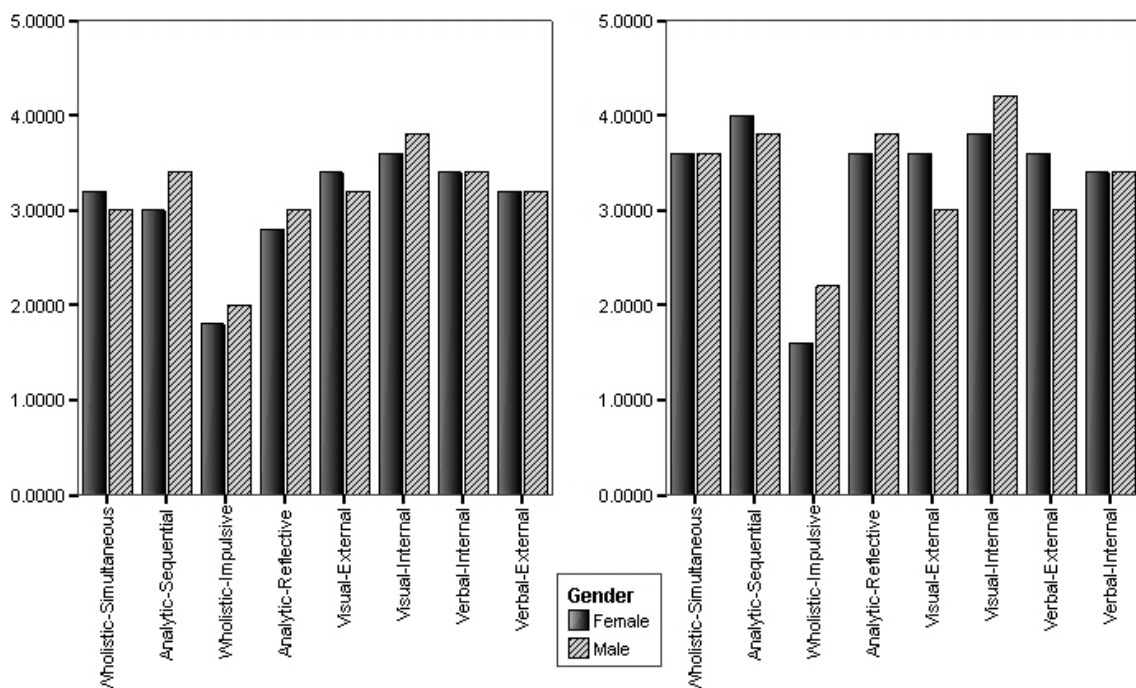


Figure 3. Comparison of learning styles (Means) by year and gender: Year 1(left), Years 4&5 (right)

This agrees with some of the former findings that discovered for male gender to be related to visual thinking, and for female gender to be related to verbal thinking (Smith, 1964). And

contradicts gender distinctions reported by Antonietti and Gioletta (1995) who ascertained that males tend to use analogical solutions (i.e. referring to previous problems to solve current problems) characteristic of field independent thinking, more frequently than females¹³.

Effects of ethnicity of participants

The joint analysis of the learning style scores, gender, year of study, and ethnic origin, showed differences between the groups based on ethnic origin. The one-way analysis of variance of cognitive style scores based on ethnic origin revealed that the Australasian and Australian groups had significantly different learning style scores on the Wholistic-Analytic dimension, and marginally different learning styles on the Visual-Imagery dimension. There are more analytic and visual learners among Australasian students and, correspondingly, more wholistic and verbal students among Australians (Table 24). The differences become less significant on both modes of the fourth and final year students when flexibilities are equalised with preferences or strong preferences (data on ethnicities is included in Appendix A tables).

Table 24. Effects of ethnicity on learning styles: Experiment II

		Year 1				Years 4&5			
		Wholist	Analytic	Imager	Verbal	Wholist	Analytic	Imager	Verbal
Australasians	Mean	3.00	3.40	4.00	3.00	3.60	4.00	4.20	3.00
	SD	0.71	0.84	1.00	0.71	0.89	0.71	0.84	0.2
Australians	Mean	3.40	3.20	3.40	3.80	3.80	3.60	3.60	3.80
	SD	1.10	0.45	1.14	1.10	1.34	0.84	0.45	1.10

The results of this study confirm the findings of a number of researchers regarding the differences in cognitive styles of ethnic populations and white students (Castaneda, *et al.*, 1972; Ramirez & Price-Williams, 1974; Kagan & Zahn, 1975). The comparisons between groups based on ethnic origin indicated that Australasian and Asian students were significantly more field dependent (field dependent individuals perform better in serial processing situations i.e. sequentially processing one thought, which is similar to *analytic sequential* mode in LSA). Equally, students from different language/cultural backgrounds often differed significantly in their learning style preferences on the Visual-Imagery dimension. For example, Korean students were the most visual in their learning style preferences, Arabic and Chinese language groups coming next, whereas native speakers of English selected visual learning as a minor rather than a major preference. However, in case with our subjects the differences may be minimal because architecture is a visually-based discipline which attracts visual learners, and because most of the Australasian students were raised in Australia (or spent there most of their lives).

Willing (1988) also came up with a similar finding about the relationship between learning styles and cultural backgrounds. He used a self-report questionnaire to collect data about his subjects, immigrants in Australia, and grouped them into four categories as analytical, concrete, communicative and authority-oriented. These four different learner groups constituted 10%, 10%, 40%, 30%, respectively, of the sample. Willing's study results suggested that preferred learning styles strongly depended on cultural differences, also leading to differences in academic achievement (Reid, 1987; Willing, 1988).

Pre-architecture, architecture students and lay people

As per the earlier discussion, design methodologists typically suggest that, to be successful, the process of designing should be a wholistic experience (McCormick, *et al.*, 1993; NEAB, 1993; Atkinson, 1997; 1998). Interpretation of this belief in the context of learning styles indicates that those at the wholistic rather than analytic end of the Wholistic-Analytic dimension should

¹³ Other literature also suggests that, overall, males have higher levels of field independence than females (Witkin, *et al.*, 1971). However, the dichotomy of field dependence-independence is only in part similar to the wholistic-analytic mode. Field independence, for instance, bears some of the features associated with both wholistic and analytical processing. Thus, comparisons may not always be appropriate.

make the best designers. The relationship between designing and the Verbalizer-Imager dichotomy can be inferred from the research showing that imagining is central in the generation and development of ideas (Garner, 1989; Kimbell, *et al.*, 1991; Liddament, 1993; Chidgey, 1994; Barlex, 1994). Thus, it is expected that those whose learning style is situated at the imaging rather than verbalizing end of the Verbalizer-Imager dimension should make the best designers (Glegg, 1986). When a combination of both learning style dimensions is considered, the wholistic imagers (visualisers) are believed to have a potential advantage over students in other learning style groupings in the context of design project work.

A significant number of the published research on cognitive and learning styles focuses on the differences in students pursuing different majors (reviewed in Subsection 2.1.2). Much of it asserts that architects and designers are predominantly visual wholistic individuals (MacKinnon, 1962; Cross & Nathenson, 1981; Davies & Talbot, 1987; Newland, *et al.*, 1987; Cross, 1995; Cross, *et al.*, 1996a; 1996b; Demirbas & Demirkan, 2003; Kvan & Yunyan, 2005), though there are variations in technical vocabulary. The problem with these seemingly credible observations is the proliferation of dichotomies used, that betokens a serious failure of accumulated empirical support due to an absence of well-grounded findings tested through replication, and a lack of theoretical coherence of the main models. There is some overlap among the concepts used but no direct or easy comparability between approaches or test results.

Regrettably, it has not been possible for us to gain access to the research involving design and architecture students that utilises either LSA (Dunn & Prashnig, 1991) or LSI (Dunn & Dunn, 1978) instruments. This is either due to the general scarcity of studies of learning styles in the domain of architecture, or because these models have been unpopular among the design studies researchers. And, complicating the situation more, some of the latest sophisticated learning models argue that different disciplines require not only different teaching and learning, but different assessment methods. Entwistle, McCune and Walker (2001), for example, are clear on this point when they maintain that methodological approaches have to be refined within each discipline or professional area to ensure they include the learning processes necessary for conceptual understanding in that particular area of study; and that these processes need being evaluated by metrics different from the ones commonly used in education or research.

Table 25. Comparison of learning styles: Years 1 and 4&5, Experiment II/b

Year 1				Years 4&5			
Learning styles (strong preferences and preferences)	Total %	Versatile %	Brain-gifted %	Learning styles (strong preferences and preferences)	Total %	Versatile %	Brain-gifted %
Wholistic	40	60	0	Wholistic	40	80	10
Analytic	30			Analytic	70		
Verbal	30	70	10	Verbal	40	80	20
Visual	50			Visual	60		
Wholistic-Visual	30	60	0	Wholistic-Visual	40*	90	0
Wholistic-Verbal	10			Wholistic-Verbal	20		
Analytic-Visual	20			Analytic-Visual	40		
Analytic-Verbal	10			Analytic-Verbal	30		

* 50% of the students with Wholistic-Visual learning style also have preferences/strong preferences in the Verbal mode, i.e. are listed in two cells, the current one and the one below it

As it is clear from Table 25, this study's results only partially match domain assumptions in terms of the students' fitting into the prevalent wholistic-visual framework. Experiment II indicates that designers are, indeed, predominantly visual learners. The amount of verbal learners is lower than of visual learners in both groups of students and majority is fairly flexible in both modes. However, it is not fully evident why there are more analytical learners among architects and designers, and why there is a smaller proportion of wholists in the fourth and final years than in the first year. There could be many reasons for this, including the previously mentioned secondary education supporting verbal analytical learning and problem solving. It is

also likely that architectural education reinforces analytical thinking because of the associated with it body of technical knowledge. Cultural, racial, environmental aspects, the size of the sample, and other issues could have also contributed to the observed situation. The important aspect, however, is that the majority of learners (60% and 80% respectively) have been assessed as fairly flexible in applying both analytic and wholistic approaches to learning or dealing with problem situations. Their overall versatility may increase with each year of study (further discussed in this subsection). Thus, reinstating our earlier idea, it may prove more important to concentrate on the repertoire of students' learning styles and the strengths of their preferences.

Additionally, as design is considered to be a combination of crafts, technologies and different disciplines, its education is likely to contain all dimensions of learning. Thus, instead of discussing which of the four measured learning styles are more suitable for designers, it may be better to suggest that different areas of design education are associated with different learning styles. It is also likely that different stages of a design process rely upon the use of different learning styles, where a design studio allows to embrace a broader repertoire of learning styles. Or that architectural projects may accommodate a wider range of learning styles by virtue of their durations and instructional settings, as well as the nature of design problems set.

Table 26. Wholistic-Analytic learning style: Frequencies by year and gender, Experiment II/b

Learning styles (strong preferences and preferences)	Year 1		Years 4&5		Learning styles (flexibilities)	Year 1		Years 4&5	
	Fem	Male	Fem	Male		Fem	Male	Fem	Male
	%	%	%	%		%	%	%	%
Wholistic simultan.	20	20	20	20	Wholistic simultan.	20	10	30	20
Wholistic impulsive	10	0	0	0	Wholistic impulsive	0	10	0	20
Analytic sequential	10	20	40	30	Analytic sequential	30	30	10	20
Analytic reflective	0	10	20	40	Analytic reflective	40	30	30	10

Learning styles (adaptabilities)	Year 1		Years 4&5		Learning styles (non-preferences)	Year 1		Years 4&5	
	Fem	Male	Fem	Male		Fem	Male	Fem	Male
	%	%	%	%		%	%	%	%
Wholistic simultan.	10	20	0	10	Wholistic simultan.	0	0	0	0
Wholistic impulsive	10	30	30	20	Wholistic impulsive	30	10	20	10
Analytic sequential	10	0	0	0	Analytic sequential	0	0	0	0
Analytic reflective	10	10	0	0	Analytic reflective	0	0	0	0

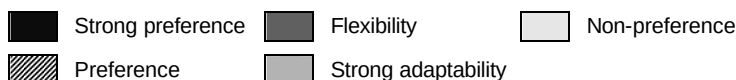
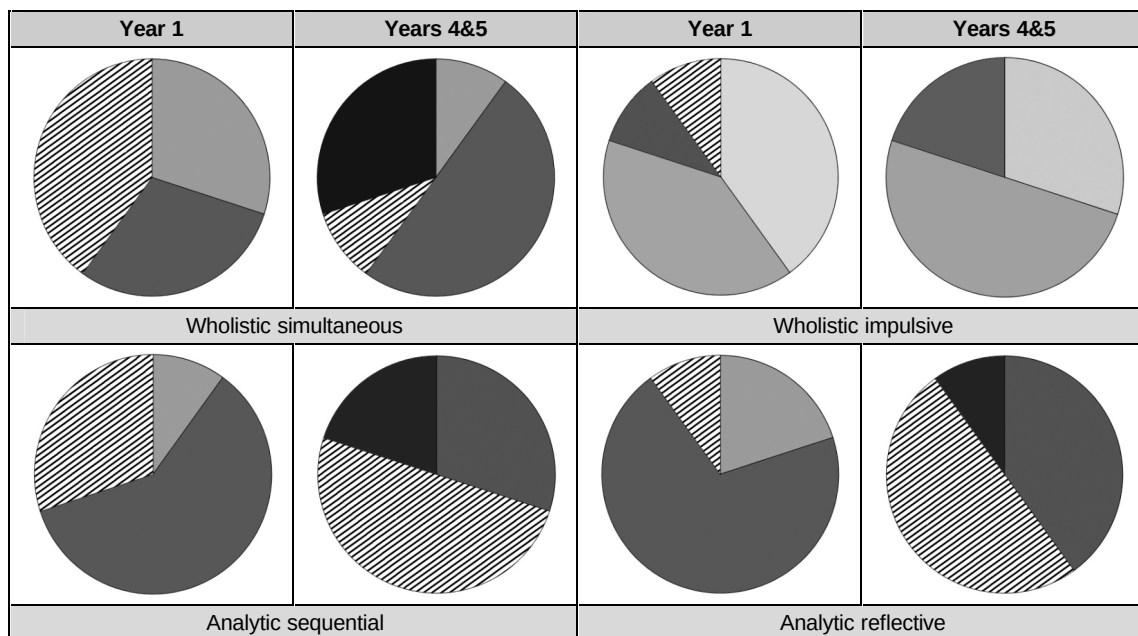
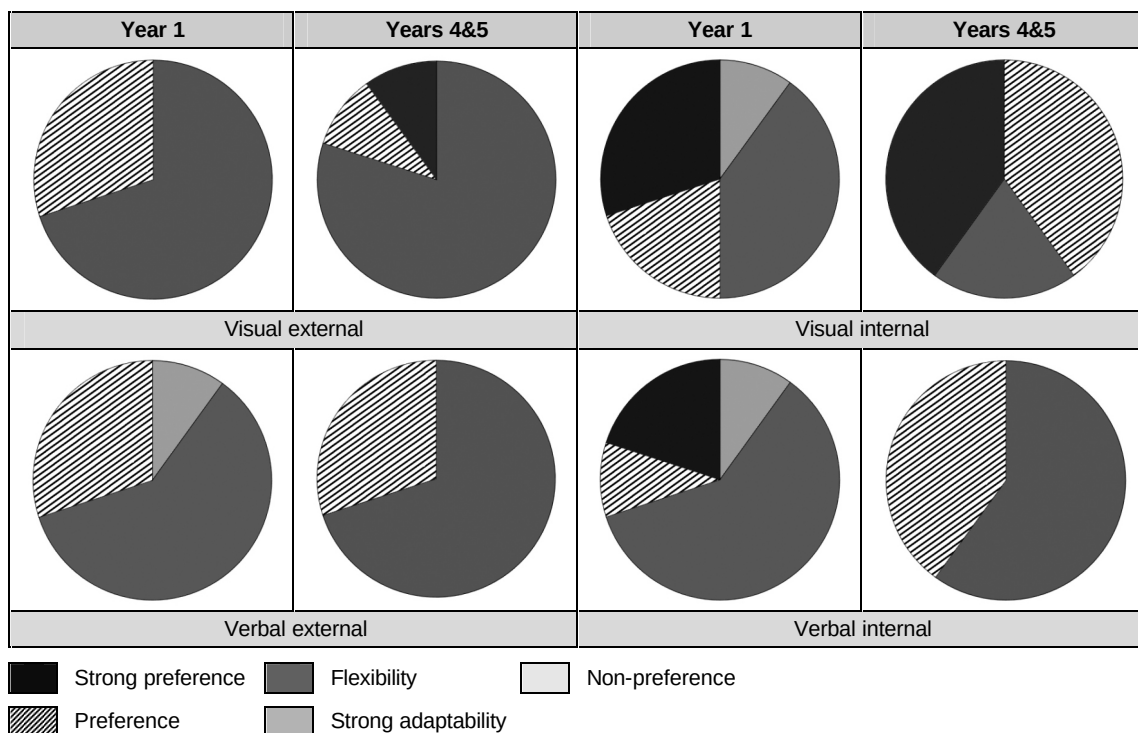


Table 27. Verbal-Imagery learning style: Frequencies by year and gender, Experiment II/b

Learning styles (strong preferences and preferences)	Year 1		Years 4&5		Learning styles (flexibilities)	Year 1		Years 4&5	
	Fem	Male	Fem	Male		Fem	Male	Fem	Male
	%	%	%	%		%	%	%	%
Visual external	20	10	20	0	Visual external	30	40	20	60
Visual internal*	20	30	20	40	Visual internal*	20	20	30	10
Verbal external	10	20	30	0	Verbal external	40	30	20	50
Verbal internal	20	10	20	20	Verbal internal	20	40	30	30

Learning styles (adaptabilities)	Year 1		Years 4&5		Learning styles (non-preferences)	Year 1		Years 4&5	
	Fem	Male	Fem	Male		Fem	Male	Fem	Male
	%	%	%	%		%	%	%	%
Visual external	0	0	0	0	Visual external	0	0	0	0
Visual internal*	10	0	0	0	Visual internal*	0	0	0	0
Verbal external	0	10	0	0	Verbal external	0	0	0	0
Verbal internal	10	0	0	0	Verbal internal	0	0	0	0



Design studio environment

A design studio can both encompass and stimulate different learning styles if its programs contain a number of phases. If they begin with ill defined design problems, permit a range of communication media and are engaged over a relatively long duration, hence allowing more freedom in learning approaches (Boyer & Mitgang, 1996). Then they come to the second phase, which is incubation where learners are allowed to think on an established problem. It is followed by the inspiration phase, where ideas are shared and students are given encouraging comments. The next two phases, verification and communication, are important in that learners can try out their solutions and get immediate feedback from peers and instructors. Evaluation and critique, the final phase of the designing process, is an opportunity for learners to get the final confirmation and potential reward for their ideas.

Additionally, studios, and design education in general, stimulate a variety of learners' senses: visual (diagrams, drawings, pictures, scale models, etc) auditory and verbal (lectures, communication, written assignments, verbal presentations, etc) and kinaesthetic (practical applications, manipulative activities). Students also engage in social learning, as studios are often nurturing environments where learners are supported and encouraged to ask questions and

develop a dialogue with their teachers and peers. A design studio offers an atmosphere that is conducive to a free exchange of ideas (Tate, 1987; Tate & Smith, 1996) through information processing which may be considered as an organisational and social process (Livari & Hirschheim, 1996) for both the students and the instructors.

It is also a type of learning environment that stimulates creative thinking by challenge, freedom, idea support, mutual trust, dynamism and liveliness, playfulness and humour (Peterson, 2001). It allows an open-ended process of problem solving, where design theory functions as an instrument supporting and stimulating cognitive abilities and styles of the designer (Symes, 1993; Verma, 1997), and fosters the learning habits needed for the discovery, integration, application, and sharing of knowledge over a lifetime (Boyer & Mitgang, 1996).

The above suggests that a design studio (as well as design education in general) provides an environment that is likely to both *accommodate* and *stimulate* students' learning styles. The latter could be signified by increased flexibility in the pattern of learning styles of the fourth and final year students (see Tables 25-27). There may be several reasons for the change (as this is not a longitudinal study, it is proposed that the growth took place over time) outlined below.

Styles matching, trainability, attrition and transition

The efficiency and the character of learning are generally related to the instructor's ability to 'read' the situation, his/her portfolio of personal teaching strategies, the learner's pre-existing knowledge, aptitude and repertoire of learning styles. A strong combination of the first two factors enable a tutor to provide appropriate actions for the individual learner in any given situation, or to adapt the instructions to respond to the learning needs of all individuals (Atkinson, 2004). To avoid depending upon the tutors' extensive experiences, numerous attempts have been made to develop instructional strategies that consider individual differences. However, no single technique or procedure has been found optimal for both the good and the poor students or beneficial for all subjects within a homogeneous group (Staub & Peck, 1995; Lajoie, 2003). Thus, the practice-oriented viewpoint suggests that effective learning in an architectural design studio is dependent upon the communication of creative ideas as well as the fit between the way of instructions and the learning styles of the students.

Matching and mismatching. The popular 'matching hypothesis' argues for the preferred learning styles of students to be linked to the instructional style of their tutor. In a traditional, teacher led, paper based environment, learning in matched conditions has been demonstrated to be significantly more effective than learning in mismatched conditions in many instances, resulting in improvement in course grades especially for students with low ability (Pask & Scott, 1972; Raines, 1978; Hunter, 1979; Carthey, 1993; Miglietti, 1994; Matthews & Hamby 1994; Ford, 1999). However, more able individuals, who were given the opportunity to use mismatched learning materials at times, were shown to develop learning strategies that coped with a wider range of materials and experiences on future occasions (Riding & Rayner, 1999). This view is supported by Vermunt's (1998) 'constructive friction', where the teacher pushes students to take more responsibility for the content, process and outcomes of their learning. And Grasha's (1984) argument that people need to be 'stretched' to learn, and stretching may mean deliberately creating a mismatch between their learning style and the teaching methods.

Smith, Sekar and Townsend (2002) recently reviewed the evidence and found nine studies indicating that learning is more effective where there is a match, and nine showing it to be more effective where there is a mismatch. Similarly, Reynolds (1997) arranged a further five empirical studies in favour of matching and three against. Spoon and Schell (1998) conducted a study of 12 teachers and 189 learners; they found no significant difference in test outcomes between congruent groups (where both teachers and learners favoured the same instructional approach) and incongruent groups. Ford conducted three relatively small but rigorous empirical studies of matching and mismatching (Ford & Chen, 2001) and concluded on each occasion that matching was linked with improved performance, but his most recent study suggests that the effects of matching and mismatching may not be simple, and may entail complex interactions with other factors such as gender, and different forms of learning (Ford & Chen, 2001).

There is, though, a factor which is frequently neglected by the learning style theorists – subject matter and linked to it differences in ideas about the fundamental purposes of education. For Kolb (1984), the educational objectives of mismatching are personal growth and creativity: the goal is something more than making students' learning styles adaptive for their particular career entry job. The aim is to make the student self-renewing and self-directed; to focus on integrative development where the person is highly developed in each of the four learning modes: active, reflective, abstract, and concrete. To teach the student to experience the tension and conflict among these orientations, for it is from the resolution of these tensions that creativity springs (Coffield, *et. al.*, 2004). This seems like a rather attractive learning idea that describes an ideal studio environment where students have to deal with multifaceted unfamiliar tasks that stretch their capabilities and promote creativity. And, since design is a combination of different disciplines, students with either learning style may have an opportunity and motivation for further development. This study will look into this issue further when correlating individual learning styles with different aspects of performance on administered design tasks.

Trainability. Supporters of the matching hypothesis are usually supporters of the concept of fixed traits and aptitudes who argue that a valid and reliable measure is a sound basis for diagnosing individual learning needs and then designing specific interventions to address them, both on the level of individual self-awareness and teacher activity. This however, might lead to labelling and the implicit belief that traits cannot be altered (Coffield, *et. al.*, 2004). In order to counter such problems, some theorists promote the idea that learners should develop a repertoire of styles, so that an awareness of their own preferences and abilities should not bar them from working to acquire those styles which they do not yet possess. In particular, as students move from didactic forms of instruction to settings with a mixture of lectures, seminars, studio- and problem-based learning, it may become possible for them to use a range of approaches.

The idea is generally supported by the learning style theorists who do not see learning styles as based on hardly malleable physiologically based traits. Typically, a training effect occurs as students complete one of their major courses. Students, who initially had cognitive styles different than the major requires, may have adapted or trained themselves to process information more effectively. If this is true, it lends credence to the idea stating that students who are aware of their learning styles, and know how they can adjust them to the learning situation can achieve higher grades (Halpin & Peterson, 1986; Cook, 1989).

Transition. In the course of training, students undergo a transition, which is typically referred to in the context of shifting between familiar, i.e. established in prior secondary education, and unfamiliar, i.e. introduced in post-secondary education, learning environments. In other educational discourses this shift is reported as 'the first year university experience'. In case with design education, transition may occupy a longer period of time as there is also a shift to the more specialised architecture education occurring after the third year of design study. In this case, one may refer to 'the first and the fourth year university experience'.

Prior to the formal assessment of their learning style preferences (i.e. before obtaining the LSA results), students indicated that they had modified their learning styles since arriving at the University. One of the first year students stated: *'University made me change my study practices. I need to do more planning and studying longer in advance... I do more independent work, but I'm still learning how to do my own research.'* Another first year student said *'...I need to make notes during lectures, there is so much new information... but I'm bad at it [writing down lectures], so I've started taking my own notes from different sources, and have a weekly discussion with a group [of fellow students] and sometimes use their notes.'* These statements represent proto-metacognitive actions where conscious decisions have been made to expand the 'tool-kit' of learning (more hours, more repetition, more notes), but not yet the 'know-how' which represents true executive control of cognition.

There is a general tendency for the fourth and final year students to be much more aware of their learning and problem solving behaviour, as they make an effort in understanding it by

habitual introspection. Their statements confirm that transition does not stop after the first year but continues through the duration of studying. One of the fourth year students stated ‘...no, I’m still learning, I need to understand myself better, because sometimes designing is easy, and sometimes not, I want to know why and also what I can do about it... I think sometimes I get stuck because I may do it wrong in the beginning if it [a design task] looks simple...I just pick the easy solution and then I have to reject it, go back and be creative...you know, come up with new ideas, but it is hard to stop thinking about it [the earlier design solution] and start anew.’ A more general remark of concerning learning difficulties was made by the fifth year student, who said ‘...I’m still not sure what I want to do [when I graduate]... may be I switch to graphic design... here I always need to think hard, try hard, work hard... too much analysis and too much structure for me... It’s not me, I’m not really like that, ... I think, I’ve learnt it the hard way... like I had to change myself... like be more realistic, work with constraints... now I want more flexibility and more creativity... I think architecture these days can be limiting if you have a wild mind.” This perception of architecture as a structured, and often rigid and analytical field, is shared by more than a half of subjects from both years, although predominantly wholists.

As teaching in secondary schools in Australia is primarily through lectures, in which students usually play a passive role during learning, students may experience a transition from reflective observation to active experimentation, creative ideation and visual synthesis during their undergraduate study as the new academic field is inclined to visual wholists and hands-on activities. The following statements indicate that, in response to new instructional settings, many students adapted their learning practices where they deemed it was necessary.

Analytic individuals when facing complex tasks often describe designing as their attempts to divide it into the components to, then, try reassembling it: ‘If I have a project I need to break everything down into bits to understand [it]. Like I decide what the main features are, and what spaces I will have [to allocate]... and I draw them... separate... and then I try to link up... and put them together... and then I can see it from there... I tried other ways too, but this one works for me best’ Verbally inclined individuals, and students with average spatial abilities, having experienced difficulties, tried different ways of addressing them: ‘I have problems with scaling, I don’t seem to be able to visualize how big these things that I’m drawing... I tried many times... now I always use computers in my design, and sketches have always been a really rough simple thing before it goes into the computer.’ They also started to use modelling as they believe haptic experiences help them visualise and memorise different properties of a three-dimensional form: ‘Yes, definitely! [I have problems expressing ideas by sketching] Designing is a three-dimensional task for me. I need building blocks to ‘see’.

Similarly, visual and wholistic students also face the need to adjust to the demands of design education with its increased body of technical knowledge. Some of them report having began drawing flow-diagrams and mind-maps that linked together packages of information by common threads and provided a global and visual overview not always obvious from daily and disjointed lectures (‘When I study or do a project I like arranging all important info on one page, so I don’t miss anything... yeah, I would draw bubbles and sort of link them up’). Other students started illustrating their lecture notes as they wrote them – in an attempt to link visual information with verbal (‘I often scribble on my lectures, I like my scribbly drawings, they make me understand better... later’). These students realised that in the verbal-dominated lecture they would need to link aural information with visual information if they were to understand or memorise new material. Some of them also reported changes in metacognitive strategies as they engage more in analytical thinking: ‘I think since uni has started I have been less creative and more practical. My ideas have sobered and I think more realistically.’

This and similar evidence, though scarce for the quantitative analysis, provides an insider’s outlook on individual learning experiences. Further studies are needed to observe the transition of learning styles during the architectural undergraduate education, and to evaluate programs or studios expected to accommodate different learning styles. Overall, studies in the area of higher education (McInnis, 2001) have found that learning is most efficient when the transition into a new academic environment incorporates positive and rewarding student experiences that

account for the needs of the student (Krause, 2001), and when a student is a conscious learner aware of his/her learning strengths and weaknesses (reviewed in Coffield, *et al.*, 2004).

Attrition. There is another research that needs being mentioned. It argues that regardless of environmental pressure or occupational demands, there are some people who strongly adhere to their preferred cognitive styles (Kagan & Kogan, 1970; Riding & Cheema, 1991). Roberts and Newton (2001) point to those studies which have shown how difficult, if not impossible, it is at times to teach people to use non-preferred learning styles or strategies. Many students show considerable resistance to change and their reasons for refusing to change are neither simple nor similar. This suggests that design education environments may not always be able to stimulate the development of new, or already existing non-preferred learning styles – there may be dispositions that are difficult or impossible to change. Additionally, the earlier findings indicate that the formulation of the design program and presentation requirements can disadvantage certain learning styles (Mitgang, 1996). Thus, attrition may occur when students with learning styles different from the learning styles required in the major drop-out or change majors.

This idea was explored in a ten year longitudinal study conducted by Witkin, *et al.* (1977) in four year institutions. It sought to determine if students' learning styles were related to their initial major choice and final degree major (science, arts, and other) and achievement in various major courses. It was established that the selection of a major was influenced by learning styles, and that students, who initially selected majors that required a particular learning style, which was different than their own, were more likely to change to a major which complemented their learning style. Other research suggests that frustration or satiation, resulting from the mismatch of instructional and learning styles, or due to other reasons, can also cause a student to switch between motivational styles and disengage from learning (Apter, 2001).

Correspondingly, students who start the university education and achieve success in it based on their pre-existing learning styles, would probably continue in the chosen major. At the completion of the three-year design program they may choose to pursue their studies in architecture. Then, as the educational demands increase, some students may discover that they can no longer maintain the same level of academic performance and may drop-out or change their majors to coincide with a more cognitively appropriate academic demand (Witkin, *et al.*, 1977). As a result, the student populations in a particular major become more uniform, reflecting a distinct learning style (or combination of styles) within the major or specialization. This may be the case with our sample, when it concerns the increased versatility and, as a result, more homogeneity among the students of the senior years of study (Table 25).

Correlation analysis: learning styles, creativity and academic achievement

Correlation analysis was facilitated by converting the LSA test results into a five-scale measure (with *strong preference* ascribed the highest value and *non-preference* – the lowest).

As previously mentioned, with regard to the connection between the Wholist-Analytic mode and design, it has been suggested that designing is successful when the process is a wholistic experience (McCormick *et al.*, 1993; NEAB, 1993; Atkinson, 1997; 1998). Similarly, as imagining has been shown to be central to the generation and development of ideas (Garner, 1989; Kimbell, *et al.*, 1991; Liddament, 1993; Barlex, 1994; Chidgey, 1994), Imagers are expected to make the best designers (Glegg, 1986). And when a combination of both style dimensions is considered, Wholist-Imagers are expected to have a potential advantage over students in other cognitive style combinations in the context of design project work. We tested this assumption to see if it applies to this study's sample.

As Table 28 indicates, similar correlations can be observed in both test groups, though the magnitudes of correlation coefficients vary. And some correlations are only present in either group of subjects. For the first year they include:

1. *Creativity* is correlated with *Wholistic Simultaneous* and *Visual Internal (Imagery)* learning styles
2. *Academic performance* is correlated with *Visual Internal (Imagery)* learning style

For the fourth and final years they include:

1. *Creativity* is correlated with *Wholistic Simultaneous*, *Wholistic Impulsive* and *Visual Internal (Imagery)* learning styles
2. *Academic performance* is correlated with *Wholistic Simultaneous* and *Visual Internal (Imagery)* learning style

Table 28. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiments II/b-III/b

Variables	WS	AS	WI	AR	VisE	VisI	VerE	VerI	C	AP
Year 1										
Wholistic Simultaneous	1									
Analytic Sequential	-0.241	1								
Wholistic Impulsive	0.140	-0.318	1							
Analytic Reflective	-0.201	0.681*	-0.610	1						
Visual External	0.184	-0.218	0.763*	-0.689*	1					
Visual Internal (Imagery)	0.635*	0.265	0.179	-0.055	0.413	1				
Verbal External	-0.441	0.167	-0.495	0.371	-0.582	-0.564	1			
Verbal Internal	-0.578	0.582	-0.416	0.284	-0.286	-0.304	0.218	1		
Creativity	0.736*	0.036	0.278	-0.122	0.429	0.890**	-0.691*	-0.548	1	
Academic Performance	0.473	0.582	-0.069	0.284	0.190	0.890**	-0.327	-0.071	0.762*	1
Years 4&5										
Wholistic Simultaneous	1									
Analytic Sequential	-0.756*	1								
Wholistic Impulsive	0.644*	-0.837**	1							
Analytic Reflective	0.123	0.379	-0.290	1						
Visual External	0.031	-0.156	0.067	-0.268	1					
Visual Internal (Imagery)	0.877**	-0.479	0.479	0.524	-0.175	1				
Verbal External	0.043	-0.218	-0.218	-0.375	0.034	-0.244	1			
Verbal Internal	0.120	-0.175	-0.175	0.064	-0.064	0.000	0.356	1		
Creativity	0.745*	-0.542	0.697*	0.254	0.254	0.728*	-0.355	-0.221	1	
Academic Performance	0.730*	-0.443	0.443	0.291	-0.097	0.693*	-0.135	0.253	0.740*	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Clearly, in terms of the roles of learning styles in creativity, this study's sample matches the domain assumptions. It is not fully evident, however, why wholistic learning style is not associated with academic performance in the first year group (although it is associated with creativity, which, in its turn, is correlated with academic performance). It is possible that the direction of the first year students' assessments is inclined towards their general strengths in acquiring new knowledge and skills. And, as the new design experience includes a wide range of subjects – a considerable body of technical and other knowledge and skills applied in studio projects – both learning styles are equally important in academic achievement (although we only look at the reports concerning design tasks). Or, because it is still possible for the students to develop a broader repertoire of learning styles via the course of study, educators tend to give equal preferences to both wholistic and analytical learners as they tend to succeed in different aspects of design tasks. And in the later years, it becomes essential to exhibit traits associated with the fields of design and architecture, whereas advanced learning styles may also become more important as the level of instruction increases (Holtzman, *et al.*, 1979).

The verbal-imagery dimension fully matches domain assumptions for both groups of students – visual learners are the most successful. According to the model proposed by Riding and Sadler-Smith (1992), imagery may be able to some extent compensate for the absence of wholism for an analytic-imager as the individual might be able to gain an overall perspective through the application of imagery. Similarly, the wholist-verbal learner may be able to draw on his or her verbal thinking to help overcome any difficulties arising from their lacking in analytic processing. Thus, there may be a possibility of considering styles according to wholistic versus analytic processing taken in combination with verbal and imagery thinking, resulting in an ordering from wholist-imager to analytic-verbaliser (Riding & Caine, 1993).

Other data from Table 28 indicates that Wholistic Simultaneous learning style is correlated with Visual Internal learning style, and these correlations are present in both groups. This means that there are more wholistic learners among imagers than there are analytical learners. The magnitude of correlation is smaller for the first year, which may be due to the overall strength of learning styles preferences (as the fourth and final year students have more developed styles). The wholistic-imagery correlation is in agreement with research concerning visual-spatial learners who are inclined to think wholistically rather than in a step-by-step fashion. Visual imagery plays an important role in their learning and problem solving, and, as these individuals think primarily in pictures rather than words, ideas are interconnected (Silverman, 1998). The observed correlation also agrees with the brain lateralisation theory suggesting that spatial thinking involves synthesis, an intuitive grasp of complex systems, simultaneous processing of concepts, inductive reasoning, use of imagination and generation of ideas by combining existing facts in new ways. It is influenced by visualisation and images and an awareness of space, thought to be associated with the right hemisphere of the brain (West, 1991). Although the right/left brain dichotomy in styles of thinking is a view no longer supported by current neurocognitive research (Kosslyn, *et al.*, 1993, 1995; Hellige, 1993) suggesting a broader view of 'interhemispheric cooperation' (Luh & Levy, 1995).

There were also negative correlations observed. Evidently, in both groups, verbalisers have a significant disadvantage in terms of achievement on design projects. This is consistent with the research by Riding and Douglas (1993) indicating that verbalisers tend to perform better than imagers in learning environments where the material is in a textual and /or auditory format. While imagers tend to outperform Verbalisers where the presentation mode is graphical and visual (the essence of studio work). Additionally, imagers score higher than verbalisers in a similar type environment when the learning material is in text and picture format. Other studies carried out by Riding and Watts (1997), Riding, Buckle, Thompson and Hagger (1989), and Riding and Ashmore (1980) are also in broad agreement with this finding.

Overall, since this is not a longitudinal study, little more can be ascertained about the source of differences and similarities in learning styles between first and fourth-final years students, or, equally, about the roles of individual styles in academic performance. A further in-depth research is necessary for arriving at the empirically validated conclusions.

5.2.2 Conclusions

Experiments II/b and III/b explored relationships and correlations between education and two principal learning style dichotomies – Wholistic-Analytic and Verbal-Visual/Imagery. The initial analysis of the learning style scores indicated that:

- 40% first year designers, and 40% fourth and final architecture students have preferences in simultaneous, wholistic processing;
- 30% first year designers, and 70% fourth and final architecture students have preferences in sequential, analytic processing;
- 30% first year designers have only flexibilities in learning styles (20% in analytic and 10% in wholistic);
- 60% first year designers, and 80% fourth and final year architecture students have preferences and flexibilities in wholistic and analytic brain processing;

- 50% first year designers, and 60% fourth and final architecture students have preferences in internal visual (imagery) mode;
- 20% first year designers, and 40% fourth and final year architecture students have preferences in internal verbal mode; and
- 60% first year designers, and 80% fourth and final year architecture students have preferences and flexibilities in verbal and visual modes.

The joint analysis of the learning style scores has revealed differences within the sample related to learning style preferences, which were based on:

- ethnic origin – there are more analytic and visual learners among Australasian students and, correspondingly, more wholistic and verbal students among Australians, though differences on the Analytic-Wholistic dimension become marginal (particularly, in the 4th & final years), when flexibilities are equalised to preferences and strong preferences.

The observed differences in the strengths of learning style preferences were related to:

- the year of study – there are more of versatile (W-A – 80%; V-I – 80%) and brain-gifted (W-A – 10%; V-I – 20%) individuals among the fourth and final year architects, than there are of versatile (W-A – 60%; V-I – 70%) and brain-gifted (W-A – 0%; V-I – 10%) individuals among the first year designers; and
- gender – females in both groups are more inclined towards the verbal mode and wholistic simultaneous thinking, and males – towards the visual mode, and analytical sequential thinking; the differences, however, become marginal when flexibilities are equalised with preferences/strong preferences (irrespective of the year of study).

The above results suggest that consideration should be given to both the type of learning style preference and the strength of that preference, as no learner fits neatly into one particular style, but rather is inclined towards one area more than another. There are more first year students with flexibilities than with (strong) preferences, which means there are less students with the natural well-developed ability for using different thought processes, and more students that may switch between different modes if necessary. There is, though, a limitation to styles flexibility – these students may find it hard to concentrate on one activity for a long time, and may become less or non-efficient when reasoning on complex tasks such as design. As a result, they may no longer maintain the same level of academic performance and, in most critical cases, may drop-out or change their majors to coincide with a more cognitively appropriate academic demand.

A favourable learning environment catering for the needs of different students could be a key to development of the necessary learning strategies. Design studios have a potential to provide such environments by stimulating and accommodating a broader repertoire of learning styles. A training effect may occur as students complete one or more of their major courses. The data in this study suggested a sound possibility for this change as indicated by the participants' metacognitive statements, though the observed (i.e. potentially revealed by LSA reports) improvement is mainly related to the strengths of learning styles preferences and increased versatility. The students' inability to acquire, or of the education to provide, new and necessary ways of learning may lead into a less effective transition between old – secondary education, and new – university, study environments. This may subsequently lead to the reduced academic learning opportunities and achievement levels.

The correlations between the four learning styles, creativity and academic performance have also been explored, they revealed both differences and similarities within the sample related to the year of study. For the first year students correlations indicated that:

- creativity was correlated with Wholistic Simultaneous and Imagery learning styles; and
- academic performance was correlated with Visual Internal/Imagery learning style.

The fourth and final year students' correlation analysis showed that:

- creativity was correlated with Wholistic Simultaneous, Wholistic Impulsive and Visual Internal/Imagery learning styles; and
- academic performance was correlated with Wholistic Simultaneous and Imagery styles.

The above data indicated that in terms of the roles of learning styles in creativity, this study's sample matched domain assumptions, as Wholistic-Visual learners are the most creative. In academic performance, it is only the Verbal-Imagery dimension that fully matches domain assumptions for both groups of students – visual learners are the most successful. It is not fully evident, however, why wholistic learning style is not associated with academic performance in the first year group (although it is associated with creativity, which, in its turn, is correlated with academic performance). It is possible that, according to the model proposed by Riding and Sadler-Smith (1992), imagery is able to some extent compensate for the absence of wholism for an analytic-imager, as the individual might be able to gain an overall perspective through the application of imagery. Similarly, the wholist-verbal learner may be able to draw on his or her verbal thinking to help overcome any difficulties arising from their lesser level of analytic processing. Other data from the analysis indicated that Wholistic Simultaneous learning style is correlated with Imagery learning style, and these correlations are present in both groups. This means that there are more wholistic learners among imagers than there are analytical learners. The magnitude of correlation is smaller for the first year, which may be due to the strength of learning styles preferences (i.e. fourth and final year students possess a wider range of better developed styles). The wholistic-imagery correlation is in agreement with research concerning visual-spatial learners who prefer to think wholistically rather than in a step-by-step fashion.

On the whole, while our understanding of the observed situation seems plausible, the conclusions are mainly intuitively compelling. There is clear lack of overarching synthesis in the field of learning styles concerning different models, as there is no agreement regarding such basic and important issues as: what influences the development of styles; how trainable or changeable they are; why, if (mis)matching is improving performance, it does not always help preparing the learner for subsequent learning tasks; how adults discover new learning strategies or how they choose between strategies in problem solving; what learning styles are based upon; and so on. There are theorists with strong beliefs about the influence of genetics on fixed, inherited traits, others talk about personal factors such as motivation and environmental factors, cooperative or individual learning, the effects of curriculum design, institutional and course culture, and there are teaching and assessment tasks on how students choose to avoid particular learning strategies. Several models (including LSA) acknowledge external factors, while others are based on the idea of dynamic interplay between self and experience (reviewed in Coffield, *et al.*, 2004). And, above all, there is a lack of independent research attesting to the validity and reliability of the majority (if not all) of assessment instruments.

It is also clear that learning and problem solving are so complex, they are unlikely to be captured by any set of learning style dichotomies. We believe, however, that LSA can be a useful data-collection tool. Its major problem so far has been its interpretation of results as individual instructional preferences and preferred styles of problem solving resulting from learning experiences and capabilities. This is a common approach for many assessment instruments as they have been designed, in the first place, to assist educators with recognizing and catering for individual differences in learning, and to help test takers with raising awareness of their learning styles. The correspondence of instructional preferences effective at the time of testing, and often viewed as changeable, to intrinsic high-level approaches to problem solving, seen as more stable over time, is not fully evident. Dunn and Prashnig (2001) argue for their instrument to have a universal nature – from assessing how individuals are inclined to (or prefer not to) deal with problem situations based on inherent characteristics influenced by biology, to measuring their learnt behaviour, including experience and conscious control. The interpretation of results, therefore, ranges from instructional preferences to thinking and working (similar to cognitive) styles. This claim, supported or not, it is a subject to further debates regarding the

strength of the model's theoretical foundation. In this study, LSA was found sufficient for ensuring the baseline information to be used in subsequent analyses. While the issue of how well the chosen instrument can tap students' capabilities and preferences in problem solving, reflected in real design tasks, will be researched further (see Chapter 6).

Finally, in future studies, when considering interrelationships between individual qualities and academic performance, to gain a better perspective one shall also incorporate such factors as a learner's intelligence, prior knowledge of the subject domain, level of motivation, anxiety, self-confidence, and the amount of learner control offered; as well as the interactions that exist between the teacher and his/her teaching style and the learner and his/her learning style.

5.3 Cognitive Abilities, Learning Styles & Academic Performance Judgements

Many investigations have been carried out concerning the relationship between cognitive styles and cognitive abilities. Researchers have agreed that their primary difference is related to the styles' bipolar nature (Witkin *et al.*, 1977; Sharma, 1986; Riding & Cheema, 1991). That is, each pole of cognitive style has adaptive value under specified circumstances, whereas to have more of an attribute such as spatial ability is better than to have less of it. At the same time, it has been suggested for the preferred way of thinking to be, to a certain degree, a result of the abilities a person possesses. Some of the earlier studies have indicated that aptitude may limit strategy selection (influenced by a cognitive style) or predict performance within strategy subgroups on cognitive tests. Similarly, cognitive styles may be a reason for a broad fluctuation in factor loadings of the ability tests since people can utilize a number of different strategies to attain correct answers. And, when the strategy choice is unrelated to aptitude and related to style/s, the effectiveness of the implemented strategy could still be limited by aptitude (Kyllonen, *et al.*, 1984; Kyllonen, *et al.*, 1985, 1995; Carroll, 1993).

Applied to this research, this means that wholistic cognitive style may support and be supported by advanced ideation abilities (among other factors), or that imagery cognitive style may draw on high visual-spatial abilities, and vice versa. At the present time, however, there is little reliable information on the relations between cognitive abilities and cognitive styles, while linear correlation and factorial analysis may not be appropriate for such studies (Carroll, 1993). Thus, this thesis does not examine the broad range of possible links between the measured ability factors, but looks into the data acquired through correlation analyses to gain the initial understanding of the situation, to determine which styles and/or abilities may have a strong(er) predictive power on academic performance.

5.3.1 Analysis and Findings

Two correlation schemes were suggested. The first one consists of nine primary sets of variables presented in Table 29 (i.e. *Wholistic-Impulsive*, *Analytic-Reflective*, *Visual External* and *Verbal External* learning styles, though included, are secondary in this scheme). The *Visual-Spatial* variable was introduced in accordance with the earlier factor-analytical studies, suggesting that general visual-spatial ability is a latent variable to which all the relevant administered psychometric tasks normally contribute. It was estimated by the use of partitional (k-means) and hierarchical (sample average and median) clustering methods to identify four ability groups (i.e. 'high', 'medium-high', 'medium-low' and 'low', converted to a four-measure scale) of the sample, then split by the year of study. A similar procedure was performed to identify four clusters of general ideation verbal, and of general ideation figural abilities.

Table 29 indicates a number of common correlations observed in both test groups, although with varying magnitudes of correlation coefficients. Whilst some correlations are only present in either group of subjects. For the first year they include:

1. *Visual-spatial ability* is correlated with *Visual Internal (Imagery)* learning style, *Academic performance* and *Creativity*

2. *Figural ideational ability* is correlated with *Visual Internal (Imagery)* and *Wholistic Simultaneous* learning styles, and *Creativity*

For the fourth and final years they include:

1. *Visual-spatial ability* is correlated with *Visual Internal (Imagery)* and *Wholistic Simultaneous* learning styles, *Academic performance* and *Creativity*
2. *Figural ideational ability* is correlated with *Visual Internal (Imagery)* learning style

Table 29. Pearson product-moment correlation coefficients (a): Years 1 and 4&5, Experiments I/b-III/b

Variables	VS	IV	IF	AP	C	WS	AS	WI	AR	VisE	VisI	VE	VI
Year 1													
Visual-Spatial	1												
Ideation Verbal	0.522	1											
Ideation Figural	0.671*	0.238	1										
Acad. Perform.	0.873**	0.579	0.509	1									
Creativity	0.752*	0.468	0.856**	0.762*	1								
Wholistic Sim.	0.441	0.344	0.651*	0.473	0.736*	1							
Analytic Seq.	0.296	0.442	-0.318	0.582	0.036	-0.241	1						
Wholistic Imp.	-0.035	-0.519	0.213	-0.069	0.278	0.140	-0.318	1					
Analytic Refl.	0.144	0.417	-0.217	0.284	-0.122	-0.201	0.681*	-0.610	1				
Visual External	0.218	-0.356	0.301	0.190	0.429	0.184	-0.218	0.763*	-0.689*	1			
Visual Internal	0.896**	0.467	0.707*	0.890**	0.890**	0.635*	0.265	0.179	-0.055	0.413	1		
Verbal External	-0.259	0.102	-0.671*	-0.327	-0.691*	-0.441	0.167	-0.495	0.371	-0.582	-0.564	1	
Verbal Internal	-0.339	-0.089	-0.648*	-0.071	-0.548	-0.578	0.582	-0.416	0.284	-0.286	-0.304	0.218	1
Years 4&5													
Visual-Spatial	1												
Ideation Verbal	0.170	1											
Ideation Figural	0.344	0.481	1										
Acad. Perform.	0.829**	0.169	0.089	1									
Creativity	0.870**	0.049	0.232	0.740*	1								
Wholistic Sim.	0.812**	0.339	0.364	0.730*	0.745*	1							
Analytic Seq.	-0.611	-0.429	-0.224	-0.443	-0.542	-0.756*	1						
Wholistic Imp.	0.535	0.221	0.184	0.443	0.697*	0.644*	-0.837**	1					
Analytic Refl.	0.292	0.156	0.602	0.291	0.254	0.123	0.379	-0.290	1				
Visual External	0.334	-0.440	-0.156	-0.097	0.254	0.031	-0.156	0.067	-0.268	1			
Visual Internal	0.747*	0.407	0.639*	0.693*	0.728*	0.877**	-0.479	0.479	0.524	-0.175	1		
Verbal External	-0.117	-0.020	-0.218	-0.135	-0.355	0.043	-0.218	-0.218	-0.375	0.034	-0.244	1	
Verbal Internal	0.218	0.408	0.117	0.253	-0.221	0.120	-0.175	-0.175	0.064	-0.064	0.000	0.356	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

The correlation between Imagery learning style and visual-spatial ability present in both groups was expected. Many earlier studies have argued for a visual style to be beneficial in a range of cognitive tasks, including psychometric tests of visualisation and ideation (Vicente, *et al.*, 1987; Sein & Bostrom, 1989; Schofield & Kirby, 1994). A further in-depth research is, however, necessary to confirm (or refute) the above results as the strategy choice on psychometric tests and other cognitive tasks could be influenced, limited, or unrelated to aptitude or styles of problem solving, while the effectiveness of the implemented strategy could be limited by aptitude or the preferred style (Carroll, 1993).

The measures of idea-production ability of the first year students are correlated with Wholistic and Imagery learning styles and creativity, suggesting that (1) developed ideation is

essential in the first year creativity, and (2) both learning styles are useful for/support ideation. It is not entirely clear, however, why not all of these correlations are present in the performance of the fourth and final year students. Or equally, why there is a lack of association with academic performance for both groups of students.

The reasons are likely to be multiple and interacting. They may be related to the sample size, higher levels of the learning styles' development (i.e. versatility of the fourth and final year students), or the growing complexity of design tasks. Tasks used in ability tests are relatively simple, and may be more useful for the first year students as their designs are typically concerned with form, composition and aesthetics. Whereas most projects in architecture are multifaceted complex activities, where ideation involves working with many different constraints to accommodate a broad range of specifications. There, idea generation can not rely upon only one type of reasoning (wholistic or analytical) and may also require support of the developed imagery/visual thinking due to the inherently visual nature of design tasks.

Thus, to establish reliable correlations between ideation factors and creativity or academic performance in architecture, a measurement beyond the measurement of the quantity of ideas produced need being used. Here, visualisation abilities may be better predictors of academic performance as they involve more complex cognitive processing characteristic of design tasks. Additionally, real design exercises may be less likely to rely upon abilities emphasizing high speed, as they are not a subject to similar to cognitive tests time constraints. It is also likely that other factors relating to teaching, previous instruction and complexity of design tasks, knowledge, experience, and so on, may be of equal or higher importance.

In terms of the strengths of predictive validity, the above results may indicate that cognitive abilities are essential for the first year students, whereas in the later years learning styles gain more importance. The differences between the magnitudes of correlation, however, are not significant. Further research with a larger sample is required to achieve a better understanding of the observed situation.

Generally, there is no uniform opinion in the fields of psychology and design studies as to which abilities, skills, styles, knowledge or other factors would have the strongest predictive effect on academic performance and should, therefore, be addressed as a matter of priority. Some of the relevant research included a meta-analyses of educational interventions conducted by Hattie (1996; 1999). It indicated the statistical significance for different types of interventions, where reinforcement had an effect size of 1.13; students' prior cognitive ability – 1.00; instructional quality – 1.04; direct instruction – 0.82; students' disposition to learn – 0.61; class environment – 0.56; peer tutoring – 0.50; parental involvement – 0.46; teacher style – 0.42, affective attributes of students – 0.24; behavioural objectives – 0.12; and team teaching – 0.06. Hattie suggested that most innovations have positive effects on student' achievement, but further estimations of the magnitude of the impact are necessary.

In future research, it seems sensible to concentrate on the interventions which have the largest effect sizes.

Speed and accuracy of performance and ability factors

Another observation concerning the possible influence of learning styles on ability measures is related to the performance on cognitive tests. Wholistic students were significantly faster (in some cases, used up to 50% less of the allocated time) on visual memory and visualisation tasks (original data is included in Appendix A tables). These tasks involve simultaneous processing and/or transformations of visual material (Carroll, 1993). The *Building Memory* test required processing concurrently one set of information while remembering another set, and integrating ideas into a coherent mental model. While *Paper Folding* and *Storage* tests required spatial thinking, comprehending the internal structure, recognizing how to combine parts together, in most cases, with imaginative rotation or transformation demand. Supporting this study's observations, the influence of individual cognitive processing styles on visual memory has been reported by Cooper (1976) and Schorr *et al.* (1982) noting that wholistic subjects display much faster response times than analytic subjects.

At the same time, analytical students performed better (up to 30% faster and with considerably lower error rates) on tests favouring sequential approaches, such as mental rotations and spatial scanning. On the whole, wholistic subjects showed a potential for better performance (in terms of the final scores), which was undermined by high error rates on few(er) tests for versatile subjects, and a large(er) number of tests for non-versatile wholists (analytical subjects from the sample, errors: Mean=2.83; SD=1.53; wholistic subjects from the sample, errors: Mean=4.25; SD=3.69). These results may partially explain why there is a lack of consistency in test scores of visual-spatial or/and ideation abilities for some subjects – differences in learning styles may have influenced individual performance. This issue, however, requires further examination.

Effects of versatility of learning styles on academic performance

The second correlation scheme includes six variables (Table 30). As the data were too few to justify a multiple regression analysis, Pearson correlation analysis with the same data but with fewer factors appeared more appropriate. Levels of versatility were determined using hierarchical clustering method applied to the results of learning styles assessment (previously converted to a quantifiable five-measure format) estimated for the whole sample, including brain-gifted students, to identify four versatility groups (i.e. ‘high’, ‘medium-high’, ‘medium-low’ and ‘low’ converted to a four-measure scale) then separated for years 1 and 4-5.

As Table 30 indicates, the broader repertoire of learning styles proved to be a statistically significant factor when this approach was adopted. The top students in each group were either versatile or brain-gifted, that is potentially more able to cope in any learning environment, or more flexible in utilising different approaches to problem solving. The correlation magnitudes are lower for the fourth and final year as there are lower score fluctuations (i.e. more students with similar strengths of learning style preferences). Additionally, versatility is correlated with high scores on tests of visual-spatial abilities. One of the possible explanations, is because different tests may require different strategies to arrive at correct answers. Or that certain strategies are more efficient for particular tests, while broader repertoires of learning styles may enable students to choose between these strategies more freely, and, therefore, attain higher scores. The same cognitive advantage may also affect non-test situations requiring the use of visual-spatial abilities (such as design tasks).

Table 30. Pearson product-moment correlation coefficients (b): Years 1 and 4&5, Experiment III

Variables	VS	IV	IF	V	C	AP
Year 1						
Visual-Spatial	1					
Ideation Verbal	0.522	1				
Ideation Figural	0.671	0.238	1			
Versatility	0.753*	0.522	0.436	1		
Creativity	0.752*	0.468	0.856**	0.752*	1	
Academic Performance	0.873**	0.579	0.509	0.873**	0.762*	1
Years 4&5						
Visual-Spatial	1					
Ideation Verbal	0.170	1				
Ideation Figural	0.344	0.481	1			
Versatility	0.643*	-0.194	-0.038	1		
Creativity	0.870**	0.049	0.232	0.725*	1	
Academic Performance	0.829**	0.169	0.089	0.663*	0.740*	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

5.3.2 Conclusions

This part of the research was concerned with the range of links between the four learning styles, creativity, academic performance and cognitive abilities, which had been established via two principal correlation schemes. They indicated differences and similarities within the sample related to the year of study. For the first year students correlations (scheme 1) included:

- visual-spatial ability was correlated with Imagery learning style, academic performance and creativity; and
- figural ideational ability was correlated with Imagery and Wholistic Simultaneous learning styles, and creativity

The fourth and final year students' correlations indicated:

- visual-spatial ability is correlated with Imagery and Wholistic Simultaneous learning styles, academic performance and creativity; and
- figural ideational ability was correlated with Imagery learning style

In terms of the strengths of predictive validity these initial results may indicate that, for the first year students, cognitive abilities are more important, while in the later years learning styles gain more importance. The differences between the magnitudes of correlations, however, are not significant. Further research with a bigger sample is required to achieve a better understanding of the observed situation. It is also understood that when considering interrelationships between individual qualities and academic performance one cannot ignore the importance of such factors as a learner's intelligence; prior knowledge of the subject domain; level of motivation; anxiety; self-confidence; and the amount of learner control offered (Valley, 1997).

The second correlation scheme indicated that the broader repertoires of learning styles proved to be a statistically significant factor influencing academic performance. The top students across the sample were versatile or brain-gifted, that is potentially more able to cope in any learning environment or more flexible in adopting different approaches to problem solving.

Finally, it has not been possible to determine how the proportion of the variance in achievement outcomes attributable to ability factors fits into other similar research because there is a lack of the relevant studies involving design students and/or utilising same or equivalent psychometric instruments. There is a considerable body of literature in which measures of prior achievement, ability, motivation, and personality have been evaluated as predictors of university first-degree performance, but we have found none in which the roles of Wholistic-Analytic and Verbal-Imagery learning styles have been examined as well. Similarly, while the information about the prediction of learning outcomes in post-16 education and training outside higher education is relatively rich (for example, Furnham, *et al.*, 1999; Drysdale, *et al.*, 2001), there is none or almost none work in which these learning styles have been compared against cognitive abilities (excluding a number of studies that have linked field dependence-independence to visualisation). In general, it can be said that no powerful predictors of learning in higher education have been identified by any researchers, since the proportion of variance accounted for in large-scale studies rarely exceeds 16%, no matter which and how many characteristics of students are considered.

A future range of comprehensive longitudinal studies drawing on large samples and utilising a variety of learning style instruments along with other predictors, such as cognitive abilities, need being carried out prior to drawing any conclusions concerning the relationship between the ability factors and academic performance.

Chapter 6. Experiments IV/b-VI/b. Protocol Studies, Introspective Reports and Design Solutions Assessment

Chapter 6 is concerned with the early stages of designing, or the *preliminary, definitional and decisional, creative or conceptual* phase, as described by prescriptive models. This phase is distinguishable from the later phases as it involves more of understanding the problem and making general, rather than specific or detailed decisions about the solution (French, 1992; Edmonds & Candy, 1993). It commences with elaboration of requirements and proceeds to a certain level of a solution description (in this study limited by the experiment duration). The process may include periods of detailing that are required to develop an aspect of a potential solution to the point where its feasibility can be confirmed.

The quantitative and qualitative methods of protocol analysis, introspective reports and questionnaires are used in Experiments IV/b and V/b as a means of revealing and elucidating cognitive processing that takes place during sketching and thinking of the conceptual phase. It examines how design contexts and intentions are embedded in design drawings along with analysing designers' reasoning reflected in retrospective verbalizations, introspective self-reports of the imagery use, and questionnaires. And, as neither internal reasoning nor mental images can be observed directly, and the resulting data is either inferred or (re)constructed in retrospect, in this study, they will not be strictly separated from the external representations and their functions in problem solving. Rather, all sources will be adjusted to supplement each other to facilitate interpretations or help in dealing with ambiguous or incomplete data.

Experiment VI is the assessment of design solutions produced in Experiment V. Evaluations are done by three independent judges according a number of parameters enabling further exploration of the relationships and correlations between the *product*, the *process* and the *input*.

In addition to combining qualitative and quantitative methods and techniques, this study also employs several partial design process models in an integrated manner. It draws upon a number of generalisations developed within the prescriptive and descriptive approaches and applies exploration to test the proposed hypothesis.

On the whole, consistent with the rest of the research, this part of the thesis aims at obtaining the baseline information as starting points for interpretation, rather than for articulating generalisations. It focuses on gaining insight and understanding and establishing initial tentative links between different sets of data to be analysed and interpreted in more depth in the upcoming studies.

6.1 Experiments IV/b-VI/b: Procedure, Areas & Structure of Analysis

This section explains how this study integrates different types of collected information, initially rich and unstructured, under an overarching approach. As there are no principal differences among the types of data extracted from external and internal representations (although via different methods and techniques) and many correspondences in underlying theories, there is one integrative schema for addressing relationships and correlations between the design ability, the design process, and the design product (see Table 31).

Procedure

Design sessions took place in a well-lit and quiet room, administered for each subject individually, following a similar procedure. Experiment IV/b consisted of two parts. In the first part, students were asked to solve a design problem within assigned for it 50 minutes. After being provided with instructional materials, tracing paper, drafting tools and calculators, they were encouraged to adopt the most comfortable or/and familiar way of designing. They were advised against modifying any processes or activities due to time constraints. The experimenter was around for assistance while students could accustom themselves with the design task requirements, to, then, leave to avoid interference. Each protocol session was videotaped.

In the second part, the participants were asked to provide retrospective reports of the experienced cognitive processing. Retrospection was facilitated via the use of visual aids, including videotapes of design sessions and produced design drawings. Along with these reports, the students also made unprompted introspective statements, while the researcher, when necessary, drew on the technique of an open interview to help clarifying unclear or ambiguous actions, processes and statements. Introspective claims contained metacognitive data on individual problem solving and the imagery use. All verbalisations were audio-recorded.

In Experiment V/b, the participants were given a questionnaire to complete. It was aimed at obtaining additional accounts of individual cognitive processing (i.e. strategies and styles applied in problem solving). Each part was preceded by the standard instructions distributed in a printed form and explained verbally. Total experiment duration was • 3 hours long (per session).

Participants

Participants were the same 20 students from the Faculty of Architecture, The University of Sydney, previously involved in Experiments I/b-III/b. In this part of the study, they are referred to as test subjects S01(I) – S20(V), where the number in brackets indicates the year of study.

The students were expected to have the level of expertise allowing to formulate a concept for a house and its interior spaces and, if necessary, execute a design which captures the essence of the overall form. The design fundamentals they learned include the investigation and application of the elements and principles of design along with creative expression in two- and three-dimensional compositions. The participants have executed, presented and critiqued several projects that utilise different methods of graphic communication, including diagramming, composition analysis, line, pattern, structure, connections, value scales, shape, form and function, and development of concepts which begin with two-dimensional design and progress to three-dimensional design. They were expected to be able to meet a range of constraints and translate their concept into a successful design, that does not mimic their previous projects, but communicates a fresh and creative interpretation of the source. Students of the same year enrolled in the same courses, were assumed to have similar educational experiences, whereas their other relevant extracurricular experiences varied, but not significantly.

Materials

Each participant was given a design task containing a site plan and detailed instructions, and was provided with the drafting and sketching tools and materials, and calculators. After reading the design program, designers were asked to start with a new sheet of tracing paper for each task, and to focus on four different concerns in conceptual, schematic design. The tasks included: (1) analysis of the site, (2) meeting aesthetic and functional constraints, (3) giving a form, and (4) completing spatial arrangement of ten spaces to specified proportions. Prior to the design session, students had to familiarize themselves with its aims and the procedure, as well as with the purpose and the method of successive retro- and introspective tasks. A questionnaire was handed out after the second part of the experiment was over. Appendix B contains descriptions of the design task, and other printed material distributed among the participants.

Collected data

The resulting pre-treated data included videotaped design sessions, recorded retrospective and introspective reports, design drawings and post-session questionnaires.

Method and sequence of analysis

A series of qualitative and quantitative analyses were performed in three major steps to facilitate comparisons and correlations between different groups of data expected to be indicative of the similar/same types of phenomena (i.e. reflecting particular characteristics of the design ability). Table 31 outlines the progression of analyses, and the structure of applied approach.

There are two principal dimensions explored in all three steps in a comparable (in terms of the types of data extracted), though not identical manner – external and internal representations.

In the first step, we propose that certain qualitative and quantitative characteristics of *generated* diagrams, sketches and annotations, as well as of *proto-/metacognitive statements* from introspective reports and questionnaires, could be associated with the differences in individual learning styles and cognitive abilities. Correspondingly, Step 1 (Table 31) focuses on resulting, typical or habitual characteristics of external and internal representations, explored as an object (or outcome) of individual differences in ability factors.

It begins with the analysis of design drawings and annotations, followed by the analysis of introspective statements and questionnaires. It proceeds to establishing initial links between the data from preceding psychometric experiments and individual accounts from protocol sessions.

Table 31. Summary of the areas of applied analysis: Steps 1-3

External representations								Internal representations					
(I) Analysis of external and internal representations as an <i>object</i>													
Analysis of Design Drawings and Annotations								Analysis of Introspective Reports & Questionnaires					
Sketches		Diagrams		Ideas		Words		Introspective Reports		Questionnaires			
Observable characteristics associated with learning styles & cognitive abilities													
2D	3D	Co	Ob	IA(v)	IA(h)	Co	Ob	W-A	V-I	W-A	V-I		
Complexity				Ideas versus words				Visual-spatial & Ideation abilities					
Visual-spatial & Ideation abilities													
(II) Analysis of external and internal representations as a <i>process</i>													
Analysis of Design Drawings and Annotations								Analysis of Retrospective Reports					
Sketches & Diagrams				Idea-annotations				Visual processing		Verbal processing			
Problem solving associated with learning styles & cognitive abilities													
Preferred mode/s of designing													
Graphic			Sentential					Imagery		Verbal			
Imagery-Verbal		Imagery-Graphic		Imagery-Sentential		Verbal-Graphic		Verbal-Sentential					
Initial approach / macro level													
Wholistic			Analytic					Imagery		Verbal			
Prevailing approach / macro level													
Wholistic			Analytic					Imagery		Verbal			
Structure of design processes / macro level													
Wholistic			Analytic					Imagery		Verbal			
Strategies in problem-solving / second grade level													
H / V			IA(v) / IA(h)					Wholistic	Analytic	Imagery	Verbal	Visual-spatial	Ideation
(III) Assessment and analysis of design solutions													
Assessment of Design Solutions (judges)								Assessment of Design Solutions (students)					
CoN	CrO	CE	FF	F	T	W-A	V-I	CrO	Pf	CrO			
Correlation analysis for all datasets													

Ob – object-diagrams / annotations; Co – concept-diagrams / annotations; IA(v) – idea-annotation vertical; IA(h) – idea-annotation horizontal; W-A – Wholistic-Analytic; V-I – Verbal-Imagery; H – Horizontal sketch development; V – vertical sketch development; CoN – number of constraints met; CrO – creativity & originality; CE – complexity & elaboration; FF – flexibility & fluency; F – functionality; T – technical merit; Pf – performance;

In the second step (Table 31), we propose that certain qualitative and quantitative characteristics of diagrams, sketches and annotations *being generated*, as well as of retrospective reports and questionnaires denoting the *progression* of problem solving, could be associated with the differences in individual learning styles and cognitive abilities. Thus, Step 2 focuses on external and internal representations, explored as a process – in relation to individual ability factors.

It begins with the general analysis of acquired data, followed by the more goal-specific exploration of retrospective statements, design drawings and annotations. It then proceeds to establishing initial links between the data from the preceding psychometric experiments and the collected accounts from protocol sessions – by correlating observed approaches, styles and strategies of problem solving with the differences in ability factors.

Step 3 involves collecting series of reports concerned with the students' final products of individual problem-solving as assessed by three independent evaluators. In this step we propose that certain qualitative and quantitative characteristics of generated diagrams, sketches and annotations could be associated with the differences in individual learning styles and cognitive abilities. The third step also contains the final multivariate data analysis determining the range of the most important relationships between external and internal representations, styles and strategies of problem solving and individual learning styles and cognitive abilities, or the *product*, the *process* and the *input*.

6.2 External and Internal Representations as an Object

This part of the research (Experiment IV/b(object)) explores graphical and sentential representations generated by students during individual protocol sessions – to compare them against introspective verbalisations and post-session questionnaires (Experiment V/b). It is aimed at (a) discovering and elucidating several characteristics of design drawings and annotations that could be associated with individual differences in *ability factors*, and (b) identifying and extracting certain groups of data from introspective reports and questionnaires that may reveal students' learning styles and cognitive abilities. The results of both analyses are subsequently compared against the assessments of design solutions.

6.2.1 Analysis of Design Drawings and Annotations

There are two main parts in the study of design drawings and annotations. The first one proposes that diagramming, sketching and annotating (their quantitative and qualitative characteristics) could be associated with the differences in individual learning styles and cognitive abilities. It establishes initial links between the data from preceding psychometric experiments and the collected accounts from protocol sessions.

To reduce the initial complexity of the available data this thesis distinguishes between two classes of external representations: (1) graphical representations, further divided into freehand sketches and diagrams, and (2) sentential representations – written ideas and annotations.

Diagrams and sketches

Further to this classification, this study distinguishes between four secondary object classes, which are: (1) *two-dimensional sketches* – building views, floor plans, elevations and sections, complete or partial, and (2) *three-dimensional sketches* – perspectives, isometric and axonometric views, complete or partial, (3) *object-diagrams* – diagrams illustrating spaces and relationships among them (i.e. sizes, adjacencies, containment, and connections), and (4) *concept-diagrams* – diagrams illustrating concepts (i.e. parts of the preliminary analysis, such as orientation and zoning, functions, and relationships between functions). Other diagrammatical depictions of objects (i.e. furniture, vegetation, cars, people, etc) and concepts (i.e. sight lines, privacy, movement, etc) are considered as sub-elements to the above higher-order representations. Other freehand sketches characteristics, including: physical relations between objects and structures (i.e. their relative locations and proximities, alignment, number or type of shared boundaries, as well as shape and size), patterns, drawing styles, presentation skills and techniques, are excluded from the current analysis.

Diagrams

The participants chose primitives from a limited range of geometric shapes and symbols to draw diagrams, and composed them in highly conventional ways. They predominantly used lines, arrows, ovals, blobs, rectangles, and, less often, hatching. When primitives were combined, they could form symbols to represent design entities, such as spaces or zones, or domain-specific architectural objects, such as boundaries, or to illustrate natural phenomena, such as the sun. For example, a circle was composed with radial lines to indicate the sun; lines were composed to indicate walls and windows; and ovals with lines or arrows were drawn to indicate zones.

From looking at the range of design drawings produced by the study's participants we found that designers used several types of diagrams to represent certain physical objects and design tasks, functions and concerns. They can be loosely categorised into six main types.

Type A. Figure 4(A) shows one of the uses of a diagram in architectural design. Here the student considers two constraints from the design brief (1) orientation of the building in relation to the North and the Sun; and (2) view of a landscape feature (an alley of flaming trees) from a certain place in the building. The diagram allows him to read off visually whether the design in its current state satisfies certain predicates: lighting concerns and adjacency. Sight lines allow the participant to test these predicates. If he retains the sight lines as part of the working design diagram, they can also serve as constraints on the developing design – do not put anything in the way. In this and similar examples, diagram is a tool for analysis that helps the student keep in mind various task constraints that are to be applied to the emerging design.

Type B. Figure 4(B) shows dimensional reasoning for spatial arrangement according to the design brief square footage requirements (numbers, markers and calculations). There were two main strategies observed in type B diagrams. (1) A student drew dimensional marks along the length and width of the site. Then s/he wrote down numbers and calculations to decide upon the size and dimension of a functional space for each room. The results were represented as squares or rectangles with annotated sizes/dimensions and labels. (2) A student built up the required space beginning with the smallest square/rectangle and until all spaces were accommodated. Then, he/she checked to see if the drawn squares could fit into the specified area by (a) adding the sizes up and checking with the brief, or (b) by overtracing them onto the site plan.

Type C. When thinking about spatial arrangements of functional spaces, designers drew several different types of bubble diagrams to represent the rooms and their connections (Figure 4, C and E). Type C is the simplest and the highly abstract form of it. It mainly shows how different zones of the house may appear to a person who walks into it – arrows indicate movement. This diagram represents functional reasoning. Though it also contains elements of structural reasoning, such as an idea of placing studios on a separate level, it contains no elements of dimensional reasoning typical of object-diagrams.

Type D. A bubble diagram like the one shown in Figure 4(D) helps the student to functionally arrange spaces within the designated area and to consider possible changes to the design. It helps him/her understand the constraints of a floor plan and the consequences of proposed changes to the design. Each bubble represents the space needed to carry out a function (living, dining, sleeping, etc.). For example, if the architect decided to enlarge one space, the diagram would reveal how the adjacent spaces needed to be correspondingly adjusted to remain adjacent and stay within their own size constraints.

Type E. This type of diagrams is, in many ways, similar to Type C, though it incorporates more constraints and more aspects of spatial reasoning. With varying levels of detailing and different symbols and shapes used, Type E diagrams typically indicate functional zones, spaces, and, less often, structures, and relationships between spaces and functions, organized horizontally (i.e. placed on the same level) or/and vertically (i.e. on different levels and between them). Both C and E diagrams are independent abstractions, as they cannot be converted into object-diagrams or floor plans by developing or refining spatial arrangements, or adding details.

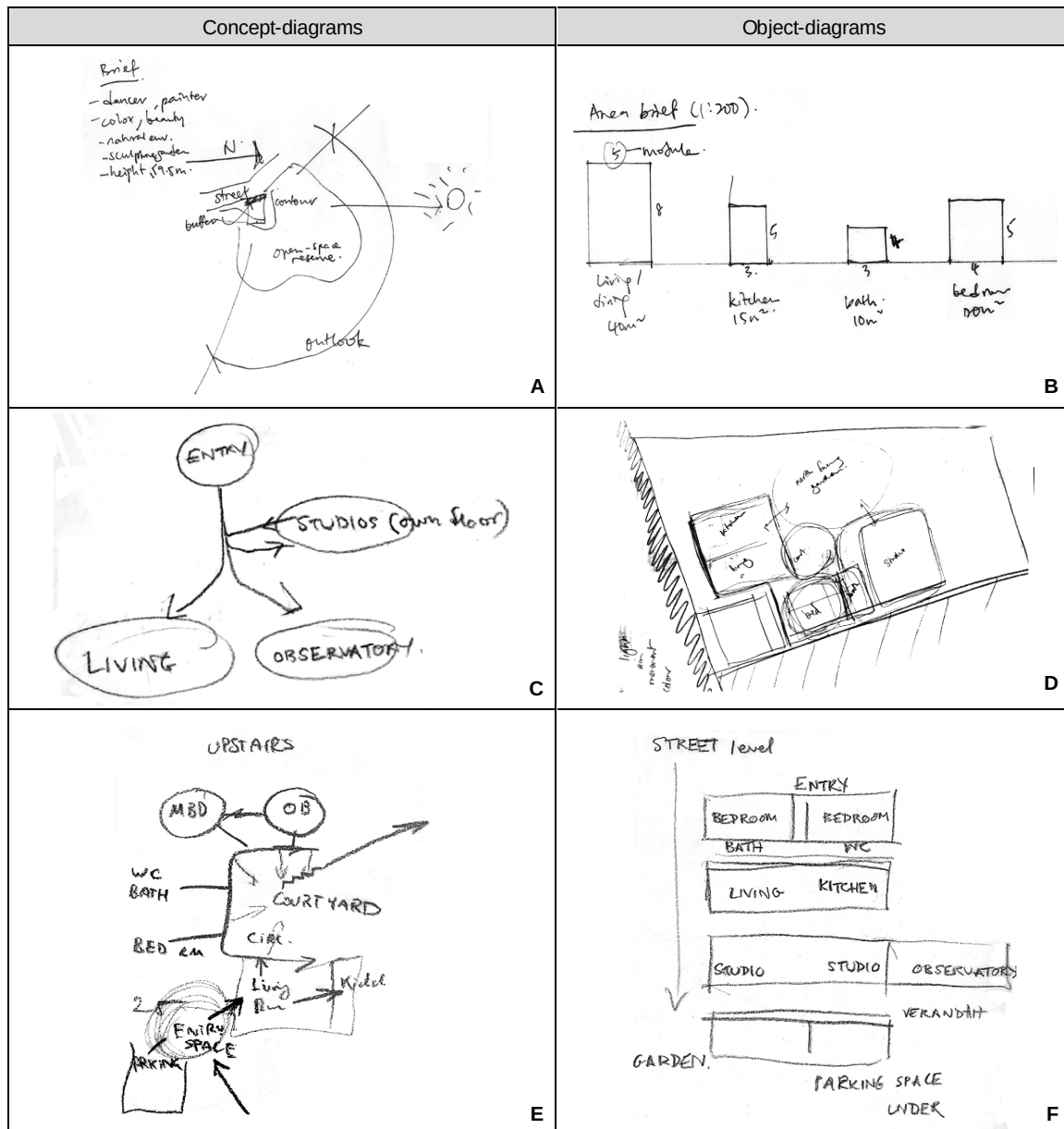


Figure 4. Examples of concept- and object- diagrams

Type F. The final example, in Figure 4(F), shows a use of diagrams in architectural thinking that is similar to types B and D. In several cases, it was an attempt to combine both. There, the elements of the diagram are abstractions for more specific details that are to be filled in later. And the design process that usually follows is incremental formalization. That is, a diagram is further detailed without changing major proportions, shapes or adjacencies – by converting it into a floor plan. In other cases, and as often, it either gets discarded or left unattended when the student started working on a floor plan. It served, primarily, as an analytical tool that helped the designer keep in mind a few constraints that were to be applied to the emerging design.

When observing concept-diagrams, it has been noted that type A was present among the drawings of the first as well as fourth-final year students, showing parts of design knowledge the entire sample was familiar with, that is irrespective of individual learning styles. Similarly, Type C is favoured by all groups of students, i.e. wholistic and analytic, as well as visual and verbal. Type E is favoured by wholistic learners mainly, irrespective of the year of study.

When considering object-diagrams, Type F represents a diagram typical of the inexperienced designers (i.e. first year students). While type C is typical of the analytical

learners irrespective of the year of study. They have one thing in common, both ‘build the diagram’, i.e., proceed from an initial diagram by simply converting the diagram lines into a floor plan. Analytic learners tend to move squares around and overtrace them onto the floor plan (by placing them underneath) in an attempt to fit all of the required spaces inside the designated area. While inexperienced designers are likely to keep the geometric shapes and sizes for rooms, the lines for walls, instead of seeing the diagram for what it really is – an abstract plan that must be further refined and specified.

The more experienced students (diagram D) elaborate on the diagram, add detail, and respond to local conditions. They are less tempted to build the diagram if its form is mostly a reminder that additional detail must be worked out. Alternatively, experienced designers use concept-diagrams, which are highly abstract analytic tools (diagrams A and C). They, having served the purpose, are only used as an aide memoire of the constraints to be considered.

In view of the above, it appears that the use of varying degrees of schematization helps to distinguish different aspects in architectural diagrams, as well as different qualities of the architectural design process. Schematizations enable the designer to focus on specific aspects of a design problem, and to explore his/her design from various viewpoints (Do & Gross, 2001).

Sketches

In contrast to a diagram, which is, predominantly, an analytic¹⁴ tool executed with a high level of abstraction, a sketch is about spatial form; it is carried out with a finer resolution that indicates attributes of that form. It often comprises repetitive overtraced lines made to explore precise shapes, rather than the intentionally abstract shapes of a diagram, and it uses graphic modifiers such as tone and hatching to convey additional information.

Sketches generated by the study’s subjects are divided into two main categories. They are classified as two-dimensional, including plans or elevations exploring the proportions of a building (Figure 5, sketches A, C1, C2, E1, E2, and G). And three-dimensional, such as a perspective providing information about a scene, specifying the shape of physical elements and visual appearance from some location (Figure 4, sketches B1, B2, D, F and H).

Within the first category of 2D-representations, there were sketches favoured by the more experienced designers only, irrespective of the wholistic-analytic and visual-imagery dimensions (Figure 5, sketch A). They can be classified as both diagrams or sketches (or diagrams-on-sketches). Their functions are similar to those of concept-diagrams type A, while other characteristics are more typical of sketches – they are less abstract than a diagram, and are not restricted to the early phases of problem definition/solving (i.e. could appear at any stage of the design development). In the coding scheme and subsequent analyses they were classified as sketches, which partially explains a lower proportion (or lesser overall frequency) of diagrams of the fourth and final year students compared to the first year students (Figure 8, Table 33).

There were also other sketches observed that either looked similar to a diagram or contained elements of a diagram (Figure 5, sketches C1 and C2). They fell short of precisely determining sizes, adjacencies, and shapes, but showed higher levels of detailing and resolution of functional, spatial and structural concerns (Laseau, 1980; Do & Gross, 2001). These, according to our observations, are favoured by wholistic and/or visual students irrespective of the year of study (though with a higher proportion of wholists among the more experienced designers), and are, in most cases, extensions/progressions of object-diagrams, type D.

Other sketches (almost exclusively floor plans) attempted precise relationships between spaces drawn to exact dimensions with a help of a ruler (Figure 5, sketch G). Due to design sessions time constraints and, possibly, other reasons, such as the designer’s knowledge, styles and abilities, precision in shapes and dimensions typically emerged as a result of the sacrifice of initial ideation and/or of more interesting spatial arrangements – in favour of the first feasible solution. These types of sketches were mainly favoured by analytical and/or verbal learners of

¹⁴ I.e. purpose-wise, processes involved in generation of diagrams may include synthetic/wholistic, as well as analytic reasoning.

the fifth-final year of study and verbal students of the first year of study (irrespective of the wholistic-analytic dimension).

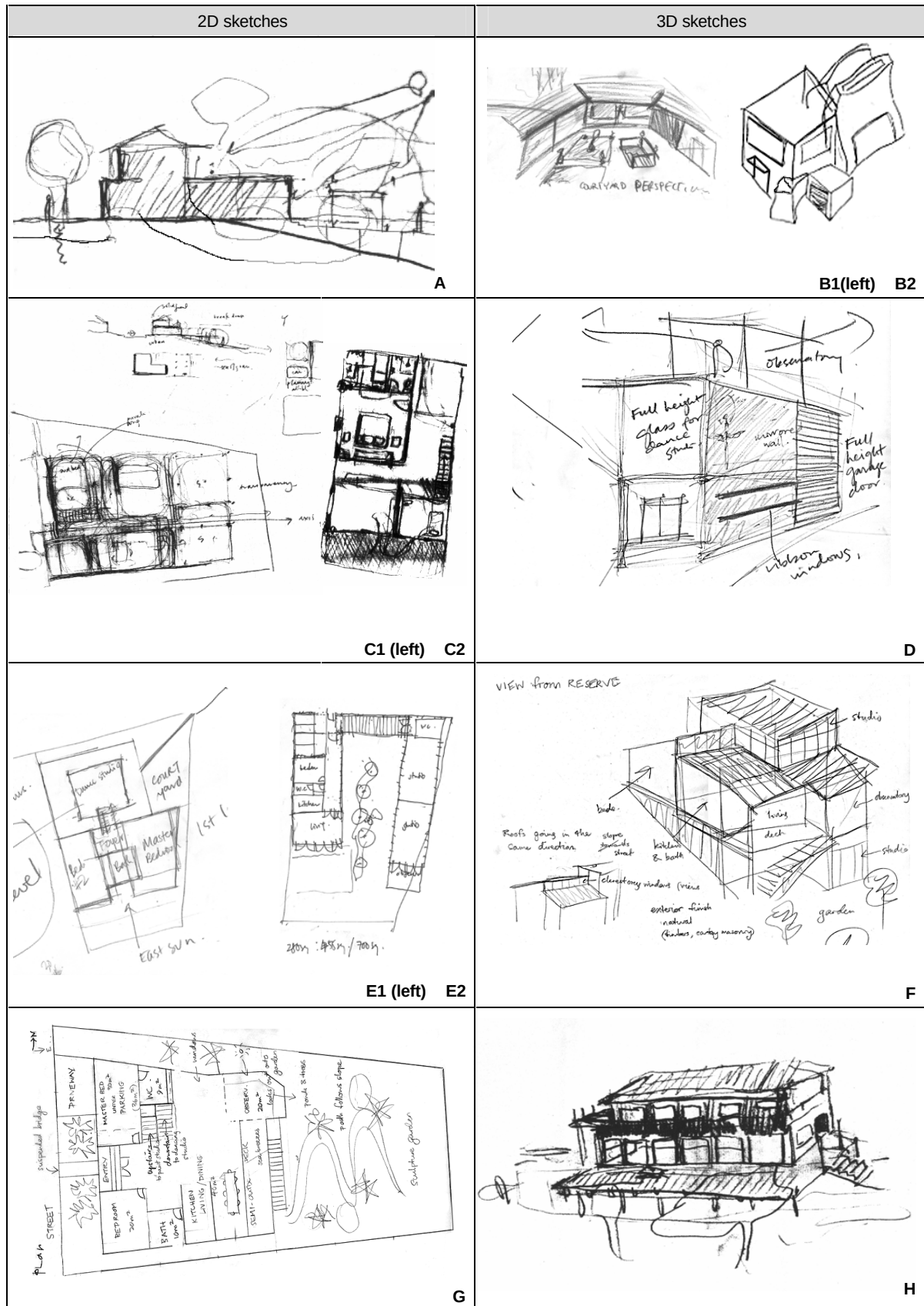


Figure 5. Examples of 2D and 3D sketches with varying degrees of complexity, detailing and abstraction

Finally, students also produced sketches that fell midway between the above two types, combining high (or medium) levels of abstraction and low (or medium) commitment to form/s and dimensions allowing for flexibility typical of diagrams type D, but with reasonable levels of detailing typical of sketches (Figure 5, sketches E1 and E2). These were favoured by visual students from both groups, irrespective of the wholistic-analytic dimension.

The second category in classification of sketches is 3D-representations. Architectural space is ultimately three-dimensional, and designers often moved or projected from 2D floor plan sketches to 3D representations such as isometric or perspective views. By doing so, they put themselves in the design context of seeing and testing how the space works in a geometric model that formally expressed the shape of the space. Figure 5 shows a collection of 3D views typically drawn adjacent to the floor plan drawings to explore various design concerns.

Figure 5, sketch B1, is the type of sketch typical of wholistic visual and visual-verbal students from the first year of study. Sketch B2 represents a complex form supplemented by no annotations, no shading and low level of detailing – these were favoured by the more experienced high spatial, visual wholistic students from years four and five.

Figure 5, sketches D and F, are typically more annotated, more detailed, use shading, but do not always depict complex or unusual three-dimensional forms. They were favoured by visual-verbal wholistic students from the first year of study, and visual-verbal fourth and final year students, irrespective of the wholistic-analytic dimension.

Figure 5, Sketch H, is the rather elaborate representation which uses shading and may or may not contain annotations. It was favoured by the more experienced visual (in case of minimal annotating) and visual-verbal students, who had preferences or flexibilities in wholistic thinking, regardless of the primary learning style preference (i.e. strong preference) on the wholistic-analytic dimension.

Further to the above classification, both 2D and 3D representations are categorised according to the three levels of complexity. Within the two-dimensional group, sketches A and C1 represent the lowest level 1, C2, E1 and E2 belong to level 2, and G – to the highest level 3. Within the three-dimensional group, sketches B1 and B2 represent the lowest level 1, and H – the highest level 3 (D and F belong to the same medium level 2). Although the differences may seem marginal, the above representations are not the same in terms of the number of constraints and design elements considered, articulation of the form, as well as the levels of detailing. Due to the protocol sessions time restrictions, and other reasons discussed further, these differences were expressed graphically as well as sententially. They – drawings and annotations, were, therefore, considered jointly when ascribed complexity levels. In future studies, it may be useful to separate them to better understand what underlies these manifestations of problem solving.

In the study of sketches and diagrams, it is proposed that varying levels of complexity, as well as the balance between 2D and 2D drawings, may be related to the students' cognitive abilities and, possibly, cognitive styles. The range of potential links between the three levels of complexity and ability factors is explored and elucidated further in this section.

Annotations and written ideas

In addition to graphical representations, the thesis explores sentential representations. The latter are viewed as equally important because practicing designers have found for the annotations of design sketches to serve as a diary of the design process. They (annotations) are also often seen as more valuable to the client, or other people concerned, than the sketches themselves (Boyarski & Buchanan, 1994).

This study distinguishes between four principal types of sentential representations (Figure 6). They include: (1) words and phrases, with/without numerals, describing objects; (2) words and phrases, with/without numerals, describing concepts; (3) words, phrases and sentences, with/without numerals commenting on or extending existing design ideas (graphic or verbal); and (4) words, phrases and sentences, with/without numerals, outlining new design ideas.

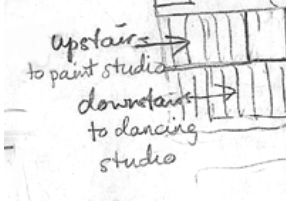
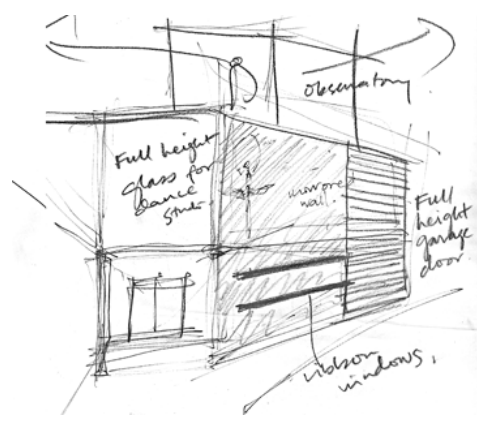
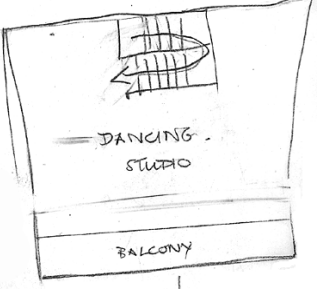
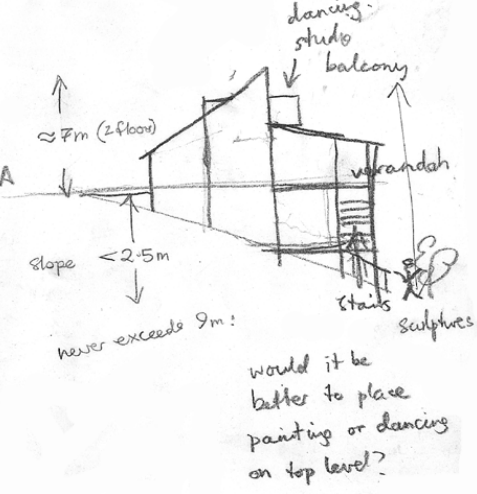
Concept-annotations		Object-annotations
 <u>Reads:</u> Upstairs to paint studio, downstairs to dancing studio A1	<u>Brief.</u> - dancer, painter - color, beauty - natural env. - sculpture garden - height 59.5m. <u>Reads:</u> Brief. Dancer, painter, color, beauty, natural view, sculpture garden, height... A2	 <u>Reads:</u> Full height glass for dance studio... observatory... full height garage door... B
Idea-annotations (vertical)		Idea-annotations (horizontal)
Changes to shape due to feasibility of construction of bottom & top  <u>Reads:</u> Changes to shape due to feasibility of construction of bottom and top C	 <u>Reads:</u> Would it be better to place painting or dancing [studio] on top level? D	

Figure 6. Classification of annotations produced during individual design sessions

The first category consists of *object-annotations* (Figure 6, B). These are written notes, specifying, describing, or defining an object, a group of objects, relationships among objects, and physical properties of objects (including size, shape, materials, colours, etc). They can also be used to specify certain properties of a relation between two objects, such as a distance from A to B, proximity or alignment.

The second category contains *concept-annotations* (Figure 6, A1, A2) They are used to describe zones, functions, relationships between functions, or characteristics of an object that cannot be formulated graphically (such as 'privacy', 'good view', 'noisy', or affective comments – 'gloomy', 'nice feel', etc).

Categories three and four are *idea-annotations*. These are comments or records of design ideas that, for some reason, were not (or could not) be expressed graphically. They are divided into *vertical* (Figure 7, C) and *horizontal* (Figure 6, D) *idea-annotations*. The first type can be associated with vertical progression of a design – as it further develops, or adds details, to an already existing idea or a drawing (i.e. 'studio needs more space', or 'trees will be planted along the road'). The second type is more independent as it is used for noting down newly emerging ideas which can be associated with lateral design (i.e. 'may change the form [of the house] to

look more organic’) or sketch (i.e. ‘swimming pool somewhere here?’, or ‘more light upstairs, move study room – [there]’) development, or their reinterpretations.

In this study, sentential representations were observed to have been used for different purposes and in different combinations (pre-treated data is included in Appendix A tables, for descriptive statistics see Table 33 and Figures 8-9). Among the types of writing that were most commonly found in all groups of subjects are object-annotations; they were favoured by all students, irrespective of individual learning styles, cognitive abilities, or experience. And concept-annotations (Figure 6, type A1 – favoured by wholistic learners mainly; type A2, also with numbers or bullets, is more typical of analytical learners, irrespective of the visual-verbal dimension). These two types of annotations have a function of clarifying or commenting on a sketch, image, or mark (Lawson & Loke, 1997), while lists of items are used to record requirements of a design task or attributes of a certain, usually graphical, idea.

Idea annotations, or words that comprise complete sentences, were favoured more by the wholistic first year and brain-gifted fourth and final year students, irrespective of the visual-verbal dimension, and appeared less frequent. These were predominantly (1) statements explaining ideas more thoroughly, when there was no time to sketch, or it was generally easier to express them in a verbal form, or (2) when new ideas needed to be recorded on the fly, before being overlooked or forgotten, also affected by the design sessions time constraints. That is, in both cases students resorted to the sentential form of idea representation when they felt there was not enough time for adequate graphic depictions. Additionally, sentential representations allowed more freedom of exploration by avoiding premature commitment to detailing (i.e. ‘*may use ‘space’ theme to reshape the upper deck*’). Finally, some of the first year students who lacked in sketching ability, as well as some of the low(er) spatial individuals from either year of study felt it was easier for them to describe ideas either verbally – in retrospect, or on paper. These and other results are analysed and explained further in this section.

Similarly to the study of sketches and diagrams, it is suggested that different qualitative and quantitative characteristics of sentential representations may be related to individual learning styles and cognitive abilities, and, possibly, to the quality of the students’ final designs. The latter is supported by research which demonstrated that there is a relationship between the design quality and the use of words (Wong & Kvan, 1999).

Descriptive statistics

Descriptive statistics for the external representations explored in this part of the study is presented for each test group as a whole, and split by gender (Table 32). It indicates quantitative characteristics of sketches, diagrams and annotations based on initial estimations of overall numbers per individual design session, and not per page. The original data is included in Appendix A, it contains individual accounts of each of the listed below dimensions of analysis.

Effects of gender on the production of external representations

The MANOVA analysis of the number and type of external representations produced, gender, year of study, and ethnic origin, has revealed the possible main effect or interaction for gender. The data suggests there could be gender differences in the number of external representations produced by the first year students: with females, on average, generating more sketches, more diagrams and more annotations (Table 32, Figure 7).

There may be a number of reasons for the observed situation. (1) As our results indicate, (Tables 26, 27, Figure 3) females from the sample are more inclined towards wholistic thinking associated with ideational fluency, which may result in an increased number of initial, usually highly schematic sketches and diagrams (Figure 10). (2) Females have also been reported (Table 16, Figure 2) to have higher levels of ideational fluency, which, in its turn, may be associated with the speed of drawing (Carroll, 1993). (3) The highest proportion of annotations may be related to the fact that female gender is associated with verbal thinking (Tables 26, 27, Figure 3)

– it is not just drawings and diagrams that are being annotated, females may also prefer to note down, rather than sketch, ideas, or to describe objects or concepts (Figure 11). (4) It was also observed that females were more inclined towards communicating the process and the outcome of individual problem solving. In a sense, they felt more responsible in terms of generating enough evidence of external and internal reasoning, after being explained the nature and the purpose of the design task. (5) Finally, the brain-gifted student from the first group is a female. And, as our results indicate, brain-giftedness on both verbal-visual and wholistic-analytic dimensions is associated with the highest number of external representations (Figures 11,12).

Table 32. Distribution characteristics for external representations by year and gender: Experiment IV/b

variables	Year 1						Years 4&5					
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Di	1.00	5.00	2.80	1.48	2.40	1.72	0.00	3.00	1.80	1.30	2.60	1.96
	0.00	5.00	2.00	2.00			1.00	7.00	3.40	2.30		
Co-Di	0.00	2.00	1.40	0.89	1.40	1.27	0.00	3.00	1.00	1.41	1.70	1.95
	0.00	4.00	1.40	1.67			0.00	6.00	2.40	2.30		
Ob-Di	0.00	3.00	1.40	1.14	1.00	0.94	0.00	2.00	0.80	0.84	1.00	0.67
	0.00	1.00	0.60	0.55			1.00	2.00	1.20	0.45		
Sk	1.00	16.00	7.80	6.06	7.40	4.43	7.00	15.00	10.2	3.56	9.50	4.50
	3.00	10.00	7.00	2.65			4.00	17.00	8.80	5.63		
3D-Sk	0.00	2.00	0.80	1.10	1.10	1.37	0.00	2.00	0.80	0.84	0.90	0.88
	0.00	4.00	1.40	1.67			0.00	2.00	1.00	1.00		
2D-Sk	1.00	14.00	7.00	5.05	6.30	3.77	7.00	14.00	9.40	3.05	8.60	3.83
	3.00	9.00	5.60	2.30			4.00	15.00	7.80	4.71		
An	6.00	17.00	10.80	4.66	10.30	4.35	8.00	13.00	10.60	2.07	10.40	2.88
	5.00	16.00	9.80	4.49			4.00	14.00	10.20	3.77		
Co-An	2.00	9.00	4.80	2.78	3.60	2.67	0.00	5.00	2.60	2.30	3.30	2.11
	0.00	6.00	2.40	2.19			2.00	6.00	4.00	1.87		
Ob-An	1.00	11.00	4.40	3.98	5.20	3.12	4.00	9.00	6.60	2.07	5.10	2.60
	3.00	9.00	6.00	2.12			1.00	7.00	3.60	2.30		
Id-An	0.00	2.00	1.60	0.89	1.40	1.35	0.00	3.00	1.00	1.22	1.70	1.49
	0.00	4.00	1.20	1.79			0.00	4.00	2.40	1.52		
Id-An(v)	0.00	2.00	0.80	0.84	0.60	0.70	0.00	2.00	0.60	0.89	1.20	1.03
	0.00	1.00	0.40	0.55			1.00	3.00	1.80	0.84		
Id-An(h)	0.00	2.00	0.80	0.84	0.80	1.03	0.00	1.00	0.40	0.55	0.60	0.70
	0.00	3.00	0.80	1.30			0.00	2.00	0.80	0.84		

Females
 Males
 Group results

Di – diagrams; Co-D – Concept-diagrams; Ob-D – Object-diagrams; Sk – Sketches; 3D-Sk – three-dimensional sketches; 2D-Sk – two-dimensional sketches; An – Annotations; Co-An – Concept-annotations; Ob-An – Object-annotations; Id-An – Idea-annotations; Id-An(v) – Idea-annotations (vertical); Id-An(h) – Idea-annotations (horizontal)

The observed situation is, evidently, complex. There could be other influences related to individual cognitive abilities, learning styles, sketching skills, levels of experience, and so on. Additionally, before any conclusions are drawn, one needs to look into other characteristics of drawings and annotations, such as: complexity, levels of abstraction, detailing, articulation of the form and the number and quality of ideas – to gain a better grasp of what the results may indicate. Whilst the size of the sample does not encourage generalisations.

The same main effect for gender is present in the second group of participants – fourth and final year students. On the outset, it may seem that the results are similar only in the number of freehand sketches and annotations – with females generating more of them, and males – more of diagrams. The reasons for the larger numbers of sketches and annotations match the reasons specified above (including the higher percentage of brain-gifted students among the females). At the same time, fourth and final year males often produced more detailed or more complex drawings. The higher proportion of diagrams could be explained by the fact that, in our sample,

male gender is associated with analytical visual thinking (Tables, 26, 27, Figure 3) which may be further linked to the nature of diagrammatic reasoning and the roles diagrams have in design.

While the lower proportion of diagrams generated by females can be explained by the observation that brain gifted and wholistic students tend to integrate analysis and synthesis in one drawing. Though classified as sketches, many of the Type A (Figure 5) representations contain elements of diagrammatic reasoning, typical of Type A diagrams (Figure 4). Additionally, many fourth and final year students preferred developing some of their early diagrams (Figure 4, Type D) by adding details and responding to local conditions – till they became working sketches Types C1 and C2 (Figure 5), and were classified as such.

Finally, the more experienced designers are familiar with, and may draw from, such a variety of design representations' types and conventions to express their ideas, or approaches and strategies to resolve design problems, it is not evident if linear correlations are appropriate.

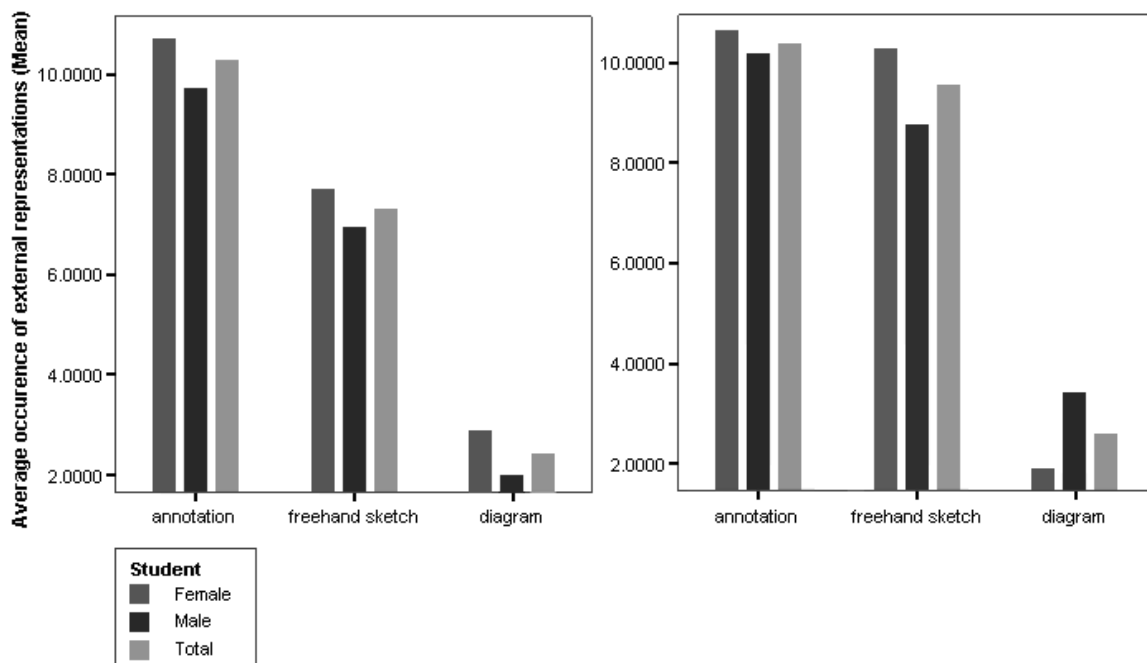


Figure 7. Average occurrences of external representations by gender: Year 1(left), Years 4&5 (right)

Effects of ethnicity on the production of external representations

The one-way analysis of variance concerning numbers and types of external representations produced, year of study, and ethnic origin, has revealed the possible main effect or interaction for ethnic origin. There are differences in the amount of external representations produced by the first year students, as Australasian students, on average, generated more sketches, more diagrams and more annotations (Table 33). However, much of these differences could be related to the fact that there are more females among Australasians (30%) and more males among Australians (30%) in the first group. When gender was introduced as the second independent variable, the analysis showed no main interaction or effect for ethnicity concerning the number of sketches produced, and marginal differences on the other two dimensions – diagrams and annotations (*words* and *ideas* were grouped together under a single category).

Table 33. Effects of ethnicity on production of external representations: Experiment IV/b(object)

		Year 1				Years 4&5			
		Words	Ideas	Sketches	Diagrams	Words	Ideas	Sketches	Diagrams
Australasians	Mean	10.40	2.00	8.40	3.40	8.00	1.4000	9.60	2.40
	SD	3.51	1.41	5.42	1.67	2.91	1.67	5.22	2.79
Australians	Mean	7.00	0.80	6.40	1.40	8.80	2.00	9.40	2.80
	SD	2.74	1.10	3.51	1.14	1.1	1.41	4.28	0.84

Similarly, no significant effects for ethnicity have been detected among the fourth and final year students. This, in part, is supported by the fact that the situation with gender and ethnic origins is reverse for the second group – there are more males among Australasians (30%), and more females among Australians (30%).

Comparative analysis

Comparative analysis between the first, and fourth and final year students allows examining the participants' preferences for presenting information and ideas either graphically (external visual mode) – by sketching, or sententially (external verbal mode) – by making notes.

Figure 8 demonstrates relations between the cumulative numbers of occurrences of different types of external representations (i.e. sums and frequencies of sums) for the entire set of drawings summarised for all design sessions, split by the two groups of subjects.

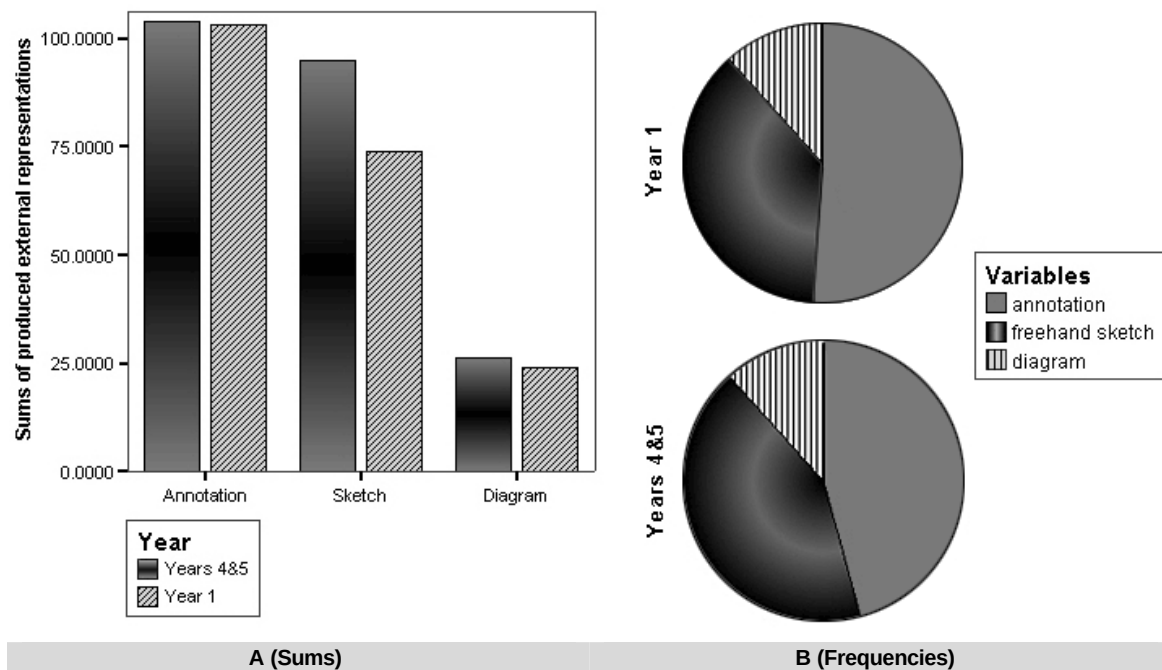


Figure 8. Sums and frequencies of graphical and sentential representations: Years 1, 4&5

Figure 8(A) indicates that there are differences as well as similarities within and between the sample. Fourth and final year students produced significantly more sketches, while both groups generated comparable numbers of annotations and diagrams. Additionally, both groups produced the highest amount of annotations, and the lowest – of diagrams. It appears, however, that the first year students annotated various physical characteristics of their external representations more. This observation is more apparent from Figure 8(B) showing frequencies of the three types of external representations, and Table 32, suggesting a higher proportion of concept- and object-annotations, and horizontal idea-annotations, as opposed to vertical idea-annotations favoured by the fourth and final year students.

Further to this comparison, Figure 9 demonstrates relations between the average numbers of occurrence of different types of external representations estimated for all design sessions split by the two groups of subjects. The means were calculated based on individual sets of drawings (cumulative numbers of each representation type), and not on a per page average basis.

Similarly to Figure 8, there are visible variations in the character of results of the first, and fourth and final year students. All subjects, on average, generated the lowest proportion of diagrams and the highest of annotations, with architecture students producing more sketches, and both groups – comparable numbers of diagrams and annotations. There are other important observations related to external representations that will be addressed further on.

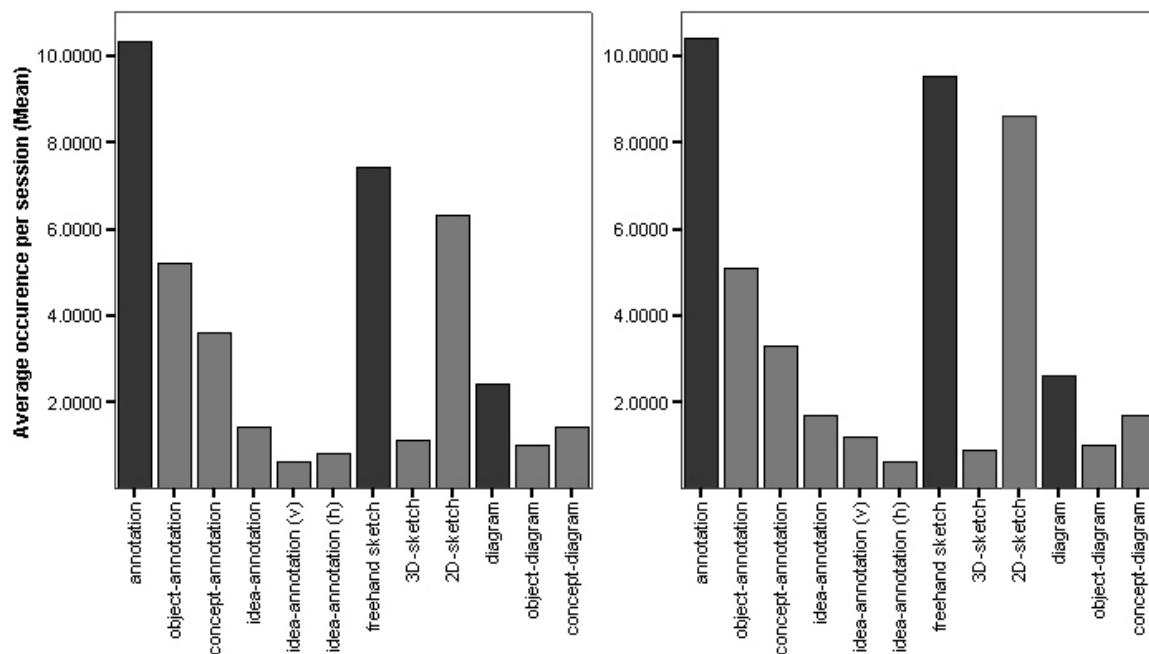


Figure 9. Average occurrences of graphical and sentential representations (Means):
Year 1 (left), Years 4&5 (right)

Diagrams. Despite of similar proportions and overall numbers of diagrams of the two groups of subjects, the ultimate balance within the sample could be estimated as • 25% in favour of the more experienced designers. This is because 50% of the fourth and final year students generated external representations (Min=1; Max=4) classified as sketches Type A, C1 and C2 (Figure 5) which either contained elements of concept diagrams Type A (Figure 4) or were actual progressions of object-diagrams Type D (Figure 4).

Some of the causes for quantitative and qualitative differences between the participants' representations are likely to be related to the specifics of design and design education. In other domains, diagramming supports analysis and inference about a problem. In architectural design, diagrams are also abstract representations of more detailed physical forms. They can be used to explore conceptual, functional, spatial and structural variations of design problems, as they allow to “see, comprehend and respond” to more visual information than can be remembered from verbal notes (Lockard, 1973). Thus, and perhaps different from thinking with diagrams in other domains (or from pre-architecture experience) an architectural design may be represented by diagrams at various levels of abstraction – with each element illustrated by a diagram at a more detailed level down. Additionally, architectural diagrams represent not only physical elements, but also forces and flows (such as forces of sun and wind and flows of people and materials). That is, arrows, lines, and other symbolic representations that convey spatial characteristics such as magnitude and direction. Thus, the ability to diagram an architectural context also depends on designers' knowledge of issues such as sun, wind, vegetation, traffic, and surroundings. It is likely, therefore, that higher proportions of diagrammatic representations of the fourth and final year students are related to their, more extensive, design experience. That is, it involves both knowledge and skill to apply diagramming as a useful planning tool as opposed to ‘decorating boxes’ more typical of the earlier years of study.

There may be similar reasons for differences in the type and quality of generated representations. Architectural designing often begins with a diagrammatic depiction of the architectural program that is gradually transformed into more complex graphic representations by adding details and responding to local conditions. That is, even the most abstract design diagrams are initial efforts to explore and resolve spatial layout concerns. Experienced designers apply a process of transformations and merging “trying to take a structural diagram, a functional diagram, and a circulation diagram” and “combine them” (Rowe, 1987). In this study, the fourth

and final students appeared more capable of using this process to develop diagrams into spatial layout sketches (diagrams Type D, Figure 4 progressed to sketches Types C1 & C2, Figure 5) by incorporating more aspects of diagrammatic reasoning within one drawing, and/or combining sketches and diagrams into one representation (Type A, Figure 5).

On the whole, as all subjects used diagramming as a tool for analysis of design concerns, the lowest proportion of diagrams relative to other external representations suggests that they have, on general, succeeded in extending design solutions beyond the preliminary analysis phase. At the same time, the inability of many students to usefully integrate results of their analyses into further designing, or equally, use diagrams as means of initial synthesis, shows that they require more experience with diagrams generation and application.

Based on this study's graphic materials, several different types of diagrams have been observed. Further elaborating on the six broad categories illustrated by Figure 4, they included:

- (1) rough structural diagrams (similar to Types D & F);
- (2) linear block diagrams with or without dimensional marks (similar to Type B);
- (3) refined structural diagrams with dimensional marks (progressions of Types D & F);
- (4) circulation diagrams;
- (5) simple functional diagrams, showing interactions between functions/zones (similar to Type C);
- (6) refined functional diagrams, also with elements of spatial reasoning (similar to Type E);
- (7) diagrams addressing design concerns, such as orientation, sun, noise, etc (similar to Type A);
- (8) functional-structural (structural-functional) diagrams;
- (9) structural-functional diagrams with dimensional marks; and
- (10) combinations of two or more of the above

There were also (a) rough diagrams with additional details to show significance / role / use / function of an object or space; (b) diagrams with alternative details; (c) diagrammatic depictions of design elements such as furniture, vegetation, etc (excluded from further analyses); (d) concept-diagrams, such as Type A (Figure 4) integrated with sketches; and (e) object-diagrams, such as Type D (Figure 4) which progressed to sketches Types C1 and C2.

According to this study's verbal accounts, there are three primary purposes for diagrams as reported by all subjects. This includes using them as (1) interactive reasoning aids, aimed at resolving conceptual, functional, spatial and structural concerns; (2) visualisation aids; and (3) memory aids. The more specific uses and the reasons for uses of diagrams included¹⁵:

- verbal-visual translations – used as tools that govern and transform the meanings of verbal statements into a graphic context to help the designer solve problems *'here I sketched roughly this alley of flame trees from the task, so that I could work with it'* (100% of the first, and 100% of the fourth and final year students);
- analysis of constraints – significance of spaces, functions and relationships between spaces and functions *'here I placed and marked all spaces I needed to include'* (100% of the first, and 100% of the fourth and final year students);
- resolution of constraints – roles / uses / functions of objects, spaces and structures *'now that I've marked [with a bubble] the observatory, I can see how it relates to other spaces... but it didn't quite fit, so I kept playing with it'* (100% of the first, and 100% of the fourth and final year students);
- initial resolution of form and layout, including rough shape and proportions to a free scale (70% of the first, and 100% of the fourth and final year students, of which 50% later became sketches-diagrams Type C1 and C2, Figure 5, having progressed from

¹⁵ In the brackets are percentages of the total number of students from the sample (split by the year of study) who resorted to the above types of diagrams, not frequencies of different types of diagrams.

object-diagrams, type D, Figure 4); and more precise dimensional reasoning (60% of the first year students applying diagrams Type B and F, and 50% of the fourth and final year students, utilising diagrams Types B, Figure 4, only);

- simplicity and appropriateness of depiction and resolution, as certain
 - functions – zones, orientation, movements, circulations, etc;
 - relations between functions;
 - symbolic representations of concepts – site lines, sun, noise, etc;
 - symbolic representations of objects – furniture, trees, people, etc;
 - relationships between objects – proportions, adjacencies, connections, etc; and
 - combinations of the above
 are easier, more efficiently, and/or more conventionally described and resolved diagrammatically, *‘here I’m drawing some bubbles of the spaces I wanted to include, and arrows to show the movement... its now easy to see how they interact’*; *‘here I drew the sun and marked the North – standard drawing practice’* (100% of the first, and 100% of the fourth and final year students)
- complexity of emerging design ideas – design ideas could not be described sufficiently with a sketch or/and annotated sketch alone *‘here I was trying to show how this area behaves when you come inside... how it tells you where to go, and what to expect’* (20% of the first, and 30% of the fourth and final year students);
- records of newly emerging ideas and concerns – design ideas needed being recorded on the fly under time constraints, or to be revisited later *‘here I sketched a quick circulation diagram to make it a focus of the studio... if I had time’* (40% of the first, and 50% of the fourth and final year students);
- a starting point of synthesis of ideas resulting from
 - one, two or more diagrams that belong to the same type (typically C, B or F, Figure 4) or seem unrelated to one another (70% of the first, and 60% of the fourth and final year students); or
 - tree of functional, structural and circulation diagrams (20% of the first, and 40% of the fourth and final year students);
- unwillingness to commit to detailing / postponing detailing *‘I just sketched it roughly here, to know what to include, because I was not sure about the form yet’* (70% of the first, and 90% of the fourth and final year students);
- allowing for ambiguity to avoid narrowing down the search space / postponing judgement *‘I sketched these thin lines and like indefinite shapes because I was still looking for the form and how all these spaces are related to one another’* (60% of the first, and 80% of the fourth and final year students); and
- exclusiveness – certain ideas could only be formulated diagrammatically (would require considerable efforts with other representations) *‘here I tried to see [by sketching bubbles and movement lines] what happens in the studio when they have visitors... if there was enough space for them to walk around’* (30% of the first year students, 30% of the final year students).

In addition to, and flowing from the above, the diagrams differed in levels of abstraction, skills of matching task requirements with corresponding diagrams, skills of matching the level of detail to the level of decision making, and, as a result, efficiency of resolution of conceptual, spatial and functional concerns. Different types of diagrams appeared at different points of problem-solving, likely to have been influenced by various individual characteristics, ranging from cognitive abilities, learning styles, reasoning strategies, to individual knowledge, experience, skills, and possibly, more. Correspondingly, as diagramming draws on a high proportion of acquired knowledge or learnt skills (also indicated by statements like *‘I did this orientation diagram here, standard design practice’* or *‘here I separate different zones, you*

always do this in the beginning') it may prove difficult, or impossible, to identify its qualitative and quantitative relationships and correlations with design abilities, or, equally, to make valid comparisons within and between the two groups of subjects (with the first year students, potentially, more reliant upon their innate abilities in problem-solving). Thus, although certain comparisons will be made (Figures 10-12; Tables 34-37), and observations interpreted, conclusions are considered tentative and, at most, indicative of future research directions.

Sketches. There is also a number of observations related to sketches. Despite differences in design experience, there were many commonalities in the way they were used by the two groups of students. Applied with varied degrees of competence and efficiency, sketches served as a memory aid, and interactive and iterative means of (1) generating concepts, (2) visualising and externalising problems; (3) facilitating problem solving and creative effort; (4) facilitating perception and translation of ideas; (4) representing real world artefacts that can be manipulated and reasoned with; and (5) revisiting, revising and refining ideas. They were executed with:

- *solid, continuous lines*, which is the most general category of graphic implementation. These were used for practically everything, from relationship and organizational lines to the contours of spaces or building elements. The arrangement of lines followed a number of general principles, which organized the image into typically discrete even though overlapping parts. These principles included: (1) formation of closed or, less frequently, open shapes; (2) correlation of structurally similar or connected elements; (3) grouping of two or more lines into the contour of a path or a grid; and (4) simple connection and co-termination, indicating that the lines belong to the same form;
- *multiple lines and bubbles* – were used to depict organisational lines or limits of spatial elements; they could form closed as well as open shapes (Figure 6, C1). Similarly to scribbled-line drawings, multiple lines made an outline of a form fuzzy and indefinitely stated. This agrees with the reluctance to make hard commitments in the early design stages, as well as with the informality and metric flexibility of the sketch;
- *overtracing* – was a common characteristic of designers' working sketches, in which their pen repeatedly outlined a particular shape or area of drawing. This redrawing, served several functions, including: (1) selection of a design entity or drawing attention to the element; (2) attending to one or another shape interpretation; and (4) shape refinement, or adding detail to an abstract or roughed-out shape;
- *broken and dashed (dotted) lines* – represented a diversification of the basic solid line. They were used to indicate projecting elements, relationships between building elements and, less frequently, spaces; and
- *texturing, hatching and colour* – were applied more sparingly (particularly the colour) in order to accentuate spaces or space groups. These were also used to indicate subdivisions of spaces within bubbles or closed shapes, as well as graphic annotations of formal principles and activity patterns.

All first and fourth and final year students resorted to the above graphical means of reasoning and communicating on paper, although to different extents and with varied degrees of proficiency. On the whole, fourth and final year students were more capable of interacting with their representations, used more drawing conventions, and produced a wider range of two-dimensional (building views, floor plans, elevations and sections, complete or partial) and three-dimensional (perspectives, isometric and axonometric views, complete or partial) sketches.

There were also a number of differences observed in the levels of complexity, further analysed in this subsection. As this study's data was limited by external representations from protocol sessions, only three levels of complexity were suggested. They apply to 2D as well as 3D drawings, and exclude diagrams, which are abstract and schematic by nature.

- *complexity level one* is a monochrome line drawing, there is no shading but there may be a use of different thicknesses and pressures of line (Figure 5, drawings A, B1, B2, C1 and C2). It is typical of initial ideation or early conceptual thinking. It shows low level of detailing; low level of the form articulation (high schematization); high metric flexibility – approximate allocations and dimensions/proportions of spaces and structures; and a minimum of constraints considered (1-4). Only object or/and one or two short concept annotations and a few dimensional markers may appear;
- *complexity level two* is a monochrome or coloured line drawing which may use rough shading to give suggestion of 3D form or accentuate elements of a 2D form (Figure 5, drawings E1; E22, D and F). It indicates medium level of detailing, higher (than level one) commitment to overall form; resolute placement of spaces and structures; more precise dimensional reasoning; and a medium number of constraints included (5-10). The drawing may contain dimensional markers, be annotated to describe objects, concepts and certain aspects of the idea/s (no more than 3 ideas); and
- *complexity level three* is a monochrome (or utilising gradations of the same colour) or coloured drawing which may use more subtle shading suggestive of 2D or 3D form (Figure 6, drawings G and H). It shows the highest (of the three) level of detailing in parts – combined with overall medium level of detailing, or as a whole; the highest commitment to overall form, exact placement and configuration of spaces and structures; the most precise dimensional reasoning/scaling; and the largest number of constraints considered (11-16). Annotations may be used to describe objects, concepts, various aspects of the idea/s depicted, as well as other ideas associated with the design.

Annotations. The largest number of annotations (both overall and means), resorted to by both groups of students, is likely to be related to the range of purposes they have in design, and, to some extent, protocol sessions' constraints. Based on this study's verbalisations and graphic material it was observed that there were multiple and interacting reasons for using annotations.

For object- and concept-annotations they included:¹⁶

- complexity of an object or space – objects ('adjustable [open-close] roof') or spaces ('dynamic sculpture enclosure') could not be described sufficiently with a sketch or a diagram alone (60% of the first year, and 60% of the fourth and final year students);
- significance / role / use / function of an object or space (100% of the sample);
- interactions between spaces or functions (40% of the first year, and 30% of the fourth and final year students);
- similarity and succession – similar objects i.e. a row of windows or an alley of trees were annotated instead of repeatedly redrawn (10% of the first year, and 20% of the fourth and final year students);
- sameness and repetition – same objects or spaces once sketched in detail, later in the process were depicted with higher degrees of schematization or lower degrees of detailing and annotated (30% of the first year and 20% of the fourth and final year students) or only annotated without being redrawn (20% of the first year, and 10% of the fourth and final year students);
- simplicity and appropriateness – certain concepts ('privacy') objects (i.e. 'mirror windows') or relationships between objects are better or easier described sententially¹⁷, (100% of the first year, and 90% of the fourth and final year students); and associated with this category are:

¹⁶ In the brackets are percentages of the total number of students from the sample (split by the year of study) who resorted to the above types of annotations.

¹⁷ Considerations behind simplicity and appropriateness were specified by the students.

- distinction – certain objects represented symbolically could be confused for other elements, i.e. human figures and anthropomorphic sculptures, etc (10% of the first year, and 20% of the fourth and final year students)
- identification – certain objects of the same class needed being separated from one another, i.e. trees and flame trees, clear, mirror and opaque windows, etc (60% of the first year, and 60% of the fourth and final year students); and
- exclusiveness – certain functions, attributes or concepts, such as ‘*noise reduction*’, ‘*relaxing*’ or ‘*wall of fame*’ (40% of the first year and 50% of the fourth and final year students) or estimations, sizes and dimensions (100% of the first year, and 100% of the fourth and final year students) could only be described in writing.

Additionally, there is a number of observations related to idea-annotations. Generally, they represented the designer’s communication with him/herself or the client (in this study – the researcher and the judges). On a more detailed level, the reasons for their use included:

- complexity of emerging design ideas – design ideas could not be described sufficiently with a sketch or a diagram alone (40% of the first year, and 30% of the fourth and final year students);
- records of newly emerging ideas – design ideas needed being recorded on the fly under time constraints, or as an aid memoire – to be revisited later (60% of the first year, and 50% of the fourth and final year students);
- unwillingness to commit to detailing / postponing detailing, i.e. ‘*need a model to design this further*’, or ‘*would arrange these [sculptures] nicely*’ (30% of the first year, and 30% of the fourth and final year students);
- allowing for ambiguity to avoid narrowing down the search space / postponing judgement, ‘*may make this form more organic*’, or ‘*may need to reconsider this [studio space encircled]*’ (40% of the first year, and 30% of the fourth and final year students);
- simplicity and appropriateness – certain ideas are easier and/or better to be formulated sententially than graphically, i.e. ‘[the yard] *needs sun and heat protection*’ (40% of the first year, and 40% of the fourth and final year students); and
- exclusiveness – certain ideas could only be formulated sententially, such as ‘*this [open space encircled] is designed to make them [inhabitants] feel inspired*’ (20% of the first year, and 10% of the fourth and final year students);

Among the commonalities of annotations usage, are their purposes and their character similar for the whole sample. All types of annotations were present in external representations of both groups of subjects. Equally, both first, and fourth-final year students generated the largest proportion of object-annotations, and the lowest – of idea-annotations. Other characteristics varied among groups and within groups. And, while the reasons for producing different types of annotations were reported during retrospection, there were no easily identifiable trends concerning their distribution – numbers and frequencies, time, and placement. With only one clear tendency for pre-architects to favour concept- and object-annotations, and horizontal idea-annotations, and architects – vertical idea-annotations. The reasons could be related to personal preferences, individual differences in cognitive abilities (including ideational and associational fluency), learning styles, problem solving strategies, knowledge, experience, skills, and, possibly, more. It is also likely that some of the constraints of protocol sessions, as well as the need to remember as many details as possible (for subsequent recollection during retrospection) may have affected quantitative and qualitative characteristics of annotations used.

The above observations and initial results are further analysed below as this study looks into the reasons for variability to establish some commonality among the individual approaches.

Levels of visual-spatial ability and external representations

Comparative and correlation analyses were performed to determine how different types of external representations were related to the participants' cognitive abilities. The connection between freehand drawing, sketching ability and cognitive abilities is supported by a large body of factor-analytical literature (summarised in Subsections 2.1.4 and 2.3.2). Including research of Bertoline and his co-workers (1995) suggesting that visualisation ability (or imagery) provides a bridge between design ideas and their representation by sketching. And the literature asserting that the ability to draw is directly related to the ability to imagine, whilst the ability to imagine feeds back into the ability to draw (Laseau, 2000). Or studies in architecture presenting evidence of the relationship between the external representations used, and the ability to generate solutions from mental representations (Goldschmidt, 1991; Goel, 1995; Scaife & Rogers 1996; Kavakli & Gero, 1999, 2001). There is also research concerned with association between sketching and diagramming activities and spatial visualisation ability. In two such studies, Fennema and Tartre (1985) and Pribyl and Bodner (1987) showed that problem solving employing sketching and diagramming strategy is favoured by high spatial ability students. The latter connection is addressed below.

Figure 10 demonstrates relations between the average numbers of occurrence of different external representations relative of the four levels of the participants' visual-spatial abilities. The means were calculated based on individual sets of external representations (i.e. cumulative numbers of each representation type), and not on a per page average basis.

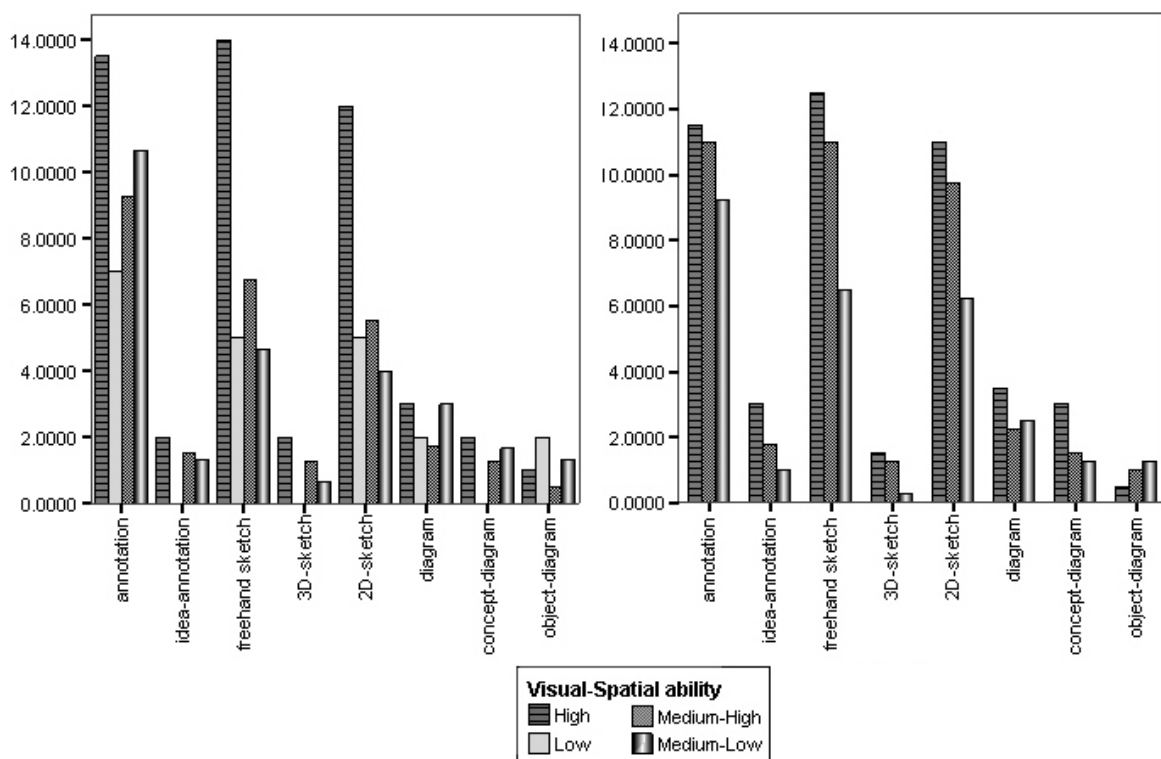


Figure 10. Means of external representations by V-S abilities: Year 1 (left), Years 4&5 (right)

Preference for Sketching & Diagramming. As Figure 10 indicates, high spatial individuals produce, on average, notably higher amounts of sketches (particularly 2D); this observation is valid for both groups of students. It is also reinforced by the fact that, as the ability weakens, average numbers of sketches also decrease exponentially. Situation with diagramming is less evident though – it is only the high spatial students from fourth and final years who generated the largest number of diagrams. Similarly, there is no link between annotating and visual-spatial ability, despite the possibility for low(er) spatial students to annotate more due to, potentially, weaker sketching ability (as it is supported by visualisation). Neither MANOVA, nor Pearson's

product-moment analysis have revealed any significant interaction or effect for general visual-spatial ability concerning diagrams or annotations for either group of subjects. They, however, revealed significant correlations between the ability and overall number of sketches of the first year students ($r=0.693^*$), also including correlation coefficient for 2-D sketches ($r=0.649^*$); and for the same variables moderate correlations for the fourth and final year students ($r=0.563$), also including correlation coefficient for 3-D sketches ($r=0.611$).

Thus, while the evidence may not hold strong enough to support claims by Pribyl and Bodner with reference to diagramming, the tendency for the high spatial individuals to generate more sketches than done by the low(er) spatial, has been observed. It is more sound when it concerns single abilities, including visualisation (Table 34).

Preference for 2D and 3D sketching. Further to the above results, the question that could be raised next concerns the association between cognitive abilities and preference for 2D and 3D sketching. That is, if a preference for three-dimensional as opposed to two-dimensional sketching could be a manifestation of a more advanced spatial ability, namely 3D visualisation.

Table 34. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiment IV/b(object)

Variables	3D-Sk	2D-Sk	CR	S	PF
Year 1					
3D-Sketch	1				
2D-Sketch	0.337	1			
Card Rotations	0.108	0.531	1		
Storage	0.757*	0.281	0.320	1	
Paper Folding	0.265	0.575	0.824**	0.479	1
Years 4&5					
3D-Sketch	1				
2D-Sketch	0.715*	1			
Card Rotations	0.642*	.228	1		
Storage	0.184	-0.072	0.425	1	
Paper Folding	0.530	0.380	0.634*	0.095	1

* Correlation is significant at the 0.05 level (1-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

As Table 34 indicates, the link between administered visual-spatial tests and external representations may exist. For the first year students 3D sketching is correlated with figural flexibility (FF, *Storage* test). On this test, participants generate new and different solutions to figural problems supported by visualisation – an ability for manipulating three-dimensional objects and for mental synthesis. FF requires fluency in successfully dealing with 3D figural tasks via a search for relevant knowledge in long-term memory, and an ability to rapidly change set and try-out a variety of approaches to solutions for figural problems that have several stated criteria (Carroll, 1976). It has strong visualisation and reasoning components, and may indicate an ability to be flexible in adopting and changing hypothesis and mental sets about figural problems. All of these criteria seem to fit well with the specifics of three-dimensional sketching.

For the fourth and final year students 3D sketching is correlated with advanced spatial relations ability (SR, *Card Rotations*). It is believed to be one of the fundamental lower level factors that support other higher level abilities (Miyake, *et al.*, 2001; Lohman, 2002). It is correlated with visualisation (*Paper Folding*) which requires spatial thinking, and the ability to mentally imagine, manipulate or transform objects or visual patterns, whilst spatial relations requires speeded rotation or reflection of the relatively simple spatial forms, and has been considered as one of the subfactors to visualisation. That is, visualisation is seen as a more complex and less speeded form of spatial relations, as both require the mental rotation of a spatial configuration in a short term visual memory (Ekstrom, *et al.*, 1976).

Although there is a general tendency for high spatial individuals to prefer 3-D sketching, when it comes to concrete cases, the situation may become complex and ambiguous. As it is evident from Table 35, two students have high and medium-high scores in tests involving 2-D (*Card Rotations*) and 3D (*Paper Folding*) visualisation and transformation within their respective groups, and compared to lay people, the second participant also has high score on 3D transformation (*Storage*). The other two participants have medium-low scores on *Card Rotations* and *Paper Folding*, although one of them scored significantly above mean on the *Storage* test. The first student did not produce any 3D sketches, and the second one generated 7 times more 2D than 3D images. Student S11(IV) generated both 2D and 3D sketches, while student S02(1) – only three-dimensional sketches with high levels of complexity.

Table 35. Spatial ability and two- and three-dimensional sketching: Experiment IV/b

Subjects	Test results						Balance of 2D & 3D sketches	
	Individual			Group means				
	Card R.	Storage	Pap. Fold	Card R.	Storage	Pap. Fold.		
S12(IV)	67	8	9	65.4	8.40	7.58	4 - 2D	0 -3D
S15(V)	78	9	7.75				15 - 2D	2 - 3D
S11(IV)	55	9	6				6 - 2D	1 - 3D
S02(1)	47	12	7	56.50	8.30	7.30	0 - 2D	4 - 3D

Thus, it is not the level of general visual-spatial ability that restricts participant S12(IV) from generating three-dimensional drawings, just as it may not be the more advanced ability of the participant S15(V) that directs him towards generating (more) 3D sketches. Similarly, lower spatial ability does not always imply a preference for 2D-sketching. Also, as subjects one, two and four have comparable, reasonably developed levels of sketching ability (different from subject three, who lacks in it) it is possible that some of the observed differences and similarities are related to the skill of architectural drawing or to graphicacy. There may also be other reasons caused by individual learning styles and strategies adopted in problem-solving, as well as by other factors. The latter issue will be addressed further in this subsection.

Levels of ideational ability and external representations

Based on the literature linking ideational abilities to sketching (Hocevar, 1979; Stroebe & Diehl, 1994; Van der Lugt & Hemberg, 2002), a connection between different characteristics of external representations and ideational abilities can be suggested. Some of these studies demonstrated that sketches may stimulate creativity by providing new directions for idea generation in an individual generate-interpret cycle (Van der Lugt, 2002; Van der Lugt & Hemberg, 2002). Other research indicated there is a high correlation between creativity and proficiency in domain relevant skills, such as sketching; and both are necessary when producing the creative product (Amabile, 1996). Many design surveys have measures that are based on a number and quality of ideas generated (Szymanski & Harkins, 1992; Gallupe *et al.*, 1994). Some of them use a label called “productivity” (Paulus *et al.*, 1993). While other assess: a number of non-redundant ideas, percentage of superior responses, a rating on the quality of the ideas (Stroebe *et al.*, 1992); a creativity production rate; and a self rating of imaginativeness (Furnham & Yazdanpanahi, 1995). There are also studies that have researched verbal ideation as a method to stimulate creative problem solving in architectural design by associative reasoning (Silberman, *et al.*, 2001). And literature demonstrating a relationship between the design quality and the use of words (Wong & Kvan, 1999).

Contrary to this literature, Experiment IV/b(object) did not yield any new evidence supporting the above claims – neither comparative nor correlation analyses have indicated significant or moderate relationships between ideational abilities (figural or verbal), and number and types of external representations generated. It is not an unexpected outcome as it concerns quantitative characteristics of sketches and diagrams. Other factors, including their complexity, quality and completeness of ideas, restrictions of protocol sessions, styles of problem solving,

complexity of design tasks drawing on multiplicity of interrelated abilities and skills, and so on, may have had a more defining impact. Additionally, as design and architecture products have to meet an extensive range of requirements (with ideas being novel, usable, appealing, practical, feasible, etc) establishing correlations between ideation and performance in architecture requires a measurement beyond the quantity of ideas generated. Whilst a view found in factor analytical literature argues for the figural fluency scores to be largely a reflection of motor speed and manual control in drawing, or a speed of doodling, as all test measures require responses in a limited time and scores are linked to the performance rate (Carroll, 1993). Thus, it may also be difficult to separate figural ideational factors from associated with them graphical skills.

To address some of these concerns, the issue of ideational fluency versus quality and quantity of design ideas in external representations, will be further attended to in Section 6.4. It deals with the assessments of produced design solutions (including their complexity, fluency and flexibility) as reported by the three independent judges. And in Subsection 6.3.3 discussing the process of idea/s generation, including horizontal and vertical sketch development, annotated and verbally expressed ideas, and so on.

Learning style preferences and external representations

Comparative and correlation analyses were performed to establish how different types of external representations were related to the participants' learning styles. They are based on the proposition that extensive/redundant annotating, sketching and diagramming may be correlated with Verbal-Imagery learning styles, whereas other characteristics of external representations, such as their complexity and number and quality of ideas generated, could be associated with the Wholistic-Analytic dimension.

This proposition is supported by the literature linking different cognitive or learning styles to sketching, reasoning, performance, and ideation (see Subsections 2.1.1, 2.1.2 and 3.1.1). Most of has utilised traditional educational approach – relating learning styles to academic achievement in design disciplines, such as engineering drawing and CAD (Simpson, 1978; Swanson & Anderson, 1982; Young, 1998). It has indicated the relationship between designing, sketching, and the Wholistic-Analytic, and Verbalizer-Imager dichotomies showing that wholistic thinking and imagining are central in the generation and development of design ideas (Kimbell, *et al.*, 1991; Garner, 1989; Chidgey, 1994, Liddament, 1993; Barlex, 1994). Other studies have shown for Imagers to outperform Verbalisers where the presentation mode is graphical and visual (Riding & Watts, 1997), and the inclination of the former to communicate or present ideas graphically, rather than verbally (Silverman, 1998). Much less research examined problem solving behaviour in relation to learning styles, sketching and underlying them cognitive abilities (Yokomoto, *et al.*, 1995; Hakkarainen & Hakkarainen, 1999; Tai *et al.*, 2001, Alias *et al.*, 2002). It suggested a range of possible links between different tasks/stages of problem solving, regulated by different learning styles, and reflected in external representations.

On the whole, while there is no single integrative method of addressing the association between learning styles and external representations, and many unresolved issues concerning existing approaches, a number of main views found in the literature can be broadly summarised as follows. (1) Wholism is associated with global, random, parallel problem-solving favouring visualising and sketching; fluency in ideation (visual and, rarely referred to, verbal); creativity, synthetic thinking; and preference for complexity (internal and external); (2) Analytic style is associated with sequential problem-solving, characteristic of verbal reasoning, with complex problems broken down into smaller units and addressed one at a time, and then re-assembled in a step-by-step manner; and analytical thinking; (3) Verbal learning style is connected with sequential verbal reasoning, internal and external; it supports verbal ideation and associative thinking; (4) Imagery learning style is associated with visual parallel problem-solving, internal (i.e. generation and transformation of images) and external (i.e. sketching, diagramming and drawing); and with preference for complexity; it supports figural ideation and figural flexibility.

We utilised these assumptions as a guide to discovering additional evidence in support of in refutation of the link between individual learning styles and produced external representations.

Figures 11 & 12 demonstrate relations between the average numbers of occurrence of different external representations and the Wholistic-Analytic, and Verbal-Imagery dimensions.

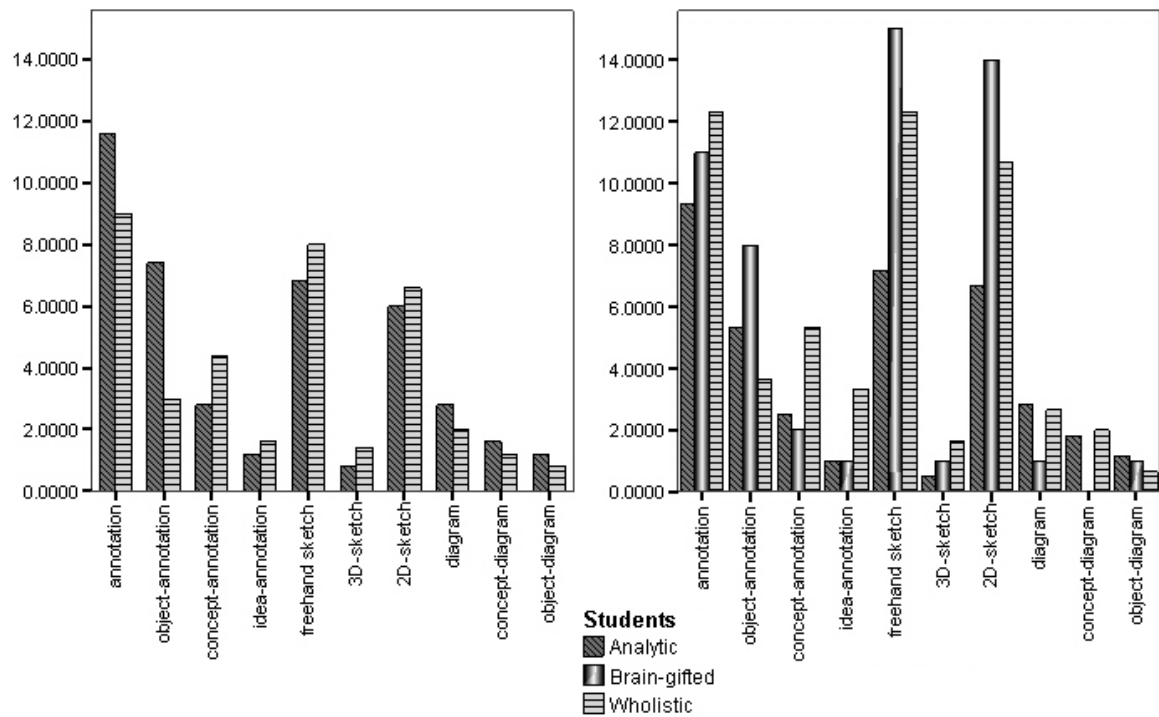


Figure 11. Average occurrence of external representations by W-A mode: Year 1 (left), Years 4&5 (right)

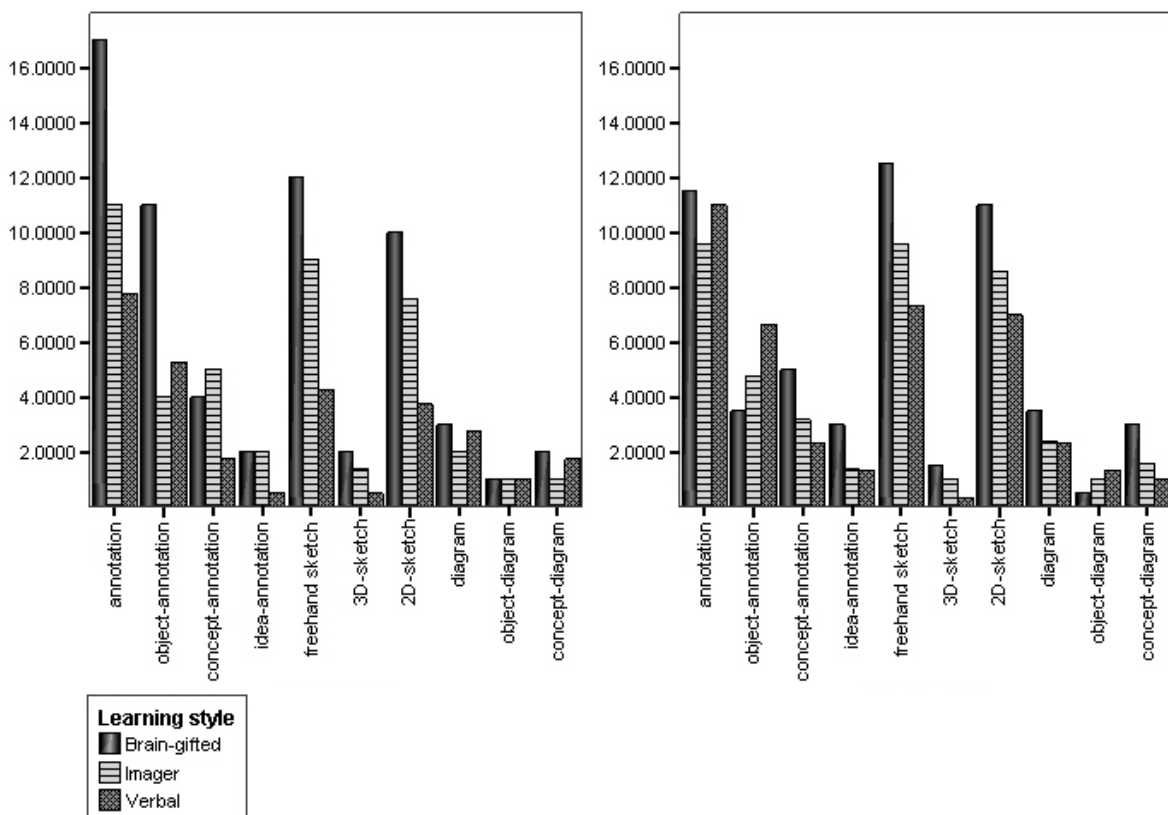


Figure 12. Average occurrence of external representations by V-I mode: Year 1 (left), Years 4&5 (right)

The means were calculated based on individual sets of external representations (i.e. cumulative numbers of each representation type), and not on a per page average basis. They were estimated for 'ordinary' and brain-gifted students separately, since the latter are believed to shift swiftly and freely between different problem-solving styles and strategies (and, as a result, modes of designing and idea-recording) independent of a particular learning style from the respective mode, but responding to design task conditions, and possibly influenced by other variables, such as individual cognitive abilities, knowledge, skills, and so on.

Annotations. On the Wholistic-Analytic dimension our initial assumption was for analytical students to annotate more (as opposed to wholists who were expected to sketch more). This is because their learning style has been associated with sequential problem-solving, characteristic of verbal reasoning. However, this has not proven to be the case for the fourth and final year students, as wholists have, on average, produced more annotations. The situation between the two groups appears more uniform when different types of annotations are considered. That is, analytical students resorted more to object-annotations, and this observation is valid for all years of study. Whilst conceptual and idea-annotations were favoured by wholistic students from both architecture and design. Thus, it is possible for the observed situation to be less related to the preferences for different modes of problem-solving and conveying information (annotating versus sketching) influenced by the Wholist-Analytic dimension, but to other associated with wholism qualities – ideation and interconnectedness of parts in a whole. That is, the two types of annotations favoured by wholists are related to idea-production and consideration/resolution of various design concerns. While such activities as labelling physical objects (or details of these objects) and writing down dimensional marks were favoured by analytic students.

On the Verbal-Imagery dimension our initial assumption was for verbalisers in both groups to annotate more. However, this has not proven to be the case for the fourth final year students, as imagers have, on average, produced more annotations. The situation between the two groups is more coherent when different types of annotations are considered. As object-annotations were favoured by verbal students, and this observation is valid for all years of study. Whilst when it concerns conceptual and idea-annotations, it is the visual students from both architecture and design, who tended to generate more of them. Thus, it is possible for the observed situation to be less related to the preferences on Visual-Imagery dimension, but to be a indication of a translation of visual ideas into the verbal form. That is, the participants may have chosen to convey their visual ideas and concerns in a written form, and there may be a number of reasons for that. They include some of the qualities of annotations (such as their vagueness and speed of noting down) and protocol session constraints. Additionally, some of the students used a process of 'verbal punning' involving translation between visual and verbal forms of expression – to stimulate the generation of ideas by allowing free associations. It is frequently employed to generate solutions with both visual and verbal resonance (Tomes, *et al.*, 1998). Or, as expressed by one of the participants: *'here I had a few ideas in my head... like I thought I could use a space theme...because observatory is about stars and space... so I write down 'space theme for observatory', and then I thought it could be something organic for the whole house... then I can't use that space theme... but I didn't want to choose [yet]... to come up with a concrete form, you know... it was too early... but if you don't write it down, you tend to forget.'*

Sketches. On the Wholistic-Analytic dimension our initial assumption was for wholistic students to sketch more (as opposed to analytics who were expected to annotate more). It is based on the general view for graphic language to be more simultaneous than verbal, as all symbols and their relationships are considered at the same time (Laseau, 1980), that is, more suited for wholistic reasoning characterised by parallel processing. And the fact that sketching remains the main means of problem-solving and idea-production in design. Or, as wholism is commonly associated with fluency in ideation (Williams, 1980), one could anticipate for wholistic students to generate a larger proportion of ideas (and, as a result, more sketches) than would be expected from analytic students. Additionally, as wholistic thinking relies on random search utilizing significant amounts of information from the start, and looking to achieve understanding by

identifying and focusing on major patterns or trends in the task, it is likely that a bigger repertoire (and, therefore, number) of sketches is produced during conceptual designing, as the wholists shift between different methods of exploration and record emerging ideas. Figure 12 indicates that this may be the case with this study's both groups of participants.

Still, while the association between the average numbers of sketches generated and Wholistic-Analytic dimension may be present, the reasons for it are complex, and may also be related to the types, and the range of purposes sketches have in design. That is, they can be generated with a particular goal in mind or simply as a vehicle of open-ended discovery. They can be complex and conceptually focused or simple and relatively ambiguous, depending on the situation and the requirement of the task (Ward, *et al.*, 1999). They can be a tool for synthesis or a means of analysis. They can be constructed in a wholistic way – from picking up an overall picture (a general concept or/and relationships between discrete classes), to building representations of separate objects and describing the links between them. Or in an analytic fashion – from picking up rules, methods and details, and fitting them together in a step-by-step manner, to building concepts for isolated objects. They may capitalise on vertical reasoning characteristic of analytical individuals, or on horizontal problem-solving expected to be favoured by wholists, and so on. Thus, while the W-A dimension may have a major impact on the production of external representations, the observed diversity of approaches and strategies adopted in problem-solving need being mapped onto the Wholistic and the Analytic learning styles – before proceeding with this type of analysis. It is also other factors, including skills, abilities, knowledge and experience that may be of fundamental importance.

On the Verbal-Imagery dimension our initial assumption was for visualisers in both groups to sketch more. It was based on the well-established link between sketching, imagery and visual spatial abilities, and the research by Riding and Douglas (1993), who discovered that imagers in their text plus picture group produce more pictures in their answers than do verbalisers from this group. Which is similar to the study by Cox (1999) who observed individual differences in spontaneously produced graphical and non-graphical external representations during analytical reasoning. The observed situation has proven to be in conformity with these studies, as imagers from both groups have, on average, produced more sketches than did verbalisers. There are, however, differences between the numbers of sketches produced by visual and verbal students from the first, and fourth and final years of study. The visually inclined designers have generated considerably higher numbers of external representations, than did the verbal students. While the difference is less pronounced for the architecture students. The explanation may lie in the qualitative characteristics of design drawings, such as their complexity and levels of detailing, some of which are discussed further in this subsection.

Diagrams. There was no initial assumption concerning diagrams as a class, as their different types may be linked to different learning styles. They can serve as a tool of analysis and resolution of design constraints, or may be used as a means of idea-recording, initial synthesis or preliminary spatial planning. They differ in levels of abstraction and may incorporate one or more conceptual, spatial and functional concerns, or may be integrated within sketches. Additionally, it is not only learning styles, but other individual characteristics, ranging from cognitive abilities, reasoning strategies, to individual knowledge, experience, skills, and possibly, more, that are likely to influence the production of diagrams. And, as diagramming draws on a high proportion of acquired knowledge and learnt skills (often described by the students as a '*standard design practice*') it may prove impossible to identify its qualitative and quantitative relationships and correlations with design abilities, or, equally, to make valid comparisons within and between the two groups of subjects (with the first year students, potentially, more dependent on their innate abilities in problem-solving).

There is only a weak tendency for object-diagrams to be preferred by analytic students (as illustrated by Figure 11). Another trend observed, is for diagrams to have different levels of complexity, with the more complex ones (i.e. integrating more different aspects of the design task) to be favoured by wholistic and visual students. Other possible associations between the learning styles and the types of diagrams used have been previously mentioned (pp. 121-122).

Correlation analysis

The Pearson's product-moment correlation analyses (Table 36) addressed the same issue but did not separate the brain-gifted students from the rest of the participants – to see if we could observe the more general (and possibly different) view of the sample. The results indicate that there are differences as well similarities within and between the sample concerning learning styles, years of study, and their relation to different types of external representations.

Table 36. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiment IV/b

Variables	W	A	I	V	Variables	W	A	I	V
Year 1					Years 4&5				
Wholistic	1				Wholistic	1			
Analytic	-0.241	1			Analytic	-0.756*	1		
Imagery	0.635*	0.265	1		Imagery	0.877**	-0.479	1	
Verbal	-0.578	0.582	-0.304	1	Verbal	0.120	-0.175	0.000	1
annotations	-0.126	0.420	0.384	-0.005	annotations	0.381	-0.189	0.287	0.180
object-annotations	-0.537	0.710*	0.188	0.560	object-annotations	-0.302	0.527	-0.362	0.215
concept-annotations	0.256	-0.276	0.188	-0.490	concept-annotations	0.597	-0.621	0.558	-0.122
idea-annotations	0.432	0.156	0.482	-0.477	idea-annotations	0.539	-0.433	0.552	0.317
sketches	0.332	0.246	0.787**	0.088	sketches	0.574	-0.184	0.445	0.048
3D-sketches	0.361	0.231	0.482	0.134	3D-sketches	0.543	-0.361	0.404	0.098
2D-sketches	0.259	0.205	0.748*	0.055	2D-sketches	0.550	-0.133	0.430	0.034
diagrams	-0.548	-0.287	-0.294	-0.107	diagrams	-0.032	-0.185	0.121	0.066
concept-diagrams	-0.341	-0.111	-0.066	-0.145	concept-diagrams	0.042	-0.255	0.182	0.022
object-diagrams	-0.538	-0.373	-0.445	0.000	object-diagrams	-0.310	0.226	-0.177	0.000

* Correlation is significant at the 0.05 level (1-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Annotations. The Pearson's product-moment correlation analysis (Table 36) indicated a main effect or interaction for the Analytic learning style on the production of object-annotations – for the first year students. And similar, but moderate correlation – for the fourth and final year students. Wholism is also associated with idea-annotations in the first group, and idea- and concept-annotations – in the second group, although the correlation coefficients are not high enough to suggest a strong, but a potential tendency.

On the Verbal-Imagery dimension, the correlation analysis indicated moderate associations between the Visual learning style and idea-annotations for both groups of students, and a moderate correlation between the imagery mode and concept-annotations for the fourth and final year participants. It has also revealed moderate correlations between object-annotations and the Verbal learning style for design students.

Sketches. The analysis indicated moderate associations between the Wholistic learning style and different types of sketches (2D as well as 3D) for the fourth and final year students, and a low correlation between the wholistic mode and the overall numbers of sketches for the first year participants. No correlations have been observed for the Analytic learning style.

On the Verbal-Imagery dimension, the analysis indicated strong associations between the Imagery learning style and external representations for the first year students (on overall numbers and 2D sketches, in particular), and moderate correlations between the visual mode and sketches (overall, 2D and 3D) for the fourth and final year participants. It has revealed no correlations with the Verbal learning style for either group of students.

Diagrams. The Pearson's product-moment correlation analysis has not indicated (Table 36) any connection between the Wholistic-Analytic and the Visual-Imagery dimensions and the numbers and types of diagrams generated for both groups of students. On the whole, the issue of diagrammatic reasoning needs to be understood further before any conclusions can be drawn.

W-I, W-V, A-I, and A-V learners. There have also been a few associations observed between the four style combinations and generated external representations. For example, Analytic-Imagers and Analytic-Verbalisers annotate the most ($r=0.752^*$, $r=703^*$, one-tailed), while Wholistic-Imagers tend to produce the highest numbers of sketches ($r=0.669^*$ one-tailed). However, there are two important considerations that do not permit discussing these as valid trends. Firstly, it is the size of the sample. That is, while there may be some reliable associations observed between single styles and external representations, when style combinations are considered, there is not enough data for statistical analyses on some of the dual dimensions, also because we treat the two groups of subjects separately. Additionally, the issue of versatility and brain-giftedness need being understood further before any conclusions could be drawn. It seems there may be differences in the performance of the ‘ordinary’, the versatile and the brain-gifted subjects. As the latter two groups, particularly the brain-gifted, tend to generate the highest numbers of external representations (Figures 11-12). While the correlation analysis indicates for them to have also produced broader repertoires of schema for external representations (Table 37). In other words, it is possible that the (potential) ability of these students to cope better in any learning environment, or being more flexible in utilising different approaches in design tasks, has resulted in differences in the process and the outcome of individual problem-solving. This issue will be explored further as this study looks into other characteristics of versatile reasoning.

Levels of complexity, repertoires of external representations, and ability factors

Correlation analysis was performed to establish how different levels of complexity, as well as individual repertoires of external representations, were related to the participants’ learning styles and cognitive abilities (Table 37).

Table 37. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiment IV/b

Variables	W	A	I	V	Rpt.	Ver.	C. 3D	C. 2D	V-S	IF	IV
Year 1											
Wholistic	1										
Analytic	-0.241	1									
Imagery	0.635*	0.265	1								
Verbal	-0.578	0.582	-0.304	1							
Repertoire	0.662*	0.167	0.908**	-0.259	1						
Versatility	0.575	0.481	0.785**	-0.339	0.736*	1					
Complexity 3D	0.549	0.152	0.727*	0.000	0.628	0.406	1				
Complexity 2D	-0.269	0.373	0.334	0.122	0.349	0.248	-0.204	1			
Visual-Spatial	0.393	0.408	0.853**	-0.356	0.663*	0.753*	0.466	0.342	1		
Ideation Figural	0.651*	-0.318	0.707*	-0.648*	0.543	0.436	0.581	0.000	0.627	1	
Ideation Verbal	0.344	0.442	0.467	-0.089	0.230	0.522	0.186	0.114	0.563	0.238	1
Years 4&5											
Wholistic	1										
Analytic	-0.756*	1									
Imagery	0.877**	-0.479	1								
Verbal	0.120	-0.175	0.000	1							
Repertoire	0.700*	-0.302	0.674*	0.185	1						
Versatility	0.419	-0.038	0.448	-0.055	0.627	1					
Complexity 3D	0.639*	-0.113	0.689*	-0.072	0.805**	0.259	1				
Complexity 2D	0.402	-0.128	0.429	-0.052	0.746*	0.274	0.643*	1			
Visual-Spatial	0.812**	-0.611	0.747*	0.218	0.779**	0.643*	0.494	0.616	1		
Ideation Figural	0.364	-0.224	0.639*	0.117	0.345	-0.038	0.264	0.055	0.344	1	
Ideation Verbal	0.339	-0.429	0.407	0.408	-0.119	-0.194	-0.136	-0.128	0.170	0.481	1

* Correlation is significant at the 0.05 level (1-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

It is based on the proposition that the high(er) (or low(er)) ranges of all types of annotations, sketches and diagrams used, could be associated with students' preferences on the Wholistic-Analytic and Verbal-Imagery dimensions. Whereas other characteristics of external representations, such as their complexity, may be linked to the Wholistic-Analytic mode and visual-spatial and ideational abilities. Three different levels of sketch complexity have been previously identified (p. 115). Repertoire of schema for external representations included a summary of all different types of diagrams, two- and three-dimensional sketches and annotations (with each type ascribed a numeric value of 1; the original data is included in Appendix B tables).

On the whole, the protocols have revealed that the fourth and final year students had a greater repertoire of schema for external representations (Mean=7.80; SD=2.01), than did the first year students (Mean=6.20; SD=1.68). The differences are more pronounced when it concerns diagrams and sketches (and less so in regards to annotations). There were also differences in the use of 2D and 3D representations. As, for example, more architecture students drew three-dimensional objects as an effort to find missing views, while more design students drew three-dimensional shapes in an attempt to externalise pre-visualised ideas. Or, as explained by one of the first year participants: *'here I'm just trying to put on paper what I see in my head... at the beginning, I imagined this organic form... for the whole house... yes, before I thought of layouts... so, I'm just sketching it here to have it on paper'*. The fourth and final year students also generated more complex 3D representations. Whilst, many of the first year students tried to map the images to familiar items but had difficulty with complex items.

In regards to the relationship between learning styles, cognitive abilities and external representations, Table 37 indicates that similar correlations can be observed in both test groups, though the magnitudes of correlation coefficients vary. And some correlations are only present in either group of subjects. For the first year they include:

1. *Larger repertoires of external representations* are correlated with *Wholistic* and *Visual Internal (Imagery)* learning styles, *visual-spatial* ability, and have a moderate correlation with *figural ideation*
2. *3D-sketches complexity* is (moderately) correlated with *Wholistic* learning style, higher *repertoires of external representations*, and *figural ideation* (also moderately)
3. *3D-sketches complexity* is (moderately) correlated with *figural ideation*

For the fourth and final years they include:

1. *Larger repertoires of external representations* are correlated with *Wholistic* and *Visual Internal (Imagery)* learning styles, *visual-spatial* ability, and *2D-sketches complexity*
2. *3D-sketches complexity* is correlated with *Wholistic* learning style and higher *repertoires of external representations*
3. *2D-sketches complexity* is (moderately) correlated with *visual-spatial ability*

The correlation of larger repertoires of external representations with wholism may be explained by the fact that wholism is commonly associated with fluency and flexibility in ideation (Williams, 1980). Thus, one could anticipate for wholistic students to generate a larger proportion and/or range of ideas (and, as a result, more sketches) than would be expected from analytic students. Additionally, as wholistic thinking relies on random parallel processing (Lynch, 1986) utilizing significant amounts of information from the start, and looking to achieve understanding by identifying and focusing on major patterns or trends in the task, it is likely that a bigger repertoire of sketches produced during conceptual designing, is related to these shifts between different methods of exploration, driven by design concerns and ideation. That is, in wholistic thinking both a higher number and a wider range of ideas is generated, and, therefore conveyed by different types of external representations.

The same reasons may have directed students to producing complex sketches. That is, as the more versatile ideas are generated in parallel problem-solving and they tend to be interlinked, the more complex external representations emerge. Additionally, the association of the preference for complexity with wholistic learning style is supported by theoretical research and empirical studies in psychology. They indicate that as analytical students follow a step-by-step learning procedure, concentrating on narrow, simple hypotheses relating to one characteristic at a time, wholists tend to form more complex hypotheses relating to more than one characteristic at a time (Pask, 1976; also summarized in Coffield, *et al.*, 2004).

The imagery link is similar to the association with wholism, as visual thinking is believed to involve synthesis; an intuitive grasp of complex systems; simultaneous processing of concepts; inductive reasoning, use of imagination and generation of ideas by combining existing facts in new ways – ideation and creative thinking (Lynch, 1986). It is supported by the wholistic-imagery correlation, addressed by the research on visual-spatial learners. As visual imagery plays an important role in these students' problem solving, and they think primarily in pictures rather than words, ideas are processed simultaneously and are interconnected (Silverman, 1998).

The latter also explains the link between complexity and visual-spatial ability. Plus the empirical evidence suggesting that high spatial ability individuals have more highly organized mental representations of objects than low spatial (Lohman & Nichols, 1985).

The relatively weak link between the sketches' complexity and ideation for the first year students may be related to the fact that, in early stages of designing, significantly more ideas are generated, and significantly fewer connections with earlier ideas are made (i.e. relative of the later stages, not necessarily of each other). As there is usually little place for their interpretation during ideation, especially under protocol study constraints. Most of the participants did build on their initial ideas but the nature of such connections made can be regarded to be mostly concerned with brief inspections that spur further associations, rather than more detailed interpretations of the ideas. The lower repertoires of external representations may have the same explanation. As our data indicates, those students who did generate several ideas in the beginning, tended to do it in the same manner – by drawing quick diagrams or sketches of simple 2D and 3D forms, or basic spatial layouts – in search for original solutions to appear amidst the less appealing ones. That is, without reflecting much on the sketching process, responding to local conditions, or trying to accommodate all/most of the task constraints. As a result, typically, only one of the initial ideas would have been developed further – to higher, more complex levels of resolution, or incorporating different views (repertoire).

At the same time, the link between ideation abilities and the sketches' complexity and repertoires has not been observed for the fourth and final year participants. This may be related to the nature of ideation in architecture. As the products there have to meet an extensive range of requirements – with ideas being novel, usable, appealing, practical, feasible, and so on, a measurement of the quantity of ideas generated (i.e. figural fluency and flexibility tests) may not be a good predictor. In this study, it has been observed for the fourth and final year students to rely much less (than the first year students) on ideation fluency, and to produce fewer of the initial remotely or loosely associated ideas, but to continuously test every new suggestion they generated against the task requirements and local conditions. As a result, although the second group of participants did produce the more complex ideas, and had higher repertoires of external representations, their ideation abilities, as measured by the administered in this study tests, may have been of little or no advantage in the process of idea generation. It is also possible, that the protocol session constraints have directed some of the students to modify their problem-solving processes and to allocate less time/effort to initial ideation in their attempts to present a reasonably developed or/and detailed solution.

Overall, it is hard to tell at this stage whether the failure of some of the students to draw high quality or complex views were due to their lack of wholism, defective mental images, poor visual-spatial ability, or because they lacked in relevant knowledge, or had insufficient levels of graphic ability, which, in its turn, may have depended upon some of the discussed design abilities. A further research is necessary to find the more compelling evidence in support or in refutation of the tentative conclusions suggested in this subsection.

6.2.2 Analysis of Introspective Reports & Questionnaires

Experiment V/b involves collecting introspective statements, spontaneous, as well as obtained via semi-directed interviews, and questionnaires. It is, largely, a supplementary source of data on the students' design abilities, styles and strategies of problem solving, analysed in association with other datasets. It was initially suggested to help clarifying ambiguous processes, actions and intentions from the records of administered design sessions.

On the whole, the study of introspection and questionnaires aims at: (a) establishing whether the participants' behaviour during protocol sessions could be viewed as typical or habitual, (b) enabling the distinction between task-specific aspects of problem-solving and global approaches to problem situations, (c) supplying additional accounts of the students' learning styles and cognitive abilities, and (d) exploring relationships and correlations among them. The ultimate purpose of this experiment is to provide a basis for inter-relations and correlations between the acquired data, and other aspects of the *input*, the *process* and the *product* of problem solving, obtained through the rest of administered experiments.

On a more detailed level, this part of the empirical study seeks to ensure additional information on (1) the participants' cognitive abilities and learning styles, (2) their (reported) flexibility and efficiency in adapting to the needs of education and design practice, (3) the possibility for learning styles and cognitive abilities to change as a result of new and different learning environments, (4) variability in learning styles and cognitive abilities related to gender and ethnic origins, (5) differences/similarities in the learning styles and cognitive abilities of the first and fourth-final years students, and (6) correlations between the measures of academic performance, creativity, learning styles, and cognitive abilities.

These are a number of parameters similar to those analysed in Experiments I, II and III. As per expressed earlier, Experiment V does not claim to have, on its own, provided sufficient evidence for supporting either of the above points, but suggests an approach which fits well with the purpose of the thesis, and may prove useful for the future research. Some of the preliminary correlation analysis is discussed in the current subsection, whereas Subsection 6.2.4 presents an extended multivariate data analysis involving Experiments I-V.

Procedure

This part of the study draws on a well-established technique of guided introspection, where subjects are asked to provide their reflections about a specific activity or event verbally – via semi-structured interviews, and on paper – via open-ended questionnaires. It typically focuses on a specific skill, ability or activity in order to extract information about respondents' views of their capabilities, problems encountered, techniques or strategies applied to tackle certain problems, as well as their ideas on acquiring specific skills, or dealing with learning tasks.

In this study, semi-directed interviews were inter-linked with retrospective self-reports, during which the participants were asked to think back or retrospect on their ongoing, at the time of Experiment IV/b, cognitive processing. The respondents were provided with an opportunity to reflect freely on any aspect of individual problem-solving – from particular cognitive actions or events, to metacognitive reasoning executed in planning, monitoring, global approaches to the task, its major stages or phases, or the main information sources used. They were strongly advised against skimming over the details of an experience and relying upon the generic cognitive structures, such as memories, opinions and stereotypes, or constructing reasons that sounded plausible. The resulting data ranged from retrospective statements of design activities, to articulations of the reasoning behind them, also in contexts of the participants' former experiences and capabilities. It had to be sorted and categorized.

The questions asked were of two types: (1) those aimed at clarifying ambiguous or unclear actions from the videos, or statements that had occurred spontaneously, and (2) providing some general information concerning the students' habitual approaches to problem-solving, i.e. whether they were similar to those observed during protocol sessions. The reasons behind are related to two main dangers this study tried minimising: (a) getting a pre-formed opinion which

may or may not have been true, and (b) influencing subjects' views and getting a distorted picture by compelling them to create reasons that sounded plausible. The intention was to look at the participants' perspectives by avoiding preconceived questions based on the researcher's ideas of what the subjects could find important in their experience. The 'filtering' of data could limit the potential findings or influence the insights participants offered. Additionally, because of the adopted approach, quality, as well as quantity, of statements could be taken into account. That is, as the degrees of self-awareness and cognitive control varied considerably among the participants, the role of introspection as a personal skill, innate or developed, was also analysed.

Finally, a post-session questionnaire consisting of twelve questions was used to acquire information on individual differences in design expertise, interest, satisfaction, performance, perceived task difficulty and creativity of the outcome. The resulting reports were, predominantly, open ended since there were no restrictions applied to what students could say in response to a question or a statement that pointed to a topic in a general way. The participants were not asked to agree or disagree, write true or false, and so forth, but, in some instances, were required to rate their performance using explicit 10-point scales, supported by the explanations of the scores attributed.

Collected materials

The sources of data analysed included: (1) statements from semi-structured interviews, (2) spontaneous retro- and introspective reports, and (3) questionnaires. In this part of the study, only proto- and metacognitive statements related to the students' preferences and non-preferences in problem solving and learning, as well as to their cognitive abilities, are analysed. The more spontaneous retrospective statements related to the subjects' ongoing (i.e. at the time of Experiment IV/b) cognitive processing, such as task-specific strategies, cognitive events, intentions and actions, are not included; they are addressed separately in Section 6.3.

Data extraction: Learning styles

After gaining the initial understanding of the collected data, it was prepared for subsequent statistical analyses. Firstly, the Learning Style Analysis (LSA) questions (included in Appendix F test materials), explanation materials, and other didactic sources were consulted to generate four different groups of descriptions and classification markers related to four learning styles. The relevant statements made by the participants were then singled out (the process repeated twice) from the transcripts and placed in individual tables concerned with either learning style.

Some of the measured style dimensions i.e. *Wholistic-Impulsive* and *Analytic-Reflective* and *Visual-External* and *Verbal-External* are not included in this experiment as (a) there have been no significant correlations observed between them and other variables in the preceding analyses; and (b) this study has not accumulated sufficient empirical support to enable further analyses on these additional dimensions. That is, neither retro- and introspective statements, nor questionnaires and other protocol materials, have provided enough pertinent data.

The following Tables 38 and 39 set out the difference in *Wholistic-Simultaneous* and *Analytic Sequential*, and *Verbal Internal* and *Imagery* learning/thinking styles as suggested by the vast literature (reviewed by Riding & Douglas, 1993) and as summarized in the methodological part of the LSA. They include several major characteristics associated with each style, supported by sample statements drawn from this study's transcripts¹⁸. The more detailed versions of the features associated with styles, formulated as statements, questions, guidelines, or else, could be found in the Learning Company educational and research materials, and in a significant number of other models concerned with similar dimensions. They are not listed in the tables below for the purposes of clarity and conciseness¹⁹.

¹⁸ Some of these statements were 'polished'(without distortions) by removing/replacing colloquialisms, repetitions and mumbling, typical of verbal speech – to provide more coherent accounts, better suited for reading comprehension.

¹⁹ Some of the generic features from several models are listed under 'Other sources' in Tables 38, 39

Table 38. Traits associated with Wholistic-Analytic learning style: Experiment V/b

LSA questionnaire	Other sources*	Proto-metacognitive statements	Metacognitive statements
Wholistic learning style (1 – strong preference & preference; 2 – flexibility & adaptability; 3 – non-preference)			
'When I have to do the same tasks, I try to do them differently each time'	welcomes risk and experimentation as a part of learning or problem solving	Unless I'm totally lost and confused, I'd rather try different solutions... than do what everyone else does... or ask for help... I think its cos I kinda get bored if I don't push myself a little more each time	I don't like limiting myself by what I don't know or can't do... its kinda 'lets try it another way, like brainstorm or may be come up with something really original'... like I try some techniques... and see if they work... I enjoy challenges
		I really don't mind new and interesting assignments, its like you never know until you've done it... and you may learn by doing it too...	If I don't have an idea and I'm like totally stuck, I may try different ways, like some of these techniques we were taught... or I'll just play around, look at the spaces, turn them... tweak them you know...
		I can get really frustrated if the task is unfamiliar and we have to figure them out on our own	...I have my approach that has worked for me... so I stick to it... cos I know it works well...
'I prefer to figure out how to do things without following instructions'	prefers flexibility in working on tasks	I like studio work more than assignments, I don't like to think 'that's wrong and that's right and that's how you do it'... I like it when its flexible, no wrong answer... so I can experiment...	I sort of don't push myself with the same thing when I get stuck, or like panic and run for help... but like, hang on, lets try it some other way... like a totally different approach, or like let it go and see where it takes you...
		I first sketch to 'see' things, but sometimes I do it with a computer, I mean I start with, or sometimes I model too... you know, I don't mind different ways so that I learn myself what's best	If I can't see it the way they told me then I will be enquiring and finding my own way, I don't always trust teaching, so I do it all different ways... till I manage...
		It bothers me when there's not enough information, or they want you to figure it out yourself... and everything is kinda flexible... like you don't know if what you're doing is ok	I prefer looking at how things were done before... or looking at other people if I'm stuck, or I ask someone to explain it to me... that way I'm sure I know enough to go on
'I prefer to understand the relevance of the information'	understands things in context, reads overall ideas and skips details	I prefer to know the task well before I start working on it, like the background information, and all that... to get the feel, you know, to see how it all is going to fit in	You sort of figure out your own way to become comfortable with a task... like I always research it by reading or looking at similar stuff... to know the background, the context... and how it all connects, and all that...
		I sometimes have to wait till I know enough, so I'm kinda used to it... its like when I know it [the task] well, ideas just pop out of me...	Sometimes I feel I don't know enough about the task, like its totally unfamiliar, and that's how I got stuck... then it helps to know more about it, so it all fits together as one idea in the end...
		I don't like it when its all wishy-washy and general... like I don't know if I'm doing the right thing... I'd rather get all the technical details first to know what I'm doing	Usually, if I'm uncomfortable with an assignment, I go and re-read the technical side, to begin with requirements and build it all up from specs... like from real things
'Rather than following well known strategies, I like to change them and find new approaches for difficult tasks'	applies random, rapid, open-ended approaches to problem solving – impulsive synthesis	...then these sort of ideas... kind of tend to spring out of nowhere...	I always like... brainstorm and like come up with a few rough ideas... they can be totally odd... before like you commit to one thing, cos u want it original, and you want an impact, so u have to take risks
		I sort of didn't think of what I was going to do... in the beginning, so I jumped into it, and then I tried to think what I have and what I can do about it... yeah... most of the time its like that, like today...	... often, I don't have an idea in my mind, and then just sort of... oh! That's what I want! And sometimes I have to think of what I've got first... and if I'm like stuck, I may doodle many different shapes fast... and may be get a good one...
		Ideas kinda build up on me... I don't like it – not to know at all if they are going to work out... so I like to take it slowly	I don't like to come up with some ridiculous stuff that won't work for [the sake of] originality, good design takes time, it grows on you...

'I like to have an overview or know the reasons and goals for something before I start'	prefers having a general overview of the problem and concrete experience	...I think I always have ... sort of very general idea of how the things are going to be, and then I work out the details on paper...	I always make tons of sketches and notes to keep up with the concept ...to make sure it will work together as a whole in the end
		I think its better to have one big idea, rather than many... for consistency, but projects are not always like that, sometimes u end up with something else... piecy stuff	In some projects, I need to keep an eye on how my concept develops so it all fits well together in the end... and does not fall into bits... its like keeping track of the big picture
		Its hard to like... stick to one idea... with all the constraints and details... its really-really easy to end up with a few bits and pieces you need to put together somehow...	I always liked the technical side better, its so much clearer and it kinda drives the design, so I start with it and then, when its done, I build up the rest from there...
'I get bored when I can't work on several learning projects at the same time'	can work with several different things at the same time	I was drawing here and there... yeah, and writing too, because I had several ideas in my mind, and I wanted them all down... yeah, its always like that with me, like nothing first and then it all comes together...	I figured it works better for me to do a few things at once, when I don't concentrate on one thing... yeah a task or a part of a task, either... something original may emerge, its kinda dull to just sit and try hard...
		I liked it... that it's a design studio and an observatory, and the characters are different too... all these different things you have to keep in mind, it is a bit hard but it's more fun...	when I have to consider a few things, like spaces and functions and specs, and all that, I sometimes do many little sketches, its clearer and it doesn't just go and disappear from my head...
		I can get distracted and lose concentration when there's too much stuff to deal with, I prefer one thing at a time... its much easier	I don't like getting side tracked, so I don't jump from one thing to another, yeah... I finish one part and then work on another one...
_____	sees relationships and likes analogies	I started with thinking, okay, what do I know about these people to make them a good home... what I could use of what I've seen to make it nice... and to get the specs right, and how to put it all together as one thing... yeah, that's how I do it...	Before I start [sketching] I like to get a feel of the whole thing, how it connects with environment and people... and I also look for inspiration... not just buildings, but other things too... like, sometimes its shapes and sometimes its words
		Yeah... here I'm a bit stuck, so I remembered about those other places I saw, and thought 'what could be useful in this task'...	If I don't get any ideas in my head, I may think of what it reminds me of... no, not just in architecture, but like nature, or other design, or movies, or something I read

LSA questionnaire	Other sources*	Proto-metacognitive statements	Metacognitive statements
Analytic learning style (1 – strong preference & preference; 2 – flexibility & adaptability; 3 – non-preference)			
'Once I have developed a routine I like to stick with it'	feels most comfortable when does not have to risk error when learning or resolving problems	I prefer no disruptions when I design, like I follow my little routine or something... like more in control	I have figured out how to do some things, and I like to keep doing them the same way... works better
		with heavy stuff I need to stick to like a plan to have my work done... like a system or something	There are a few approaches that I've already learnt, I like using them with difficult tasks
		I hate routine... we have enough of boring assignments already, and all the technical stuff you need to think about... I really didn't want it in the studio too...	I have to distract myself somehow if I end up doing the same thing for too long... yeah, an assignment or a project... it becomes so boring... so I take a break and do something else
'For difficult tasks I need clear guidelines, then I know what to do'	prefers precise instructions to follow and feedback	I prefer to receive really specific information, like some sort of guidelines before I start something... because in architecture, for example, the technical side is very important	I feel, its always better to have the technical side sorted out first, because you know precisely how to do it... but if you can't have it before the actual design, you work it out on your own... yeah, like impose some sort of structure to follow...
		It was a little hard because this assignment was new to me... and also with time [constraints] and all that... I really wish I knew what was expected, or like was told a bit more what to do...	Before starting something it helps to know what I'm going to do, so clear directions are always better, but if I can't have them I may try to create them or forget all about it and do a concept first... whatever works...

		I don't think I like to be told how to do things, because you want to be independent in your work... so I think I really enjoyed the flexibility [of the design task]	I don't start on the technical side till I work out the concept, because I think too much structure too early is not good... you sort of let it grow and see where it takes you...
'Lots of details help me to understand difficult learning content'	understands facts better than concepts, concentrates on details	Here I'm working out other constraints on my own, to keep going... cos It was a real problem for me that the task was so general	I figured I can start designing when I know the site like my own backyard... so no little detail is missed... and it builds from there
		...when you are doing a real project, you deal with a lot of information, you work out requirements and try putting pieces together, like build it up... projects like today's are harder, but sort of ok too	I don't always need to get down to details to understand the task better, sometimes its enough to just have a look at it... but it always helps to know all the concrete things before you start...
		Here, I'm getting down with details, but its too early and it didn't work, because I haven't decided on the concept yet, so I give up and start thinking about it again...	You don't see many details because I always get the big idea sorted out first, it works better, because by the time you worked out the concept, they all change anyway...
'I like assignments that move step by step to an answer or a conclusion'	applies step by step approach to problem solving and learning – structured exploration	I don't like getting side-tracked, its too easy to get lost with all the constraints I have to keep in mind... so I worked them out first and then built it up from there... yeah, that's how I usually do it	It just works for me better if I break a task into small parts, calculate sizes, allocate spaces, decide where they go, and so on... and then assemble it back into one design...
		I sometimes find it hard being creative... cos you may end up with a nice concept but spaces don't fit well... or it can't work altogether... so here I figured out the requirements first and did it... like part by part	If I analysed the site and spaces and put them together... but the concept wasn't happening... like I restricted myself too much by the technical side... then I may I start it over with a big idea, but its harder...
		I got confused by too many things here, cos I think I lost the big picture, and was just sitting putting pieces together... and it didn't work	I figured the big idea works for me better... its like you have to wait till 'bang' and you have it, and it all falls into place
'I benefit most from analysing information and study topics that move in logical sequence, and contain plenty of details'	prefers logical sequence in problems and concentration on concrete details	I'm calculating spaces here because I need to see exact proportions of all rooms before I can arrange them within the house... sort of what I'd usually do with a computer	I'm not one of those people who comes up with a concept straight away... and then half of constraints don't fit... and so you do another concept... I have to build it up from requirements and specs
		I'm trying to organise some of the constraints from the brief... so its logical... I think it helps me think...	I tend to build my projects gradually ... and I think I'm quite meticulous with details... well its my good side
		Ideas with me... well, they sort of just come to me... like all at once or may be just one, but its kind of like 'bingo! now I know what to do' and not like okay lets try this rule or like a method or something	I think it's a problem when you give in to constraints too soon... I get the duller designs that way... I mean you need to know the task well, but make sure it doesn't get in the way of creativity... or like an insight
'I don't like to stop in the middle of one assignment to start working on a new one'	does one thing at a time	I'm getting confused here, and side-tracked cos I'm trying to do too many things at once... so I stop...	What I did here is separated the main issues, I always do that to deal with smaller tasks, one by one
		It's easier to just do one thing at a time, to remember stuff... constraints and all that	I may need to break down the problem into smaller bits when its too complex... to manage it better
		Yeah, as you can see I'm sort of doing little drawings here and there... its cos I'm like thinking of a few things... and just want them down on paper... like today, it all comes together at once	I think I'm better, like more relaxed and productive too when I don't do just one thing continually... disruptions could work too... and you just know when it all comes at once its really happening...
	prefers precise data, rules, methods and details	I'm applying here what they taught us about how you analyse the site and all that... I feel this part is easy and I'm still relaxed... its good stuff	I'd say I prefer structure in designing, when you apply some sort of system you always have a better analysis and then you produce more useful designs
		I liked the initial part of designing [site analysis] better because I knew what to do, and how to do it	I think using some of the methods they taught us really works... or at least I always try to see if they will

As it is clear from the above, *non-preferences* were introduced into the process of data preparation. In theoretical studies of cognitive styles they generally form a bipolar continuum/s whereby an individual is classified as having a style that falls somewhere between two polar extremes (Riding, 1996), suggesting that more of one mental ability is less of the other. This is different from the theories of learning styles, where an individual does not have to belong to either side of the continuum, but may possess equally strong (versatile), weak (adaptive) or combinatory (weak and strong) preferences in one, or more, of the bipolar dimensions. And, equally, lacking in one style does not imply an inclination for the opposite. In order to accommodate both approaches, this research tried to minimise a possibility of ascribing both styles (of the same axis) to one individual when one, or more, responses strongly contradicted others, particularly in cases of conflicting metacognitive statements – by noting down *non-preferences*. As a result, two first year students were contacted before proceeding with statistical analyses to clarify encountered ambiguities. Both cases were successfully resolved.

A similar approach has been adopted for the Visual-Imagery dimension (Table 39). The resulting data shows more uneven ratios of the proto- and metacognitive statements. As some aspects of visual reasoning, such as sketching, have been reported more than others, and via metacognitive statements mostly. While verbal statements, although high in numbers on some of the characteristics listed in Table 39, were predominantly proto-metacognitive. The reasons are likely to be related to education (including lecturing on the relevant theoretical issues), experience in design, and, possibly, the very nature of issues described. In future studies it may prove useful to decide on specific questions (as in this research the responses were mostly unprovoked, but at times prompted for clarification) to evaluate a real degree of conscious control. Another observation concerns *non-preferences*. They varied significantly in terms of their strengths, with the W-A statements typically stronger than the V-I, which may be related to the higher proportion of versatile and brain-gifted students on the visual-imagery dimension.

Table 39. Traits associated with Verbal-Imagery learning style: Experiment V/b

LSA questionnaire	Other sources	Proto-metacognitive	Metacognitive
Verbal learning style (1 – strong preference & preference; 2 – flexibility & adaptability; 3 – non-preference)			
'Talking to myself helps me to organise my thoughts and understand difficult concepts'	represents information verbally during thinking	I'm thinking to myself... like I have this constant inner dialogue going on... I'm trying to understand what needs to be done...	I need to think it through to sort out the priorities in a task, to structure it... to sort of have a sense that things are moving logically
		I think things were moving too fast, so I'm telling myself hang on, slow down, think about it... you need to think about it now...	I'm often thinking [verbally] and imagining things simultaneously but I need to talk to myself to understand things better
'I remember best by reading or seeing information written down'	remembers much of what he reads, remembers names better than faces	I had to write these things down to recall later what I was thinking... I didn't sketch them because it was easier to just write them down	I usually write down ideas as they emerge, its faster, more flexible, less constraints, and I can easily recall what I meant
		Here I'm just reading the brief to understand it and commit it to memory, but I also often draw little diagrams from words... like here	When I'm organising brief requirements I choose what suits me or a task better, usually words are faster and kinda more logical
		I kept going back to the brief because I couldn't remember some of the constraints... if it was more visual, it would have been better	If I see it, I remember it, and I grasp it at once, its much slower with text, and I can't retain it as well as some visual stuff
'I like reading and prefer books and assignments with clear, written instructions'	prefers verbal/ written data and instruction	No, I didn't really mind that you didn't give us much of a visual brief... It is much easier to get down to details with written stuff... they are all there already	When it comes to like things that need being structured, I think writing them down is much more common and it always worked much better for me
		Here I'm reading what I wrote cos I couldn't understand how I [had] sketched this thing... I forgot what I had in mind... how I solved it	I tend to read a lot when I feel I don't know enough about something in design, but I also look at images of course

		...the site is not very graphical... like there are no trees or anything, so its just a lot of words, and that's like a bit difficult...	I constantly build these little diagrams to be able to work with specs, written stuff doesn't work for me... it like doesn't help with designing at all... slows me down
'Talking out loud helps me to organise my thoughts' 'Note-taking helps me to learn and remember difficult concepts'	likes to write or speak to remember or understand	I always make lots of notes... they are like all different kinds of notes	To understand better I often talk things over with someone else
		Here I am writing it down to remember and to explain it to myself, and to you later, its sometimes easier and also quicker than sketching	I may discuss things with my lecturers or tutors before I begin working on assignments, it helps to structure your thoughts and know you're on the right track
		Yeah I don't have many notes, it feels more natural for me to draw than to write in design	I think a sketch is more precise than words, words can be too vague, to not guess what I meant but to know exactly, I try to write very little... unless I want it vague
'I love debating and enjoy participating in discussion groups'	likes to interact verbally	Here I'm thinking, I would have loved to just go and discuss my design with someone now... to like share my ideas with them	I think talking about my projects is something I've always done with other students... I've always found this interaction useful
		No, I didn't really mind introspection, I could clarify some of my thoughts	I think it was useful what I did today, we could discuss it and I feel I know more now
		I have problems with presentations [or] defending and even explaining my designs, they are kinda supposed to speak for themselves	I sort of stick to my own company to not get influenced by other people's ideas when I'm thinking of concepts
'By talking to myself I often find solutions to my problems'	has an ongoing inner dialogue which helps them remember and understand	I'm talking to myself here, yeah, loud, how embarrassing, but that's just what I do when I think hard	I always try to like dissect a problem in my head and plan how I tackle it, like come up with a plan, its easier to stick to it if you like agreed with yourself
		I was worried here a little cos my design wasn't going too well, so I'm having a lot of self-talk going on in my head about that	I may discuss it with myself, like what's good in it [design solution] and what's bad, and sometimes just talk myself into it
		Too much thinking makes me worried, I prefer to get down and dirty with it... yeah just sit down and do it, don't talk	I try to shut down on negative thoughts when I design, cos when you're frustrated, you don't have an overview, like buried in details

LSA questionnaire	Other sources	Proto-metacognitive	Metacognitive
Visual(Imagery) learning style (1 – strong preference & preference; 2 – flexibility & adaptability; 3 – non-preference)			
'Visualising what I have heard, seen, or read helps me to remember and/or understand new information better'	mentally visualizes data to conceive ideas or while thinking	Here I'm imagining in my head... how I walk around and how the house looks from the street... like I need to imagine myself at the site, its more real that way and also my ideas tend to appear what I do it	Like with phone numbers... I need to see them in my head to recall... same with other stuff, if I just read or even listen I can feel dumb, its like its gone next minute, but if I sketch or imagine stuff, then it sort of stays with me
		I'm just trying to see in my head how these spaces are related to one another... I kind of tried writing it down, with a little diagram, but you need to see things in your head first	Sometimes when the stuff is not happening or like I'm stuck in my thoughts, I need to close my eyes and sort of wonder... kind of let my imagination do it for me
'I remember best by looking at pictures and other visual sources'	remembers much of what he sees, remembers faces better than names	I'm sketching a few things here to commit them to memory... like I also drew a few diagrams to remind me of some constraints... I always remember better when I can put things down, like in a graphic form	I usually sketch down ideas as they pop up, its fast, you can play with them, they are like... yeah abstract... but also they are real, and I can easily recall what I had in mind when drawing them
		I'm always producing tons of sketches and annotations, because so many things are going on in my head, but more sketches, because like they can record my thoughts a bit better... like I can look at them and see what I wanted to say	I use different media in my designs, like sketches, and models, and computer, sometimes clay... I write a bit too, but I prefer sketches cos its like thinking on paper... like I learnt that if I look at them I can see what I thought of [when making them]

		We learnt at school to like write down everything, so I'm used to it, and it sort of helps with projects as well... like its easier for me to express myself that way, and to think too...	I always have to write down everything that comes to my mind, to structure it, and to remember it... pictures can be too vague, you just never know what it means later on...
'I prefer to learn from graphs, tables and charts instead of class lectures'	understands best through watching, prefers visual data	I prefer to have visuals, like pictures or drawings to understand a project before I read it... I can sort of get what they want from us better... Its also easier to learn when there's something visual in lectures	I figured that if they don't show us much visual stuff with whatever they teach it, it just goes above my head after 5 minutes... well, to cope I sometimes doodle along or can surf the web for it later
		Here I'm going over some of the earlier ideas I sketched, and here I'm looking at the brief again, next to it... yeah, I made a little sketch of it [brief] to understand it better	I generally like architecture education cos they use different media, so if I don't understand one thing I sort of have a change to still get it with more visual stuff
		No, I didn't mind the brief at all... It is actually easier to understand constraints with written stuff... they were already there... very clear... its other stuff that bugged me	I think writing down ideas during analysis works better for me, verbal language seems more accurate, and it kinda has a structure of its own, its important
'I like to sketch, draw charts and symbols when working on a new assignment'	likes to sketch, thinks on paper	Here I'm drawing circles around this space over and over again... like in very fine lines... its not a shape but its important and I was thinking about it... I just do these things, I think they help me think	I always re-draw... its not like looking at something... when you draw something, you're discovering... by drawing it, you commit to memory... I imagine on paper...
		I couldn't see it in my head how these things are related, and if there's enough space for the rooms ... so I'm trying to work it out on paper... its like sometimes you know before you draw it and sometimes you can only see it on paper	...and also if you have them [design elements] in one drawing, it allows you to see a pattern emerging, which might give light to another idea... or sometimes you talk to yourself, and it can also give you some new ideas...
		Here I'm struggling to show how the house looks in 3D... I couldn't see it, so I had to draw it... but its not really happening, sketching can be so hard sometimes...	I find it difficult sometimes to express what I mean by drawing, that's why I write a lot of notes, like today also
'I really enjoy computer programs with pictures, colours and graphics'	needs visual stimulation	Here I'm a bit stuck, cos I would have preferred to actually see the site from the brief... like pictures or something... to get the feel	Surely, the more visual information I get the better, but its okay, I can work from my imagination if I don't get it
		I was drawing these flame trees and the street line here, because I thought if I have them, it could show me how I shall make the house address the street	I sketched a few things that were not in the brief to learn about the site better, like the slope wasn't defined for me till I drew it... but I could also manage without it
		-----	-----
'I can quite easily picture the outcome when I have to solve a problem'	usually has a strong imagination	I saw [i.e. visualised] this general idea from the beginning... how the things will fit together and how the form will be... its kinda normal for me... yeah, I can still see in the end most of what I planned initially	I think my problem is never my imagination, cos I think its pretty good, but its how put on paper things I see in my head... so I'm trying to improve my sketching as much as I can
		Here I'm thinking if I've gone too far from what I originally imagined... because, you know, things can change a lot [in the process] sometimes	Most of the time, in the beginning, I already see the whole idea as it will be in the end, so I try elaborating on it and hopefully don't change much
		You never know what it is going to be like in the end, you kind of put pieces together... and they have to fit in, so you change them constantly, then it turns out to be something else, not what you initially planned for it [to be]	I think my imagination is not too good, like its ok, but others seem to have a better one... so I use computers, cos you can manipulate computer stuff easily and see what's going in... and it's not as hard [i.e. final] as sketches

The main observation resulting from the data extraction process was that students often referred to both visual and verbal reasoning in the same statement, related to the same cognitive event or triggered by the same process. It was also, at times, hard to separate verbal and visual reports as

students used phrases like ‘I’m *thinking* there about how I’m *walking around* the house and what *I can do* about the rooms... I sort of do that a lot’ or ‘I’m trying to *see* what’s the best way of *making them feel* at home... because when you design a house it has to have something unique about it, but it has to suit everyone [who lives there]’ which are inherently confusing. And when asked to clarify whether the participants were actually ‘visualising’ or ‘talking within themselves’ they often referred to both activities as inter-related or even inseparable. The explanation may be the dual coding theory proposed by Paivio, which attempts to give equal weight to verbal and non-verbal processing. As ‘human cognition is unique in that it has become specialized for dealing simultaneously with language and with nonverbal objects and events. Moreover, the language system is peculiar in that it deals directly with linguistic input and output (in the form of speech or writing) while at the same time serving a symbolic function with respect to nonverbal objects, events, and behaviours. Any representational theory must accommodate this dual functionality.’ (Paivio, 1986, p. 53). Additionally, as most of the students were flexible in both visual and verbal modes (as assessed by the LSA) it is also likely that they shifted freely and frequently between different associated with them strategies.

Data extraction: Cognitive abilities

In addition to the information on individual learning styles, we suggested it was possible to extract data on the students’ cognitive abilities – to be correlated with task-specific cognitive strategies and activities (extracted and analysed as a process in the following subsection) and design abilities. It was well understood that a large body of empirical research that has relied on introspective reports of imagery use, has failed to find any consistent relationship between visual imagery, spatial, and ideational factors, as self-report techniques seem to be unrelated to cognitive test performance (Di Vesta, *et al*, 1971; Richardson, 1983; Kosslyn, *et al.*, 1984; Poltrock & Brown, 1984; Poltrock & Agnoli, 1986; Dean, 1994). We, however, were not concerned with direct comparability, but wanted to point at the potentially useful source of data that may, in future, help establishing associations between the *input* and the *process* (Table 40).

Table 40. Introspective statements associated with ability factors: Experiment VI/b

Proto-metacognitive	Metacognitive
Ideation abilities	
I’m just thinking of the concept here, like a word pops up, its ‘ballet’... and then I’m trying to think of what I know about it... and how would it affect the space and the atmosphere... and then I start seeing some of the things that would shape up the design	I think what I tend to do when I’m stuck is to relax and sort of free-wheel... let the images just come into my head, one usually triggers another... words can do it to... like before you commit to anything, you let the craziest ideas sit in your head... and then, hey, you might even use one of them later
Visual-spatial abilities	
Here I was thinking about what I could see if I was inside the gallery... I think it helped me with sorting out a few things... like do I really want it there, or if enough sun is coming in and all that... yeah, I was visualising it in my head as if I were inside that room... yeah, that how I usually do it...	I usually try to imagine the whole thing in 3D... because I tend to produce piecy stuff on paper, but when you visualise things from the inside and outside [of the designed space] you tend to see it as whole... I sort of go back and fourth, from the more detailed technical stuff on paper to the more conceptual in my head...

It appeared that many students did have a fairly good understanding of their visual-spatial and ideational abilities as the cognitive testing results confirmed their predictions concerning how well they would perform. However, the data on their proto- and metacognition were too few to be considered in statistical analyses. A similar approach proved more useful in the analysis of design protocols as a process, as there was enough data generated on the students cognitive actions and processes that could be co-analysed with the differences in their design abilities.

Demography and quality of results

There was no discernible difference in the quality of responses received according to the country from which the respondent originated, or their gender. That is, in what concerned the

ability, good or poor, to articulate proto- and metacognitive ideas. The main distinction pertained to the year of study, with the fourth and final year students being more eloquent, as well as more confident with their responses. There is also a general tendency for the fourth and final year architects to be more aware of their learning and problem solving behaviour, as many of them make an effort in understanding it by habitual introspection. It is supported by the statements where the students indicate that they have, initially to 'survive' and then consciously, modified their learning styles since arriving at university (previously reported on pp. 104-105).

Data preparation

The data, resulting from the above extraction process, was subsequently converted into the quantifiable format by (1) estimating how many statements were related to each style, and by (2) considering the strengths of reported preferences. The second aspect is based on the distinction between proto- and metacognitive statements, where the latter ones usually indicate stronger or crystallized over time preferences and a higher degree of cognitive control in problem-solving. That is, while proto-metacognitive statements denote a degree of inner understanding most people possess as a result of learning of working experiences, metacognitive statements, denote an ability of conscious addressing of the issues resulting from having either of the learning styles. They were, therefore, ascribed different numeric values. Proto-metacognitive statement flexibility – '1'; preference – '2'; metacognitive statement flexibility – '3'; and preference – '4'. Sums of the statement-values were then used in analyses.

Descriptive statistics

Descriptive statistics for all variables analysed in this part of the experiment is presented for each test group split by gender, in Tables 41-42. Table 41 describes the initial data. It is concerned with the numbers of the extracted proto- and metacognitive statements, where preferences and flexibilities were treated as equal and added up.

Table 41. Distribution characteristics for ability factors by year and gender, Experiment IV/b

Variable	Year 1						Years 4&5					
	Proto-metacognitive statements											
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Wholist	3.00	5.00	4.20	0.84	4.30	0.95	3.00	6.00	4.20	1.30	4.30	1.25
	3.00	6.00	4.40	1.14			2.00	5.00	4.40	1.34		
Analytic	3.00	6.00	4.40	1.52	4.70	1.49	3.00	7.00	4.80	1.48	5.10	1.10
	3.00	7.00	5.00	1.58			5.00	6.00	5.40	0.55		
Imagery	4.00	7.00	5.80	1.30	5.40	1.08	4.00	7.00	5.40	1.14	5.70	1.77
	4.00	6.00	5.00	0.71			2.00	8.00	6.00	2.35		
Verbal	3.00	7.00	5.00	1.58	5.10	1.37	3.00	7.00	4.60	1.51	4.80	1.48
	4.00	7.00	5.20	1.30			3.00	7.00	5.00	1.58		
	Metacognitive statements											
Wholist	1.00	2.00	1.40	0.55	1.80	0.92	2.00	5.00	3.00	1.41	3.00	1.41
	1.00	4.00	2.20	1.10			1.00	5.00	3.00	1.58		
Analytic	1.00	3.00	1.80	0.84	2.10	0.88	3.00	5.00	4.00	0.71	3.60	1.08
	1.00	3.00	2.40	0.85			2.00	5.00	3.20	1.30		
Imagery	2.00	4.00	2.60	0.90	2.60	1.26	2.00	6.00	3.80	1.64	3.90	1.37
	1.00	5.00	2.60	1.67			2.00	5.00	4.00	1.22		
Verbal	1.00	3.00	2.20	0.84	2.00	1.55	2.00	4.00	2.80	0.84	2.70	0.82
	0.00	4.00	1.80	1.48			2.00	4.00	2.60	0.89		

Females
 Males
 Group results

*Whol. – Wholistic statements; Analytic– Analytic statements; Verbal – Verbal statements; Imagery – Visual (Imagery) statements; V-S – Visual-Spatial statements

As it is clear from these initial results, both groups of participants have, on average, made more proto- and metacognitive statements related to the Verbal-Imagery dimension, than to the

Wholistic-Analytic mode. The average numbers of proto-metacognitive statements are similar for both the first, and the fourth and final year students. While the final year students reported more on their metacognition. These results, however, may have been influenced by the researcher, who asked clarifying questions when the responses were confusing or inarticulate.

That is, although the students were not directed towards creating reasons behind their problem-solving approaches and strategies, some of them were asked to elaborate on their statements when their nature seemed unclear (similar to the example on page 146). For the duration of retrospection, especially in its early stages, the researcher tried to avoid questions that could trigger introspective reports, but it was not always possible. Thus, it is not improbable that, influenced by some of these questions in the beginning, later, students felt compelled to explain themselves better and more. If this is the case, then the numbers of statements may not be particularly appropriate for statistical analyses. Also, when treated separately, proto- and metacognitive statements, their preferences and flexibilities, are likely to fall below the statistically acceptable numbers, and complicate data interpretations. Thus, it seemed more plausible to use the type of data that considers both the strengths of reported preferences and the statements themselves (as explained in the *Data preparation* paragraph, p. 147).

Table 42. Distribution characteristics for ability factors by year and gender, Experiment IV/b

Variable	Year 1						Years 4&5					
	Statement-values											
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Wh. s-v	6.00	16.00	11.20	3.83	12.5	5.80	11.00	27.00	16.80	7.01	16.50	6.45
	7.00	24.00	13.80	7.53			6.00	22.00	16.20	6.65		
An. s-v	7.00	21.00	12.80	5.40	13.80	4.52	15.00	29.00	20.60	5.32	19.80	5.30
	9.00	19.00	14.80	3.77			13.00	28.00	19.00	5.79		
Im. s-v	12.00	24.00	17.20	5.45	17.10	6.05	13.00	29.00	20.00	7.04	20.70	6.80
	10.00	28.00	17.00	7.25			10.00	28.00	21.40	7.30		
Ver. s-v	9.00	22.00	15.60	4.92	15.20	5.94	13.00	27.00	17.40	5.69	16.50	5.64
	7.00	27.00	14.80	7.40			11.00	26.00	15.60	6.11		

 Females
  Males
  Group results

*Wh. s-v – Wholistic statement-values; An. s-v – Analytic statement-values; Ver. s-v – Verbal statement-values; Im. s-v – Visual (Imagery) statement-values.

Similarly to Table 41, the data from Table 42 indicates that both groups of participants have, on average, reported more on the Verbal-Imagery dimension, and less on the Wholistic-Analytic mode. The mean numbers of statement-values concerning each style are different for the first, and the fourth and final year students. The architects seem to have a higher degree of conscious control over their problem-solving approaches and strategies in design (excluding verbal thinking where they seem to be similar to designers). And this includes wholistic reasoning, which disagrees with the LSA assessment results concerning individual preferences in learning, according to which there are more wholists among the first year students.

Protocol sessions' constraints and habitual designing

One of the major concerns in this research were constraints of the protocol method. Thus, the study of introspection and questionnaires was also interested in establishing whether the participants' behaviour during design sessions could be viewed as typical or habitual. As our interviews indicated the students, on the whole, felt comfortable with the process of designing under protocol conditions, including the setting, and the type and specifications of the task. Some of their written comments are included in the questionnaires (Appendix C).

In regards to the habitual versus the more artificial protocol problem-solving, the majority agreed they did it in a usual way, although there were complaints related to (1) the design task, (2) personal issues and capabilities, and (3) some of the protocol session conditions. The first type of comments ranged from requiring more visual information and/or stimulation by similar

projects, to having too many (or too little) constraints to consider. The second group of comments denoted the students' affective states ranging from 'I'm not in a very creative mood today' to 'I felt a little frustrated, I could do with a good break, but I had to continue'; as well as some of the issues concerning their knowledge, skills and capabilities, such as 'I needed a model to continue with this task', 'I can't sketch very well, I'm more used to computers', 'I couldn't sketch what I visualised,' and 'I wish I had a better experience with this type of projects.' Within the third category, the most popular comments were related to (a) time constraints, including lacking time to complete the task when the ideas were finally there, and the pressure to produce a quality design within a short period; (b) inability to do background research prior to designing – to gain more knowledge on the subject or some of the task aspects, and for inspiration; (c) inability to communicate design concerns with fellow students, and bounce conceptual ideas of them; and (d) lack of incubation. Architecture students were, in general, more confident about their approaches to solving the set problem. While design students were more enthusiastic about the task and the process of design problem-solving.

Effects of gender of participants

The MANOVA analysis of the learning style statement-values, gender, year of study, and ethnic origin, has not revealed a significant main effect or interaction for gender. The data suggests there could be marginal gender differences in the values of cognitive statements on both W-A and V-I dimensions, with females in the sample more inclined towards the verbal mode and wholistic simultaneous thinking²⁰, and males – towards the visual mode. This, generally, agrees with the LSA assessment results illustrated by Figure 3 and Tables 26, 27. And may have some of the same explanations.

Effects of ethnicity of participants

The joint analysis of the learning style statement-values, gender, year of study, and ethnic origin, showed differences between the groups based on ethnic origin. The one-way analysis of variance of cognitive style scores based on ethnic origin revealed that the Australasian and Australian groups had significantly different learning styles on the Wholistic-Analytic dimension, and marginally different – on the Visual-Imagery dimension. Within the sample consistent for all years, there are more analytic learners in the Australasian group, and more verbal students in the Australian. The differences on the Imagery dimension are insignificant for the first year students, but there are more high imagers among Australasian students in the fourth and final years. There are also more wholistically inclined students in the Australasian group, but more high wholists in the Australian. Table 43 illustrates some of these results.

Table 43. Effects of ethnicity on reported learning styles: Experiment V/b

		Year 1				Years 4&5			
		Wholist	Analytic	Imager	Verbal	Wholist	Analytic	Imager	Verbal
Australasians	Mean	11.20	14.80	17.00	14.40	17.60	20.60	22.40	12.80
	SD	3.42	5.49	6.08	4.72	3.78	5.77	4.93	1.48
Australians	Mean	13.80	12.80	17.20	16.00	15.40	19.00	19.00	20.20
	SD	7.72	3.63	6.72	7.45	8.74	5.34	8.52	5.93

They are mostly consistent with the results reported in Table 24 (concerned with LSA assessments), while some of the reasons for the observed situation may also be similar.

Effects of metacognition and versatility of learning styles on academic performance

The initial proposal was for metacognition to be associated with versatility and brain-giftedness in learning styles, academic performance, and, possibly, creativity. It is based on the studies of students' metacognitive strategies indicating that metacognitive capabilities such as self-

²⁰ When one of the first year male students, who has the highest value of wholistic statements (n=24) in the sample, is excluded from statistical analysis as an outlier.

regulation are keys to the development of appropriate learning strategies (Rojas-Drummond, *et al*, 1998; Schraw, 2001). That is, while learning styles are necessary for performing a task, metacognition is critical to understanding how the task is performed, and self-regulation helps in a more efficient conscious choice of learning strategies. Table 44 indicates if this has proven to be the case with the present study.

Table 44. Pearson product-moment correlation coefficients (b): Years 1 and 4&5, Experiment V

Variables	Wholistic	Analytic	Imagery	Verbal	Versatil.	Creativ.	Acad. Pf.
Year 1							
Wholistic	1						
Analytic	-0.106	1					
Visual(Imagery)	0.848**	0.294	1				
Verbal	-0.536	0.482	-0.310	1			
Versatility	0.535	0.399	0.645*	-0.008	1		
Creativity	0.873**	0.148	0.868**	-0.558	0.752*	1	
Academic Performance	0.595	0.555	0.772**	0.081	0.873**	0.762*	1
Years 4&5							
Wholistic	1						
Analytic	-0.490	1					
Visual(Imagery)	0.971**	-0.473	1				
Verbal	-0.499	0.223	-0.618	1			
Versatility	0.437	0.149	0.423	-0.374	1		
Creativity	0.753*	-0.345	0.765**	-0.699*	0.725*	1	
Academic Performance	0.578	-0.271	0.567	-0.220	0.663*	0.740*	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

The above results indicate for the higher levels of cognitive control to be a statistically significant factor on several dimensions. In both groups of students, self-regulation on the wholistic and visual learning styles has a significant impact on creativity. Imagery also affects academic performance on design projects of the first year participants, and indicates a tendency for the similar effect for the fourth and final year students. There is also an association between versatility and visual metacognition for designers, while the correlation magnitudes on the same dimensions are low for the architecture students. Versatility has a stronger predictive validity on academic performance which may suggest that the learners (especially the less flexible ones) need being encouraged on a metacognitive approach to enable them to choose the most appropriate learning strategy from a wide range of options to fit the particular task in hand.

In view of the above, it can be suggested that as learning styles can be improved, the nature of the process of developing versatility may be similar to (or goes in parallel with) attaining a more conscious control in cognition. However, to prove this relationship one needs to consider many parameters, including the innate potential of an individual, their ability to learn, and the amount of prior learning done – which is often too difficult. What is more evident though, is that cognitive control in problem-solving is, indeed, an important factor in design education that requires further attention. This is also supported by the evidence in favour of metacognition by Marzano (1998) who reported on the largest meta-analysis of research on instruction ever undertaken. He found that approaches which were directed at the metacognitive level of setting goals, choosing appropriate strategies and monitoring progress, are more effective in improving knowledge outcomes, than those that simply aim to engage learners at the level of presenting information for understanding and use. Interventions targeted at improving metacognition produced an average gain of 26 percentile points (across 556 studies).

Questionnaires

Post-session questionnaire consisting of twelve questions were used to acquire information on individual differences in design expertise, interest, satisfaction, performance, perceived task

difficulty and creativity of the outcome. In this part of the study, only the summaries of processes the students followed to complete the design task, are analysed. These summaries contained enough data to form an opinion on the Wholistic-Analytic dimension, and had some indications of the Verbal-Imagery style. Table 45 illustrates this point (the original data is included in Appendix C; the resulting data on ascribed styles is given in Appendix B).

Table 45. Summaries of individual problem-solving as reported in questionnaires: Experiment V/b

Year 1	Years 4&5
Analytic-Verbal (S04)*	Analytic-Verbal(S14)*
First, I set aside space for the parking, because the amount of space available for the building is dependent upon it. Next, I organised all the parts into categories (public-semi public- private) and decided which spaces would have a view of the recreation space (studios, master bedroom, observatory). Then I set aside some space for the sculpture garden, next to the painting studio. Then, I used the rest of the floor plan for semi-public space (living, dining, WC). Finally, I decided on a floor plan design to fit everything together	- what are the site issues, views, orientation, access... - what spaces are needed (organisational diagram) - writing down ideas on what my strategy would be - attempting a block diagram on site with appropriate sizes
Analytic-Visual (S01)*	Analytic-Visual (S16)*
I worked out the site restrictions, then diagrams of space placement, integrated the living spaces into a plan, took views to visualize it 3 dimensionally and thought about character. I had problems arranging studio spaces but major living spaces I was certain about from the start.	1. Diagram showing how services vs living areas related to each other and to North 2. Plans, showing relationships between rooms 3. Sections, showing relationships vertically 4. Axonometric showing 3-dimensional form, how roof work, starts to show external cladding and openings 5. Elevations showing external cladding openings + proportions
Wholistic-Visual (S10)*	Wholistic-Visual (S20)*
1. Thought about art and its connection to life and nature 2. Came up with a concept plan and shape 3. Tried to fit brief requirements into that	1. Contemplate: site/context, recognise what brief contained 2. Relationships between rooms defined 3. Understanding of the whole house as a number of rooms and also as a whole 4. Opened several spaces up to one and other, and tried to segregate seclusive and active

* According to LSA assessments

It is clear from the above that students with similar learning profiles, as assessed by LSA, share a lot of similarities in problem-solving. They structured their designing processes in a comparable manner, had similar macro approaches, and addressed similar issues. This observation is valid for most but not all of the participants. As their dominant and secondary styles varied in terms of the strengths of preferences, and each student had a unique repertoire of learning styles, some of the versatile subjects produced reports that contained features that could be associated with each pole of W-A and V-I dimensions with equal strength. This means that although there may be a link between the students' preferences for wholistic or analytic reasoning and the general, higher-level organisation of their design processes revealed in questionnaires, its understanding requires further research (see Table 46). The nature and the specifics of a design task need also being considered before any conclusions are drawn.

The structure of the representation that the participants used as explaining their activity did not coincide with the structure of the actual activity. The students described it as being organised in a linear or hierarchical way. This may be a reflection of metacognitive monitoring and control associated with dominant learning styles, or/and an inherent to the task of completing a questionnaire expectation to construct descriptions that sound logical and plausible. The actual activity was opportunistically organised – a characteristic of design activities that has been observed in empirical design studies (Visser & Hoc, 1990).

Finally, while it was possible to extract some of the information on the Verbal-Imagery dimension, that is to form a general opinion on the students' preferences and strengths, we did not perceive it as suitably justified – the data was few and often ambiguous. It was, therefore, not included in statistical analyses. Similarly, there was a lack of evidence concerning the students' cognitive abilities, with the most common statements denoting difficulties in generating ideas and/or expressing them by sketching. This may be related to poor visual-spatial or ideation abilities, but does not provide enough indication on its own.

Ability factors in introspective statements & questionnaires and academic performance

Correlation analysis was performed to establish how three different accounts of the students learning styles (as derived from LSA assessments, introspective reports, and questionnaires) were related to their cognitive abilities, creativity, and academic performance (Table 46).

Table 46. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiments III/b-V/b

Variable	W	A	I	V	W	A	I	V	W	A	V-S	IV	IF	AP	Cr
Year 1															
Wholistic	1														
Analytic	-0.241	1													
Imagery	0.635*	0.265	1												
Verbal	-0.578	0.582	-0.304	1											
Wholistic	0.865**	-0.091	0.751*	-0.417	1										
Analytic	-0.360	0.871**	0.358	0.530	-0.106	1									
Imagery	0.691*	0.169	0.890**	-0.160	0.848**	0.294	1								
Verbal	-0.474	0.698*	-0.219	0.740*	-0.536	0.482	-0.310	1							
Wholistic	0.878**	-0.164	0.514	-0.572	0.573	-0.379	0.413	-0.206	1						
Analytic	-0.565	0.744*	0.100	0.554	-0.273	0.883**	0.025	0.352	-0.573	1					
Vis-Sp.	0.441	0.296	0.896**	-0.339	0.495	0.373	0.645*	-0.106	0.482	0.197	1				
Id. Ver.	0.344	0.442	0.467	-0.089	0.427	0.343	0.370	0.029	0.401	0.298	0.522	1			
Id. Fig.	0.651*	-0.318	0.707*	-0.648*	0.742*	-0.153	0.667*	-0.767**	0.443	-0.155	0.671*	0.238	1		
Ac. Perf.	0.473	0.582	0.890**	-0.071	0.595	0.555	0.772**	0.081	0.411	0.302	0.873**	0.579	0.509	1	
Creativ.	0.736*	0.278	0.890**	-0.548	0.873**	0.148	0.868**	-0.558	0.501	-0.034	0.752*	0.468	0.856**	0.762*	1
Years 4&5															
Wholistic	1														
Analytic	-0.756*	1													
Imagery	0.877**	-0.479	1												
Verbal	0.120	-0.175	0.000	1											
Wholistic	0.929**	-0.642*	0.913**	0.000	1										
Analytic	-0.619	0.959**	-0.333	-0.130	-0.490	1									
Imagery	0.909**	-0.605	0.953**	-0.120	0.971**	-0.473	1								
Verbal	-0.403	0.280	-0.501	0.801**	-0.499	0.223	-0.618	1							
Wholistic	0.541	-0.163	0.526	0.110	0.599	0.115	0.520	-0.232	1						
Analytic	-0.585	0.688*	-0.513	0.047	-0.581	0.624	-0.630	0.407	-0.278	1					
Vis-Sp.	0.812**	-0.611	0.747*	0.218	0.808**	-0.382	0.733*	-0.325	0.773**	-0.399	1				
Id. Ver.	0.339	-0.429	0.407	0.408	0.334	-0.498	0.354	0.144	-0.251	-0.459	0.170	1			
Id. Fig.	0.364	-0.224	0.639*	0.117	0.572	-0.148	0.613	-0.227	0.221	-0.459	0.344	0.481	1		
Ac. Perf.	0.730*	-0.443	0.693*	0.253	0.578	-0.271	0.567	-0.220	0.542	-0.142	0.829**	0.169	0.089	1	
Creativ.	0.745*	-0.542	0.728*	-0.221	0.753*	-0.345	0.765**	-0.699*	0.693*	-0.498	0.870*	0.049	0.232	0.740*	1

LSA assessments
 Data from introspective statements
 Data from questionnaires

Vis-Sp. / V-S – Visual-Spatial; Id. Ver. / IV – Ideation Verbal; Id. Fig. / IF – Ideation Figurative; Ac. Perf. / AP – Academic Performance; Cr / Creativ. – Creativity

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table 46 indicates a number of common correlations observed in both test groups, although with varying magnitudes of correlation coefficients. Whilst some correlations are only present in either group of subjects. For the first year they include:

1. *Wholistic Learning Style (LSA)* is correlated with *Wholistic Learning Style (Introspective reports)*, *Imagery Learning Style (Introspective reports)*, *Wholistic Learning Style (Questionnaires)*, *Figural Ideation*, and *Creativity*
2. *Analytic Learning Style (LSA)* is correlated with *Analytic Learning Style (Introspective reports)*, *Verbal Learning Style (Introspective reports)*, and *Analytic Learning Style (Questionnaires)*
3. *Imagery Learning Style (LSA)* is correlated with *Wholistic Learning Style (Introspective reports)*, *Imagery Learning Style (Introspective reports)*, *Visual-Spatial abilities*, *Figural Ideation*, *Academic Performance*, and *Creativity*
4. *Verbal Learning Style (LSA)* is correlated with *Verbal Learning Style (Introspective reports)*
5. *Wholistic Learning Style (Retrospective reports)* is correlated with *Imagery Learning Style (Retrospective reports)*, *Figural Ideation*, and *Creativity*
6. *Analytic Learning Style (Introspective reports)* is correlated with *Analytic Learning Style (Questionnaires)*
7. *Imagery (Introspective reports)* is correlated with *Visual-Spatial abilities*, *Figural Ideation*, *Academic Performance*, and *Creativity*

For the fourth and final years they include:

1. *Wholistic Learning Style (LSA)* is correlated with *Wholistic Learning Style (Introspective reports)*, *Imagery Learning Style (Introspective reports)*, *Visual-Spatial abilities*, *Academic Performance*, and *Creativity*
2. *Analytic Learning Style (LSA)* is correlated with *Analytic Learning Style (Introspective reports)*, and *Analytic Learning Style (Questionnaires)*
3. *Imagery Learning Style (LSA)* is correlated with *Wholistic Learning Style (LSA)*, *Imagery Learning Style (Introspective reports)*, *Visual-Spatial abilities*, *Figural Ideation*, *Academic Performance*, and *Creativity*
4. *Verbal Learning Style (LSA)* is correlated with *Verbal Learning Style (Introspective reports)*
5. *Wholistic Learning Style (Introspective reports)* is correlated with *Visual-Spatial abilities*, and *Creativity*
6. *Imagery (Introspective reports)* is correlated with *Visual-Spatial abilities*, and *Creativity*
7. *Wholistic Learning Style (Questionnaires)* is correlated with *Visual-Spatial abilities*, and *Creativity*

6.2.3 Conclusions

This subsection presents a summary of conclusions resulting from the above analysis, concerning introspective reports and questionnaires, and their relation to individual learning styles, cognitive abilities, creativity and academic performance. It does not review the broad range of observations derived from the earlier qualitative and quantitative (comparative and correlation) analyses for the purpose of clarity and conciseness. A summary of all results discussed in Section 6.2 is presented in Chapter 7.

LSA assessments and Introspective reports. Correlation analysis performed for the first, and fourth and final year participants, allowed examining relationships between their reports of

proto- and metacognition and individual learning styles as assessed by LSA. The results suggested a strong link between the two measures of Wholistic learning style and the preference for wholistic problem-solving on design tasks, present in both groups of participants. A similar association was discovered between the two accounts concerning the Imagery dimension. Another consistent across the sample correlation was found between the Analytic learning style (as assessed by LSA) and the students' reports of experienced (preferred) analytic problem-solving and macro approaches to design tasks. A similar link is present between the two accounts concerning the Verbal dimension. There is also a correlation between the measures of Analytic learning style and the preference for verbal processing for the first year students.

Wholistic learning style was found to be correlated with Imagery learning style within and between LSA assessments and introspective reports, and these correlations are present in both groups of participants, suggesting that there are more wholistic learners among imagers than there are analytical learners. The magnitude of correlation coefficient is lower for the first year students, which, in part, is due to the strength of their learning styles preferences (the fourth and final year students have more developed, i.e. strong, styles). The wholistic-imagery correlation is in agreement with research concerning visual-spatial learners who are inclined to think wholistically rather than in an analytic sequential fashion (Silverman, 1998).

The results indicate consistent correlations between proto- and metacognitive reports and individual learning styles as assessed by LSA. Their nature, however, is likely to be complex. The association between LSA assessments and introspection could be affected by varying degrees of self-awareness of individual cognitive processing (i.e. proto- and metacognition), while the quality and quantity of introspective claims made could be influenced by individual learning styles, specifics of the design task, and, possibly, other factors.

LSA assessments, Introspective reports, and Questionnaires. The link between the students' summaries of their design processes, learning styles as assessed by the LSA, and self-reports was confirmed on both Analytic (significant correlations) and Wholistic dimensions (significant and moderate correlations) for the first year students. The situation with the fourth and final year participants is similar, but there is only one strong (and the rest are moderate) association between the Analytic mode (LSA) and the data from questionnaires. The reasons are likely to be related to individual learning style profiles. As the students' dominant and secondary styles varied in terms of the strengths of preferences, and each individual had a unique repertoire of learning styles, some of the versatile subjects produced reports that contained features that could be associated with each pole of W-A dimension with (almost) equal strength. Other reasons for differences in correlation coefficients could be multiple and interacting, including the perceived (by the students) need to organise their reports in a structured and linear way characteristic of analytical reasoning. This means that the nature of the association between the students' preferences for wholistic or analytic problem-solving and the general, higher-level organisation of their design processes revealed in questionnaires, requires further research.

LSA assessments, Introspective reports, and cognitive abilities. A range of links between the two learning styles accounts, creativity, academic performance and cognitive abilities was established; it indicated differences and similarities within and between the sample.

Visual-spatial ability was correlated with Imagery learning style both in LSA assessments, and in introspective self-reports. It was confirmed for both groups of the participants. The association may be supported by the earlier studies that have argued for a visual style to be beneficial in a range of cognitive tasks, including psychometric tests of visualisation and ideation (Vicente, *et al.*, 1987; Sein & Bostrom, 1989; Schofield & Kirby, 1994). It may also indicate that Imagery draws on high visual-spatial abilities. Spatial visualisation is also correlated with Wholistic learning style, but the magnitudes of correlation coefficients vary across the sample. They are significant for the fourth and final year students and weak for the first year participants. The reasons for the less strong association for the latter group are not entirely clear. Whereas the link between the style and the ability is in agreement with research concerning visual-spatial learners who are inclined to think wholistically (Silverman, 1998).

There are no significant correlations between the measures of verbal ideation and any of the four learning styles from both accounts, i.e. LSA assessments and introspective reports.

The levels of figural ideation ability (*IF*) of the first year students are correlated with Wholistic and Imagery learning styles and creativity. The magnitudes of correlation coefficients are significant on the measures of individual learning styles (LSA) as well as on self-reports. The results suggest that developed ideation is important for design creativity in the first year of education, and that both learning styles are beneficial for, or support ideation. It may also mean that Wholistic learning style draws on advanced ideation abilities.

A similar association was discovered between the measures of figural ideations and two accounts of the Imagery dimension for the fourth and final year students. It is strong when it concerns learning styles as assessed by LSA, and is moderate when it comes to self-reports. The magnitudes of correlation coefficients are weak and moderate on the Wholistic dimension. The association of figural idea-production with creativity is also low.

The sources of difference concerning the *IF* measure are not entirely clear. The reasons may be related to the sample size, higher levels of the learning styles' development among the senior students, or the growing complexity of design tasks. Tasks used in ability tests are relatively simple, and may be more useful for the first year students as their designs are typically concerned with form, composition and aesthetics. Whereas most projects in architecture are multifaceted complex activities, where ideation involves working with many different constraints to accommodate a broad range of specifications. There, idea generation can not rely upon one type of reasoning (wholistic or analytic) and may also require support of the developed imagery/visual thinking due to the inherently visual nature of design tasks. Similarly, the complexity of design tasks may explain why there is no correlation between ideation abilities and overall academic performance in both student groups.

A further analysis is necessary to confirm (or refute) these results as the strategy choice on psychometric tests and other cognitive tasks could be influenced, limited, or unrelated to aptitude or styles of problem solving, while the effectiveness of the implemented strategy could be limited by aptitude or style (Carroll, 1993).

LSA assessments, Introspective reports, Academic performance, and Creativity. This study also sought to determine whether the results of correlation analyses would agree with the domain assumptions concerning the Wholist-Analytic and the Visual-Imagery dichotomies suggesting that designing is successful when the process is a wholistic experience (McCormick *et al*, 1993). And that the Imagers make the best designers, as visualisation has been shown to be central to the generation and development of ideas (Glegg, 1986).

The Verbal-Imagery dimension is in conformity with these studies when it comes to the association with creativity. It was confirmed for both groups of students. The magnitudes of correlation coefficients are significant relative of the measures of individual learning styles (LSA) as well as of self-reports. The situation with academic performance is similar. For the first year students, the correlations are significant both in LSA reports and in proto- and metacognitive statements. The magnitudes of correlation coefficients are also high for the fourth and final year students when it concerns LSA assessments, and are moderate relative of the introspective self-reports.

The association between the two accounts of the Wholistic learning style and creativity was confirmed for both groups of participants. The situation with academic performance is different as the correlation is consistent only for the fourth and final year students; it is strong when it concerns LSA assessments and moderate relative of introspective self-reports. For the first year participants, the link is weak on the measure of individual learning styles (LSA) and moderate on proto- and metacognitive statements. It is not fully evident why Wholistic learning style is not associated with academic performance in the first year group (although it is associated with creativity, which, in its turn, is correlated with academic performance). It is possible that, according to the model proposed by Riding and Sadler-Smith (1992), imagery is able to some extent compensate for the absence of wholism for an Analytic-Imager, as the individual might be able to gain an overall perspective through the application of imagery. Similarly, the

Wholist-Verbal learner may be able to draw on his or her verbal thinking to help overcome any difficulties arising from their lesser level of analytic processing.

It is also possible that the direction of the first year students' performance assessments is inclined towards their general strengths in acquiring new knowledge and skills. And, as the design tasks draw on a wide range of qualities, in addition to a considerable body of technical and other knowledge and skills, both learning styles may be viewed as important in academic achievement. It is still possible for the students to develop a broader repertoire of learning styles via the course of study, and educators, therefore, may give equal preferences to both Wholistic and Analytic learners as they tend to succeed in different aspects of design tasks. Whereas in the later years, it becomes essential to exhibit traits associated with the fields of design and architecture, whereas advanced learning styles may also become more important as the level of instruction increases (Holtzman, *et al.*, 1979).

The stronger association between metacognition, academic performance, and creativity of the fourth and final year students is perhaps related to the studies of students' metacognitive strategies indicating that metacognitive capabilities such as self-regulation are keys to the development of appropriate learning strategies (Rojas-Drummond, *et al*, 1998; Schraw, 2001). That is, while learning styles are necessary for performing a task, metacognition is critical to understanding how the task is performed, and self-regulation helps in a more efficient conscious choice of learning strategies.

In terms of the strengths of predictive validity the above results indicate that, confirmed by both learning styles accounts, for the first year students, cognitive abilities are more important, while in the later years learning styles gain more importance. The differences between the magnitudes of correlations, however, are not significant. Further research with a bigger sample is required to achieve a better understanding of the observed situation. It is also understood that when considering interrelationships between individual qualities and academic performance one cannot ignore the importance of such factors as a learner's intelligence; prior knowledge of the subject domain; level of motivation; anxiety; self-confidence; and the amount of learner control offered (Valley, 1997).

6.3 External and Internal Representations as a Process

Experiment IV/b(process) is concerned with the process of individual problem solving. The method of protocol analysis is used as a means of revealing and elucidating cognitive processing that took place during sketching and thinking. It examines how design contexts and intentions are embedded in design drawings along with analysing designers' reasoning reflected in retrospective verbalizations. The ultimate purpose of this examination is providing the basis for inter-relations and correlations between the acquired data, and other aspects of the *input*, the *process* and the *product* of designing, obtained through all administered experiments.

On a more detailed level, this part of the research aims at: **(1)** establishing a coding scheme that enables the distinction between (a) task-specific aspects of problem-solving and global approaches to problem situations, and (b) manifestations of learning styles and cognitive abilities; **(2)** extracting data on individual design processes that can be related to the differences in design abilities; **(3)** extracting data on individual design abilities and exploring relationships and correlations among them, including (a) variability in learning styles and cognitive abilities related to gender and ethnic origin, and (b) differences/similarities in the learning styles and cognitive abilities of the first and fourth-final years students; and **(4)** exploring a range of links between the measures of academic performance, creativity, learning styles, cognitive abilities, and some of the design process characteristics.

The above parameters are similar to those analysed in Experiments I/b-III/b, and IV/b (object). The data from the current experiment is discussed in the following three subsections, whereas Subsection 6.3.3 also presents an extended multivariate data analysis involving Experiments I/b-V/b.

6.3.1 Method and Preliminary Analysis

In Experiment IV/b(process), we propose that certain qualitative and quantitative characteristics of diagrams, sketches and annotations *being generated*, as well as of retrospective reports and questionnaires denoting the *progression* of problem solving, could be associated with the differences in individual learning styles and cognitive abilities. The analysis in this subsection is called preliminary as it describes a general broad-spectrum range of differences in problem-solving. It does not separate internal and external representations as neither internal reasoning nor mental images could be observed directly, and the acquired data was either inferred or (re)constructed in retrospect. While the inference of context and intention from a design drawing was used to reveal the relationship of sketching to design thinking.

The preliminary analysis is followed by the more goal-specific exploration of retrospective statements, design drawings and annotations treated separately (Subsections 6.3.2 and 6.3.3). After which we proceed to establishing a range of links between the data from psychometric experiments and the collected accounts from protocol sessions – by correlating the observed approaches, styles and strategies in problem solving with the differences in ability factors.

The method can be summarised as a sequence of 5 main steps: (1) develop a coding scheme; (2) extract activity episodes; (3) transcribe and segment episodes; (4) code episodes (generate trace); and (5) visualize/perform analyses on trace.

Coding scheme

The approach presented here involves the development of a coding scheme prior and during the analysis. It differs from the standard approaches in introduction of the overarching scheme based on the theories of learning styles and human abilities, and the drawn from them set of codes, in addition to the previously existing design-dependent coding categories.

Many recent protocol studies utilise a combination of coding categories that are derived from real data collected in earlier studies, and categories that are derived from theories of design. Similarly, our coding scheme originates from the process oriented scheme proposed by Gero and McNeill (1998) which has been used extensively in design studies. From the onset it was clear that some of its categories fit well with the purpose of this research. Their approach could facilitate the exploration of correlations between the formerly classified micro and macro strategies observed during the performance on design tasks, and the measures of individual styles and abilities. For example, in learning theories, Wholist and Analytic personalities are different in whether they primarily perceive wholes or parts of a problem-solving task, this fits well with an idea of dividing the problem domain into a number of levels of abstraction. According to Gero and McNeill, coding registers designer's attention shifts from high-level overall views of the problem down to consideration of low-level details of the problem, and this dimension is derived from the way in which the designer approaches the problem.

However, it appeared that many other formerly used categories were either indirectly or unrelated to the subject of this research, or were imprecise in their association with the design ability properties. Among the first group, is the function-behaviour-structure that needs to be further defined and/or broken down to establish what could be its link with individual cognitive abilities and learning styles. The second group includes categories similar to analysis-synthesis-evaluation. When performing analysis, the designer may analyse a system as a whole, several details in parallel, or one detail at a time. Similarly, synthesis in design is not always a wholistic experience as solutions can be synthesised in a complex hierarchical (heterarchical) all-at-once, as well as in a more analytical linear one-by-one manner. While evaluation could be done in an step-by-step, piece by piece fashion, or it could be characterised by parallel processing, considering many details at once, and preserving a global overview of the problem (e.g. *wholistic assessment* as suggested by Löwgren and Stolterman, 1998).

Thus, the process of refining the coding scheme in search for additional and more relevant categories, made us turn to the learning styles and the human ability theories. They suggested a framework that is both model- and data-driven: in that the protocols are the source of the

repertoire, while the theories we chose are used to add further structure to the repertoire. The final scheme incorporates a number of existing categories along with a new a new set of codes related to individual design abilities (Table 47).

Table 47. The coding scheme: Experiment IV/b(process)

Preliminary analysis			
Preferred models of designing			
Graphic (Gr) Sketching, diagramming, overtracing, doodling, drawing invisible lines, hatching, drafting, colouring, etc.	Sentential (St) Annotating objects and concepts, recording ideas, clarifying ideas, labelling spaces, writing down dimension markers, etc	Visual / Imagery (Im) Visualising, 'walking around, mentally scanning, rotating transforming, visual ideation, visual analysis, synthesis & evaluation, etc	Verbal (Ver) Reading, inner dialogue, making verbal connections & associations, verbal ideation, verbal analysis, synthesis & evaluation, etc
Plus combinatory codes are ascribed when two or more processes are referred to or implied in a single episode, i.e. Imagery-Verbal (Im-Ver); Imagery-Graphic (Im-Gr); Imagery-Sentential (Im-St); Verbal-Graphic (Ver-Gr); Verbal-Sentential (Ver-St)			
Initial approach / macro level			
Wholistic (IA Wh)	Analytic (IA An)	Visual / Imagery (IA I)	Verbal (IA V)
Determines and analyses the initial designer's approach that can be viewed in the longer term with the designer executing a plan or a macro strategy. It is associated with individual learning styles distinguishable from the more spontaneous aspects of problem-solving. To identify it, the relevant statements are singled out and classified in accordance with characteristics of the four learning styles as suggested by learning style theories (summarised in Tables 38-39).			
Prevailing approach / macro level			
Wholistic (PA Wh)	Analytic (PA An)	Visual / Imagery (PA I)	Verbal (PA V)
Determines and analyses the prevailing designer's approach that can be viewed in the longer term with the designer executing a plan or a macro strategy. To identify it, the relevant statements are singled out and classified in accordance with characteristics of the four learning styles as suggested by learning style theories (summarised in Tables 38-39).The resulting data considers frequency (overall numbers) and duration (cumulative) of the relevant design activities.			
Structure of design processes / macro level			
Wholistic	Analytic	Imagery	Verbal
Several design process models were selected and classified in accordance with learning style theories as being representative of a particular learning style. Then, the general structure of each design session was mapped onto one or more of these models to determine if there were observable similarities.			
Analysis of external and internal representations			
Strategies in problem-solving / second grade level			
Development of external representations		Development of internal representations	
Transformational balance of sketches: Horizontal Sketch Development (HSD), Vertical Sketch Development (VSD)	Cumulative balance of idea annotations: Vertical Idea-Annotations (IA(V)) Horizontal Idea-Annotations (IA(h))	Wholistic (St Wh), Analytic (St An), Imagery (St I) and Verbal (St V) strategies Visual-spatial (St V-S) and Ideational (St Id) strategies	
Determines and analyses task-specific strategies suggested to be associated with the four learning styles, visual-spatial, and ideational abilities. To identify them, the relevant statements are singled out and classified in accordance with characteristics of the four learning styles as suggested by learning style theories (summarised in Tables 38-39), and visual-spatial and ideational abilities, as described by human ability theories. The resulting data considers frequency (overall numbers) of the relevant design activities.			
Strategies in problem-solving / third grade level			
Visual-spatial and ideational abilities			
Differences between the three levels of cognitive activities are identified to establish which of the relevant data remained unclassified and, therefore, uncoded. The issues encountered are indicated and elucidated.			

We believe that the multiple measures suggested adequately reflect the complexity of the protocol data without distorting it. However, they are not intended as a complete list of categories that might be used to describe the students' design processes, or, equally, as a list including all features that could be associated with ability factors addressed in this study. They suggest a framework that can be improved and enhanced in future studies.

We also realise, that concerned with this study's agenda, and having departed from many traditional coding categories, we face the issue of a lack of comparability with other protocol studies. However, application of traditional codes generated results that were inconclusive.

Extraction of activity episodes

The activity episodes that contained claim-relevant behaviour were isolated. First, we started out by reviewing the notes and protocols in order to home in on the activity of interest. Then, we reviewed the protocols one or more times to become familiar with them.

Transcribing and segmentation

Retrospective verbalisations were first transcribed, then cross-referenced with the design activities observed on videotapes, as well as with the graphical and sentential representations produced during design sessions. The transcripts were then segmented into units of text and time-stamped in preparation for coding (Appendix C contains an example of the final segmented transcript referenced against events on the screen). The method used focuses on designer actions or intentions, and not time units, verbalisation events, or syntactic markers. The designer's intention is interpreted for each segment, where a change in intention flags the start of a new segment. This suggests there may be more than one code in one segment, as subcategories do not affect segmentation.

Table 48. Segmentation reliability: Years 1 and 4&5, Experiment IV/b(process)

Year 1								Years 4 & 5							
Segmentation 1 & final %				Segmentation 2 & final %				Segmentation 1 & final %				Segmentation 2 & final %			
Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
78.12	91.02	86.15	3.91	75.09	91.02	85.65	3.84	79.03	91.12	85.15	4.10	75.04	91.00	84.80	3.96
Agreement between segmentation / consensus results %															
Min		Max		Mean		SD		Min		Max		Mean		SD	
67.04		88.07		80.85		6.76		66.35		88.13		79.75		7.24	

Segmentation was done by one coder twice, at the rate of • 10 days apart, checked for reliability, after which any inconsistencies were resolved. Table 48 shows the levels of agreement expressed as a percentage of total segmented episodes. Agreement was checked between the coder's self-arbitrated protocols, and between each coded protocol and the final arbitrated protocol. Results are aggregated over the three dimensions for the two groups of students. The agreement between codings is generally high probably due to the nature of segmentation.

Table 49. Data on segments, their numbers and length: Years 1 and 4&5, Experiment IV/b(process)

Year 1								Years 4 & 5							
N of segments				Length in seconds				N of segments				Length in seconds			
Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
80.00	201.00	130.70	43.87	5.00	310.00	21.52	25.71	92.00	130.00	103.80	11.82	5.00	120.00	20.96	16.18

Table 49 contains descriptive statistics concerning the number and the length of the segments calculated for the two groups of students. It indicates how subjects move through design sessions marked by the change in their intentions and actions defined as episodes. An episode usually entails one type of observed activity, including: reading, annotating, calculating, thinking, sketching, etc. But it can involve one or more cognitive processes that could not be separated due to their intermingled nature. For example, one rarely reads brief without trying to analyse it, or, in many cases, visualising the constraints. We also divided one type of activity into two or more episodes when retrospective verbalisations or/and actions on the screen suggested so. Including the movement between sketches, starting a new sketch, horizontal transformations to a sketch, change in the type of writing (i.e. moving from object-annotations to concept-annotations), and so on. We looked at both the total number of episodes, and the

episode rate (length and number of episodes per minute). As Table 49 indicates the first year subjects averaged 131 movements between the episodes during the total process. This resulted in a mean rate of 2.6 episodes per minute. The fourth and final year students had an average rate of 2.1 episodes per minute that led to 104 movements between design episodes in a session. On the outset, it may seem that there is much similarity between the two groups of subjects. However, a broad variation in individual design processes (first year SD 43.87; 25.71 and fourth & final years SD 11.83; 16.18) indicates a more complex picture (Figure 13).

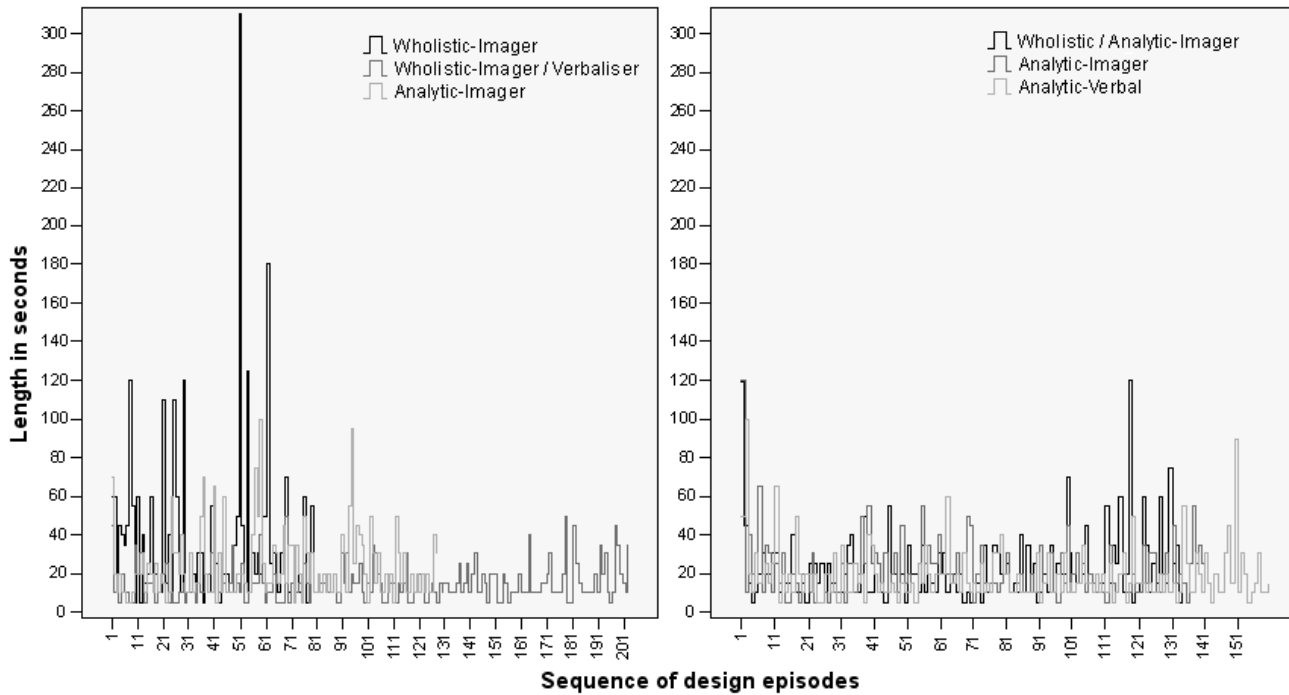


Figure 13. Structure of design processes by intention-based episodes: Year 1 (left), Years 4&5 (right)

Among the first year students, some moved almost frantically between the episodes, and modes of designing, with an average rate of 5.5 episodes per minute. Others tended to concentrate on one activity at a time for as long as 3 or more minutes (i.e. 0.3 episodes per minute). While the rest were much similar to the final year students, but with a slightly lower average episode rate (Figure 13). The reason for this could be a better integrated design process of the more experienced students, which is discussed further in this subsection. Another observation concerns the differences in learning styles. Analytical students in both groups moved more often between the episodes (which, correspondingly, were shorter), that is above the mean for each group. The explanation may be related to the nature of the issues tackled, as well as to the processes the analytics adopted in addressing them. They tended to break them down into small(er) units and deal with them in a step-by-step one-at-a-time fashion.

Coding episodes

To achieve a coded sequence of events verbal protocols were cross-referenced with design activities observed on video recordings, as well as with notes and sketches produced during design sessions. Each segment was coded twice with respect to the variables as suggested by the coding scheme (Table 47). That is, two codings of each individual protocol session were performed independently, at the rate of • 10 days apart. The codes were then compared, inconsistencies resolved, and the consensus results used for successive analyses.

Table 50 shows the levels of agreement expressed as a percentage of total coding events. Agreement was checked between the coder's self-arbitrated protocols, and between each coded protocol and the final arbitrated protocol. Results are aggregated over the three dimensions for the two groups of students. Agreement between codings is generally high, probably due to the mostly unambiguous nature of the codes used.

Table 50. Inter-code reliability (agreement between codings): Experiment IV/b(process)

Year 1								Years 4 & 5							
Coding 1 & final %				Coding 2 & final %				Coding 1 and final				Coding 2 and final			
Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
73.05	91.01	84.20	4.66	74.08	90.01	83.25	4.55	75.04	90.01	84.70	4.14	77.11	90.03	84.20	3.72
Agreement between codings / consensus results %															
Min		Max		Mean		SD		Min		Max		Mean		SD	
68.12		87.21		78.55		4.52		69.42		86.05		77.85		5.11	

Demography and quality of reports

There was no discernible difference in the quality of responses received according to the country from which the respondent originated, or their gender. That is, in what concerned the ability, good or poor, to articulate the experienced cognitive processing. The main distinction pertained to the year of study, with the fourth and final year students being more eloquent, more aware of their learning and problem solving behaviour, as well as more structured with their responses. Differences in ability, personality and other dimensions are likely to be accountable for the uniqueness of each individual introspection.

Modes of designing

This study distinguishes between design activity statements indicating subjects' *modes of designing*. Mode of designing refers to the nature of design activity associated with each protocol statement, i.e. external – graphical and sentential, or internal, visual and verbal. Thus, in the coding scheme, modes of designing are divided into *internal-visual* and *internal-verbal* (revealed through retrospective verbalisations supported by video records, introspection and sketches), and *external-visual* and *external-verbal/sentential* (identified in produced design drawings and annotations, and referenced against intro- and retrospective verbalisations). For example, *external-sentential* activities included *idea-annotating*, *concept-annotating*, and *object-annotating*, whilst *internal-visual* activities involved *visualisation*, *mental rotation*, *mental scanning*, etc. Consistent with this classification all reported and observed activities were referred to either mode, including: analysing, brainstorming/ideation, calculating, choosing, deciding, decomposing, defining, developing, documenting, evaluating, integrating, judging, justifying, observing, reading, recording, reflecting, searching, selecting, specifying, structuring, synthesising, testing, unifying, validating, verifying, and writing.

It is recognized that in addition to processes involved in the reasoning that operate more or less exclusively within the realm of external representations (e.g. in diagrammatic reasoning systems), and those that operate on mental representations (such as in mental image inspection), there are those that involve both mental and external representations (e.g. when reading an information item from a sketch and then using it in mental reasoning, etc). Working with design task specifications or other types of information presented in non-graphic forms triggers series of 'to' and 'fro' translations of this data, indicating a co-existence of both visual and verbal processing interconverted through neural linkages. While the externalisation of non-verbal (pictorial) ideas may be done by the means of written notations. Or, as was clear from the students' verbalisations, who referred to both visual and verbal reasoning in one statement, related to the same cognitive event or triggered by the same process: '*I'm thinking there about how I'm walking around the house and what I can do about the rooms... I sort of do that a lot' or '*I'm trying to see what's the best way of making them feel at home... because when you design a house it has to have something unique about it, but it has to suit everyone*'.*

Clearly, in order to explore the complexity of design thinking one shall focus on the above processes and interactions among them. However, researching the interplay between mental imagery, sketching, and verbal reasoning is a demanding task to undertake, that exceeds the scope of the current research. Alternatively, we introduced five combinations of the above four

modes into the data extraction process (Table 51) to include all observed activities, without further concentrating on their nature, sequence of occurrence, causality, and interactions.

Table 51. Modes of designing in problem solving: Experiment IV/b(process)

Code*	Retrospective statement/s	Observed action/s **
Gr	Yeah, first thing I do was, yeah, I drew just a diagram... site, I do that... site retracing	Draws a blob to (later) do site analysis, re-draws the site in a bigger scale with a ruler.
	I decided to finish drawing these bits to do it properly	Refines/decorates earlier sketches.
	After that I'm going over to doing a section because I was interested to see how it looks inside... I'm just translating highlights from the plan	Draws projection lines from the plan to build a diagram of the section.
St***	Yeah, making some notes... the measurements, the height, restrictions, requirements... and then I read the note about it	Checks the brief and annotates accordingly; reads her notes.
	I wrote down all the names of the rooms that were required, so I can just say, kinda scratch them off, every time I put them somewhere. I just do it.	Reads the brief and makes a list of required spaces on the drawing sheet.
Im	Yeah, I was imagining it as I walk, I walk into it, look around	Detached look at the circulation diagram
	I'm thinking of the form here, kinda trying to let it evolve a bit, like I see it in my head but can't quite capture it yet	Sits with his eyes closed and moves hands as with modelling.
Ver	And then I looked at the brief again to check with the requirements... and I say to myself, okay I've done that too	Reads the brief, goes through requirements and ticks them out.
	Im just thinking about the requirements here, trying to structure them in my head... like what's more important	Goes through the brief. Makes a 'priority' list of rooms by underlying and numbering them
Ver-Im Im-Ver	The idea just popped out, a sculpture garden is organic, so the whole house can have an organic form... so then I started to think about it more, visualise it	Thinks before proceeding with sketching small shapes in 3D.
	Well, I just drew all these blocks and I placed all the different rooms from the brief, and now I'm looking at them	Refers to thinking about how to convert an object annotated diagram into a plan
Im-Gr Gr-Im	Well, I drew it, I just started, then I imagined and I drew as I would imagine... then I checked it and it changed in my head	Horizontal & vertical plan transformations
	I'm imagining it 3D, but I was also looking down on it [floor plan and section] to get the other dimension of the site	Sketches a 3D view from a plan and a section.
Im-St St-Im	This is where I started to put down how this room is gonna look like, where are the doorways, the entry, how its gonna be going up	Notes down concept and object annotations.
	I saw it in my head and I'm just writing it down as I see it... and then I read it later and started to think about it again, like how the shape will look	Annotates 'will look better more fluid', Later comes back to the sketch and starts thinking prior to refining a shape by sketching.
Ver-Gr	I had this very strong idea of the house to be ordinary, so I wanted the front to be similar to all the other houses on the road and that it had this very ordinary street type frontage	Wrote down 'ordinary look'. Checked with the brief, then proceeded to drawing the facade by simple 'decorating boxes.'
Ver-St	I'm just writing again... what rooms are needed... then I scratched that out because... I just thought that it was very unclear; I didn't want to use the entire space at first	Writes down a list of all spaces next to a blank outline of the site. Then crosses some out to move them next to another outline.

* Gr – Graphic (External-Visual); St – Sentential (External-Verbal); Im – Imagery (Internal-Visual); Ver – Verbal (Internal-Verbal); Im-Ver – Imagery-Verbal; Im-Gr – Imagery-Graphic; Im-St – Imagery-Sentential; Ver-Gr – Verbal-Graphic; Ver-St – Verbal-Sentential

** Video records and sketches were supported by introspective statements to clarify the nature of observed processes

*** Sentential (external verbal activities) activities are likely to be interwoven with reading comprehension and other internal verbal activities, we treat them as a single process to distinguish from the more complex verbal-sentential activities linked to idea-production

Table 51 is supported by the descriptions of observed actions and introspective statements – to elucidate the basis for coding. Rather than providing an excerpt from one of the analysed protocols, several examples are given as an illustration of the range of extracted statements we considered as relevant to either of the nine codes.

The data, resulting from the extraction process, was then converted into the quantifiable format by estimating (1) the number of statements related to each mode of designing, and (2) the length of reported/observed activities. In subsequent analyses, the second aspect generated more meaningful results; it was measured by analysing how each student spent his/her time in the design process, by summing up the total coded time from when the subject first reads the problem statement to when the subject notes that he or she is finished.

Descriptive statistics

Descriptive statistics for the variables analysed in this part of the experiment is presented for each test group split by gender in Table 52.

Table 52. Distribution characteristics for modes of designing by year and gender, Experiment IV/b

Mode*	Year 1						Years 4&5					
	Length in seconds											
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Gr	220.00	450.00	326.00	97.62	336.00	92.04	190.00	420.00	294.00	103.59	314.00	103.41
	190.00	420.00	346.00	96.33			210.00	450.00	334.00	111.04		
St	100.00	210.00	162.00	43.24	146.00	43.51	85.00	170.00	121.00	31.70	125.50	27.53
	80.00	190.00	130.00	41.83			90.00	150.00	130.00	25.50		
Im	230.00	470.00	314.00	91.81	321.00	96.08	220.00	450.00	304.00	90.99	280.00	90.92
	230.00	490.00	328.00	110.54			150.00	390.00	256.00	94.23		
Ver	410.00	570.00	488.00	59.33	460.00	85.77	310.00	600.00	398.00	120.91	415.00	109.68
	320.00	590.00	432.00	105.21			270.00	550.00	432.00	108.26		
Im-Ver	590.00	750.00	638.00	64.58	679.00	92.43	670.00	980.00	791.80	128.94	822.90	128.97
	600.00	820.00	720.00	104.16			700.00	990.00	854.00	135.57		
Im-Gr	430.00	530.00	490.00	40.62	511.00	93.51	390.00	900.00	680.00	190.13	626.00	194.61
	390.00	670.00	532.00	130.08			400.00	870.00	572.00	204.38		
Im-St	190.00	320.00	282.00	53.57	259.00	70.62	120.00	240.00	176.00	55.95	192.00	67.13
	90.00	300.00	236.00	83.83			100.00	300.00	208.00	79.81		
Ver-Gr	100.00	210.00	144.00	40.99	149.00	28.85	110.00	160.00	146.00	20.75	162.00	44.67
	140.00	170.00	154.00	11.40			100.00	250.00	178.00	58.48		
Ver-St	140.00	220.00	184.00	32.09	169.00	49.99	80.00	250.00	152.00	61.81	146.00	49.49
	90.00	250.00	154.00	63.48			90.00	200.00	140.00	40.00		

Females
 Males
 Group results

* Gr – Graphic (External-Visual); St – Sentential (External-Verbal); Im – Imagery (Internal-Visual); Ver – Verbal (Internal-Verbal); Im-Ver – Imagery-Verbal; Im-Gr – Imagery-Graphic; Im-St – Imagery-Sentential; Ver-Gr – Verbal-Graphic; Ver-St – Verbal-Sentential

Comparative analysis

Comparative analysis between the first, and fourth and final year students allows examining the participants' preferences for reasoning and presenting information (Figures 15, 16).

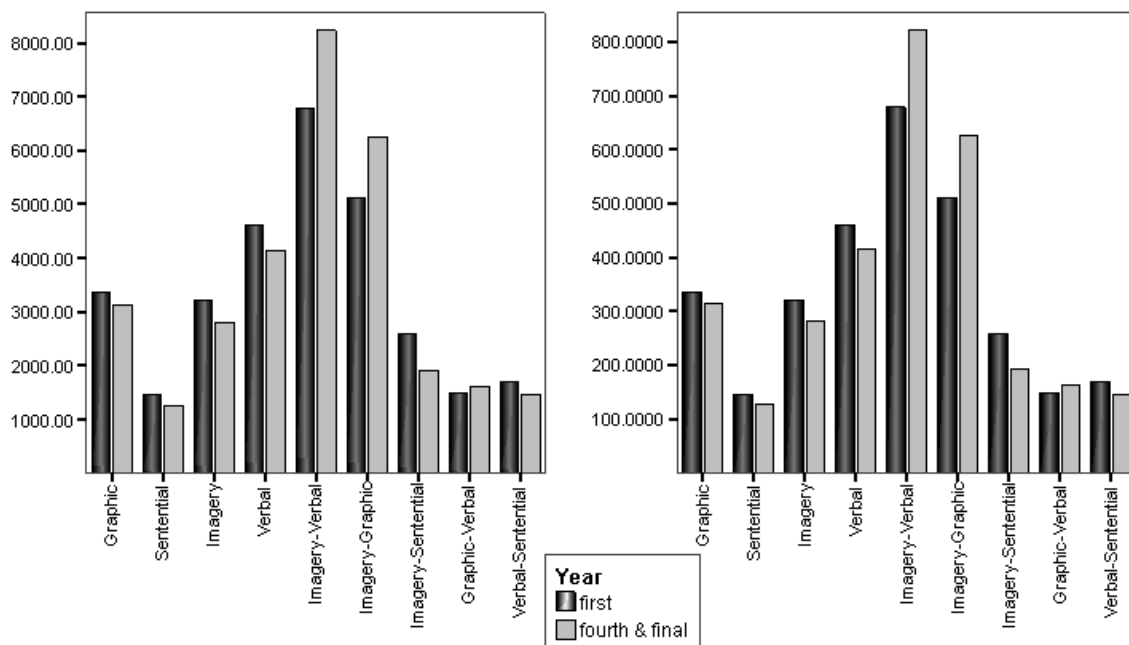


Figure 14. Modes of designing by years of study: Sum (left) and Mean (right)

Left graph of Figure 14 demonstrates relations between the cumulative lengths of different modes of designing (i.e. sums of the total length of each mode) summarised for all design sessions, split by the two groups of subjects. Right graph shows the mean values of each mode of designing (i.e. mean length in seconds) estimated for both group of subjects.

It is clear that there are similarities as well as differences within and between the sample. Both groups of students have spent the longest proportion of time on problem-solving that integrates two types of processing: (1) combining internal imagery and external pictorial-diagrammatic reasoning (*imagery-graphic* mode); and (2) combining internal imagery and internal verbal processing (*imagery-verbal* mode). That is, approximately 20% and 25% of the protocol session duration. They spent the shortest proportion of time in *sentential*, *verbal-graphic*²¹, and *verbal-sentential* modes of designing, each not exceeding 5% of the session duration. More time was spent in the *imagery-sentential* mode, i.e. • 8%. And still longer and comparable time was spent in the *graphic* and *imagery* modes (i.e. about 10% in each).

Different from the first year designers, the fourth and final year architects allocated more of their time to the *imagery-verbal*, *imagery-graphic* and *graphic-verbal* modes. Whereas the designers spent more time in the *imagery*, *verbal* and *imagery-sentential* modes. A comparable time was spent in the *graphic*, *sentential*, *verbal-sentential* (favouring the first year students) and *graphic-verbal* (favouring the fourth and final year students) modes. This suggests that the architecture students may prefer, or are more familiar with/capable of, integrated design processes than are the design students.

Further to this comparison, Figure 15 demonstrates relations between the percentages of different modes of designing (i.e. their frequencies relative of the protocol session duration) based on the group (i.e. year 1 and years 4&5) mean values of their cumulative (for each individual session) lengths in seconds.

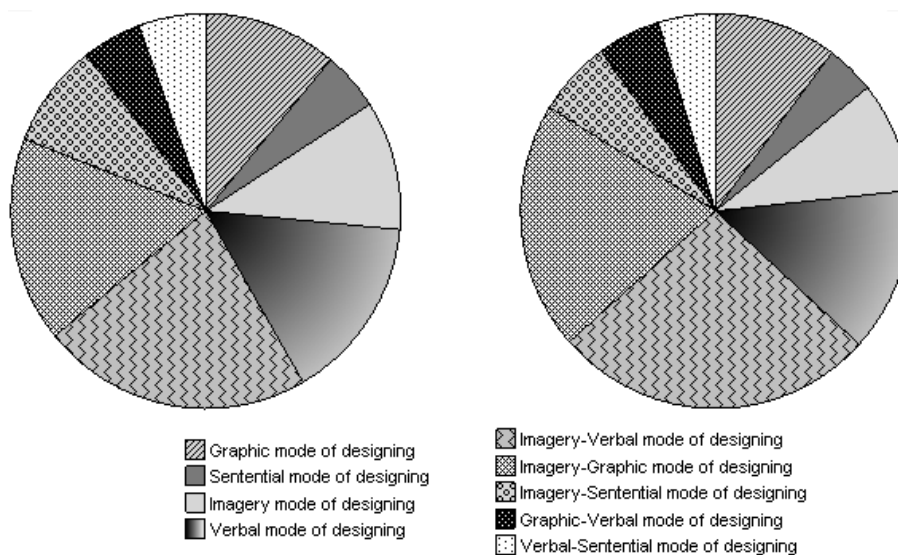


Figure 15. Frequencies of modes of designing: Year 1 (left), Years 4&5 (right)

The suggestion of the more integrated design processes of the fourth and final year students may be supported by the observation that the first year students, on average, moved more frequently between design episodes while trying to tackle a small(er) number or/and of less complex issues at a time (Table 49). They were less capable of using sketching as the efficient means of problem-solving. When addressing complex design concerns, they resorted to the familiar mode of expression – writing, more (particularly duration-wise) than did the senior students.

²¹ *Verbal-graphic* (less *graphic-verbal*) mode is characteristic of ‘decorating boxes’ triggered by a verbal idea (i.e. sketching/drawing in the realm of paper only) or retrieving and sketching simple shapes/objects from the memory (furniture, vegetation, etc) also triggered by verbal processing.

Initial approaches to problem-solving

Table 53 contains sample excerpts from protocol sessions describing the beginnings of twelve individual design sessions, organised in accordance with the two superordinate learning styles.²²

Table 53. Initial approaches to problem solving: Experiment IV/b(process)

Year 1		Years 4 & 5	
Wholists	Analytics	Wholists	Analytics
I started with retracing the plan, then... the first thing I drew was this line across the site, I diagonal line I kind of took that and made a roof plan and from this roof plan I then played around with different levels and it was this, I was drawing this deck because in my mind I had this, if I was standing here and seeing that I want this deck kind of hovering out but wasn't really hovering but breaking through this line and then I drew this little perspective...	I like to understand what is required of me, especially as a designer... what are the pre-requisites of my client... what I'm actually working towards... Basically I like to start off with doing site analysis. I like to break up the problem... into easier, manageable units, then I like to write down what I've seen, what I would think would be appropriate in my design or what are the key elements that I can add to my design... This is what I'm doing here. It's like breaking it down and structuring...	Well I was reading the brief, got some ideas, kinda like, contact with nature & close to beauty... So then... I looked at the site. I looked at the site for a while. I just sat there looking at it. Trying to think, trying to see it, because I decided that I'm going to get inspired by ...I mean you have to have a starting point. So I had 2 starting points. One was, from the program & from the idea of arts & how that would influence the design. And the other one would come from what's happening on the site.	I'm starting with the requirements, looking at the site plan given... I'm trying to work out this scale that site boundary and site area given...The next one was basically looking at the site. I jot down the characteristics to remind myself looking at the site in a larger context when I actually drew the constraints and the opportunities such as the north outlook the reserve the street, basically retracing the site conditions. Next stage I zoom in to look at the spatial requirements as requested.
Yeah, first I'm reading and trying to get some ideas into my head, yeah that's it. So then I'm doing my first concept which I thought... I thought I wanted to have a hierarchy of spaces, have the studio down at the bottom, site is sloping, sort of access throughout the courtyard, and that I would have to cut the water, upstairs drain down, and a playground there... I mean I had an idea on where I wanted to put them, and how the circulation between them will work.	Well I was just reading ... whether there was any location specifically that each room needed... I just did an outline of the site to figure out where an entry might be... then, I wrote down all the names of the rooms that were required... I'm writing again what rooms are needed on the first floor, basement & the, second floor & then I scratched that out because... I just thought that it was very unclear; I didn't want to use the entire space at first. I wanted to draw a rectangle, 'cause I thought my house would be, in a rectangular shape.	Basically reading the brief first and then thinking what sort of building would it be, so the light structure, what sort of heavy platforms, what's a timber glazing and opening out to the outside... And then I diagram to just separate the living and the working space, it said that this is painter's studio and dancer's studio because one is a painter and one is a dancer, so it's a big part of the area if you think about it... and because that's what they are I think that its important not to have it in the same pattern...	I'm looking at the brief ...seeing the areas that I will plan and I'm drawing them to scale... so that its accurate; I don't like to simply draw the form & then find out that the space doesn't fit & stuff. So I draw with everything, make them out into shapes, like square blocks & things. And I separate them, in the living area, the kitchen area, the shower area. So these are their utilities... And the bedrooms; then finally there's the observatory.... & then the parking, ok? So, now I'm thinking how should I organize these spaces...
First thing I drew just a diagram... site, I do that... and then I looked at the brief and I'll pick this [calculator] up to estimate how these lines would be... and after that I'm making an idea of where everything should be, how they should relate to each other ... then I just did some diagrams of how you enter the space... Oh, I probably started with my view on how I wanted it to look... and just based on other buildings I've seen... Probably about three... yeah three... I knew the context was just like that, so I had to think what buildings might fit that I've seen in the past... that's how it starts...	Well the first thing I, that I was doing there is I underlined what I thought was important information; ... a couple of times I had to go back & read & sort of underline other things.. look at what I was being asked to do.. some details.. I was calculating the area, how, area ... how big in relationship to that drawing that they gave us, what were the proportions & measurements... then I tried to trace it... then I, labelled the streets & the subjects as reference points. I did know that this was going from higher to lower it could be a good design idea to use the natural landscape, that would also allow for them to have a view of the trees there.	What I'm doing there is trying to visualize in my head in 3D what I'm trying to do because I wanted, the working spaces and some living spaces to be separate ... and how to use the slope as well... I'm drawing the shape as I'm looking at the line of the street, how you approach it by the car... how to look into the entry... what's your line of sight... I'm just trying to see if I can use that as a way to going to the building... and that's sort of like part of my concept with the wall's incision into the house, like it needs to move into... cuts into the house... that like quite nicely has a courtyard area which faces North...	I read the brief first to check the things that were most important and I felt... I had to try and work out what the measurement were of the site so I could work out the site & my rooms were in proportion, and then I started to think about placement of the areas. about breaking the house up so I could have private areas that were still out door spaces so I could get the maximum amount of views because a lot of these areas needed views like the painting studio and the living area so I was just breaking the spaces up there was some areas that needed to be in certain areas, like the observatory.

²² Parts of these statements were 'polished'(without distortions) by removing/replacing colloquialisms, repetitions and mumbling, typical of verbal speech, as well as some of the sidetracking – to provide more concise and coherent accounts, better suited for reading comprehension.

This part of the analysis was aimed at determining the initial students' approaches to problem-solving that can be viewed in the longer term with the designer executing a plan or a macro strategy. Many learning style theorists have been associating these approaches with individual learning/cognitive styles distinguishable from the more spontaneous aspects of problem-solving (summarised in Coffield *et. al.*, 2004).

As it is clear from Table 53, there are both differences and similarities in the early stages of the students' design processes. All of the subjects began with reading the design brief and trying to understand/define the design problem, identify needs, gather (additional) information, including performing the site analysis, and so on. Or, as expressed by one of the wholistic students: *'I think, like I haven't from that part, I haven't really started designing. All this is just like background work design, just setting up the ground work... Looking at everything, absorbing all the information. Much later, you can see that I'm thinking about, how this should work'*.

Clearly, the complex nature of most design tasks in architecture does not encourage ideation, brainstorming, creativity and other associated with wholistic thinking characteristics, from the very onset, without the initial understanding of the problem, or the necessary preliminary analysis. Thus, all students reported it as their first intention. However, there were apparent variations in individual approaches. Wholistic students, on average, spent more time reading the brief and trying to build up an overview of the situation, and much later filled in the details of the problem-solving schema. They described it as *'absorbing all the information'*, *'working out the whole picture'*, *'trying to understand how it all fits in'*, *'making up the initial idea from the brief'*, and so on. Alternatively, analytics preferred to concentrate on particular features of the design task by consulting with the brief more often, but for shorter periods of time, and built up a conception of the situation from these details much later in the process. They described it as *'breaking up the house/task'*, *'dealing with details'*, *'structuring the problem on a lower level'*, *'writing all down to make a plan'*, *'setting up a scheme'*, *'working out a strategy'*, and so on.

After the initial understanding of the problem, or the site analysis, the students proceeded with further problem-solving. Analytics, in general, were very systematic in their approaches, as well as in describing their design processes. They, although to various degrees, exhibited many or most of the features associated with analytical learning style. Including, combining information in a linear sequence, working on well-defined chunks of information that are connected by low-level relations, picking up rules, methods and details, using specific, externally-offered descriptions to assimilate procedures and to build concepts for isolated topics. They typically addressed one goal at a time which, once achieved, was followed by the next goal. Their ideas were built up slowly and systematically from careful analysis. They mainly varied in terms of being constructed/developed on paper or/and involving an adaptation of the previously seen cases, with parts of the knowledge readily visualised / retrieved from the memory.

At the same time, there was no much similarity in approaches to designing among the wholists. Although, after understanding the problem, these students proceeded to ideation preserving broad perspectives and using global strategies, the ideas development bore little in common. They ranged from concepts triggered by visual or verbal associations, to retrieving and combining formerly seen cases (analogical/synthetic reasoning), to descriptions like *'interesting forms were suddenly popping out'*, or *'developing a central idea from looking at the plan'*, or *'playing with lines till I saw something was there, that brings the whole thing together.'* Many wholists also showed a tendency to make hasty decisions based on insufficient information or analysis, which resulted in many ideas abandoned further in the process, much more so than observed among the analytical students. The wholists, generally, had many subgoals under the main topic, and addressed many issues in parallel, which is also clear from their rather sporadic verbalisations. Although guided by some strategy, they were very vague on the applied methods and rules, excluding the preliminary analysis described as the *'standard design practice'*.

On the whole, it is clear from Table 53 that students with similar learning profiles, as assessed by LSA, share a lot of similarities. They reported on their designing processes in a comparable manner, had similar macro approaches, and addressed similar issues. This observation is valid for most but not all of the participants. As their dominant and secondary styles varied in terms of the strengths of preferences, and each student had a unique repertoire of learning styles, some of the fourth and final year versatile subjects exhibited highly integrated approaches that contained features that could be associated with each pole of W-A with equal strength. While some of the first year students have reported modifying their problem-solving behaviour that disagreed with their natural inclinations: *'I guess that was the way I've been learning in studio... I've done it the same way as I've been taught... I guess that's why its so cliché, not really my own doing... My doing is probably I would start backwards with the character, shape it into what is supposed to be useful... I'd rather start with a concept.'* These students are particularly accountable for fluctuations in structure and approaches to problem-solving inconsistent with the general picture (Figure 13, left graph, Wholistic-Imager).

This means that although there may be a link between the students' preferences for wholistic or analytic reasoning and the general, higher-level organisation of their design processes revealed in their initial approaches to the set problem, its understanding requires further research. The nature and the specifics of a design task need being considered before any conclusions are drawn. As well as the degree of 'naturalness' in individual problem-solving.

Finally, while it was possible to extract information on the Verbal-Imagery dimension, that is to form a general opinion on the students' preferences and strengths at the beginning of problem-solving, we did not perceive it as duly justified – the number and the quality of statements varied significantly. Some students used phrases similar to *'I'm just trying to see if it looks better if I turn it around in my head,' 'here I'm visualising to understand,' 'I'm just trying to work it out in my head how the house looks from the inside,'* and *'It came all together in my mind first'* many times, and in different combinations, while others preferred to concentrate on the ideation or analysis aspects of problem-solving in their retrospection. It seems it was more difficult to gain access to visual and/or verbal processing for some of the participants (excluding the defining moments), possibly because these processes were often interwoven or/and not as strategically important as wholistic and analytic. Additionally, unlike the situation with proto- and metacognitive statements on the verbal-imagery mode, we could not determine (lacking a point of reference) the strength of visual and verbal statements describing the initial approach to problem-solving – to enable comparisons with the LSA assessments.

Thus, it can be concluded that although there are wide variations in the approaches students take to problem structuring and problem-solving, they can be loosely mapped onto the W-A learning styles as described by the LSA and similar models. They, however, are also excluded from the further correlation analyses as, while in general conformity with LSA assessments, a method of identifying their strengths need being developed to make them into a source of statistical data.

Prevailing approach

In addition to identifying the designer's initial approach associated with a long-term plan or/and learning styles, macro strategies can be identified by looking beyond the current state and assessing the designer's behaviour in the context of the whole design solution (Gero & McNeill, 1998). The macro strategies are more likely to be associated with the four learning styles (and their combinations) or metacognitive reasoning executed in planning, monitoring or global approaches to problem-solving situations, than the lower-level task-specific learning strategies (classified as micro strategies in protocol studies).

To identify the prevailing approach the relevant statements were singled out and classified/coded in accordance with characteristics of the four learning styles as suggested by the learning style theories (summarised in Tables 38-39). The data, resulting from the

extraction/coding process, was subsequently converted into the quantifiable format by estimating (1) the number of statements related to each learning style, and (2) the length of reported/observed activities. The total time spent on each macro strategy was calculated by summing up the total coded time from when the subject first reads the problem statement to when the subject notes that he or she is finished.

Table 54. Prevailing approaches in problem solving: Experiment IV/b(process)

Code*	Retrospective statement/s	Observed action/s **
PA Wh	You know I just had the simple idea of like the Mobius strip where the division of living, bedrooms, she's in her art stuff & the tower, are all connected by some sort of circulation, so, you can go between them &, I mean they're all separate, but they're also connected.	Constructed a three-dimensional tree of diagrams (structural, circulation, etc) building up on an idea of the Mobius strip.
	I'm just trying to make it work and just trying basically to fit the spaces in and then to see how that works with my concept and how I can manipulate and sort of balance between the concept and the spaces and the requirements. Keeping an overview, you know... you need to keep an overview, or you will end up with piecy stuff that falls apart	Continuously re-adjusts the boundaries of the spaces by drawing fine and invisible lines consistent with the initially proposed organising concept. Sketches along little perspectives to see the changes in 3D.
PA An	Here, I write down bubble diagrams or square diagrams showing what are the pre-requisites and the requirements; after writing down all the rooms I like to interlink the rooms together... so that's how I actually connect and organise where my allocation would be and stuff.	Sketched squares of different spaces next to each other, to dimensions specified in the brief. Then moved them around underneath a sheet of tracing paper with the site contour to retrace onto it.
	Ok, initially I organised all the boxes, squares, I mean the living area, the painters studio, and all that. And then I started adding where my driveway is going to be, where my sculpture garden is going to be, how my steps is gonna lead the person up to the 2 nd level, and then you have the balcony, is because this is facing east.	Reserved spaces for different rooms by drawing squares adjacent to the inner perimeter of the house, one-by-one. Then started adding other requirements and filling in empty spots by shifting inner walls.
PA Im	I was imagining this idea of the repetition & the twisting, one element of my design was going to, keep that idea of um, the streetscape. Then there was going to be a shift where another space would occur & then another shift, um, where a third space would occur. So, I was playing around in my head with the idea of 3 or 4, forms shifting & twisting around the site... I knew that I wanted these forms to, to meet &, where they intersect for the circulation or something interesting to happen... So I started to sketch them to resolve it...	Sketched a rough complex three-dimensional shape. Then took a strip of paper and started to bend it. Then sat down with his eyes closed. Then proceeded to sketching simple 3D shapes and merging them together. After that he reproduced the final shape and started refining it and adding details.
	Next I looked at the site. I looked at the site for a while. I just sat there looking at it. Trying to think, trying to see it... because I decided that I'm going to get inspired by... I mean you have to have a starting point. So I had 2 starting points. One was, one would come from, the program & from the idea of arts & how that would influence the design. And the other one would come from what's happening on the site.	Was sitting looking at the site plan trying to form a mental image that integrates the idea of the arts influenced design with the context and the requirements of the site.
PA Vr	Here I'm writing trying to organise my thoughts... This is my way of designing because I like to annotate whatever I'm thinking... When I finish sketching, I like to keep everything simple by reorganising what I actually thought, so I like to keep things straight. Writing things down in a less complex way you know.	Stopped sketching, sat for a while thinking, then started to write down thoughts and ideas, also by producing word diagrams.
	I like to understand what is required... what I'm working towards... I'm actually reading as well as thinking, what I'm going to annotate onto the tracing paper. I like to start off with doing site analysis... I like to write down what I've seen & what I would think would be appropriate in my design or, what are the key elements that I can add to my design. And then, with my site analysis, on a macro scale, I would shrink down to a micro scale whereby its only on the site itself, and I would come up with all the key responses to my analysis.	Performs site analysis by noting down some of the site characteristics viewed as important. Proceeds to breaking down the task requirements into small(er) units and structuring it according to their importance and progression in designing (as it would be attended to) in writing.

* PA Wh – Wholistic (Prevailing Approach); PA An – Analytic (Prevailing Approach); PA Im – Imagery (Prevailing Approach); PA Vr – Verbal (Prevailing Approach)

** Video records and sketches were supported by introspective statements clarify the nature of observed processes

Table 54 is supported by the descriptions of observed actions and introspective statements – to elucidate the basis for coding. Rather than providing an excerpt from one of the analysed protocols, several examples are given as an illustration of the range of extracted statements we considered as relevant to each of the four codes.

As it is clear from Table 54, some of the examples of macro strategies denoting one style (second example of the PA Wh code, etc) contained lower-level strategies associated with the opposite style. Similarly, neither Verbal nor Imagery (both metacognitive, and task-dependent aspects) problem-solving occurred in isolation from Wholistic or Analytic modes or/and strategies. The latter is in conformity with the superordinate nature of wholistic and analytic cognitive styles proposed by Riding (1998). Unlike the situation with the initial approach to problem-solving, there was enough data on the V-I dimension to use in statistical analyses.

Descriptive statistics

Descriptive statistics for all variables analysed in this part of the experiment is presented for each test group split by gender, in Table 55.

Table 55. Distribution characteristics for ability factors by year and gender, Experiment IV/b

Variable	Year 1						Years 4&5					
	Prevailing approach: Number of statements											
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Wholistic	4.00	12.00	7.40	3.21	6.80	2.49	7.00	17.00	10.60	4.16	10.50	3.17
	4.00	8.00	6.20	1.64			7.00	12.00	10.40	2.30		
Analytic	6.00	12.00	9.60	2.51	10.60	4.48	8.00	15.00	11.20	2.59	12.50	4.74
	7.00	22.00	11.60	6.02			10.00	25.00	13.80	6.30		
Imagery	11.00	25.00	17.60	7.06	17.10	5.86	12.00	25.00	18.00	5.43	18.40	4.47
	12.00	25.00	16.60	5.18			15.00	25.00	18.80	3.90		
Verbal	14.00	30.00	21.00	6.56	19.30	5.12	11.00	21.00	14.80	4.27	16.20	4.19
	15.00	22.00	17.60	2.97			14.00	24.00	17.60	4.04		
	Prevailing approach: Total length in seconds											
Wholistic	150.00	390.00	266.00	87.64	236.50	90.00	140.00	370.00	227.00	93.64	259.50	111.50
	120.00	320.00	207.00	91.49			150.00	460.00	292.00	128.14		
Analytic	180.00	400.00	303.00	84.38	293.00	85.61	200.00	370.00	280.00	66.24	325.00	67.49
	200.00	400.00	283.00	95.49			340.00	400.00	370.00	28.28		
Imagery	170.00	500.00	290.00	137.66	280.00	114.81	170.00	350.00	250.00	65.95	314.00	103.84
	200.00	450.00	271.00	102.37			250.00	500.00	378.00	98.34		
Verbal	270.00	490.00	342.00	87.58	278.00	94.021	220.00	280.00	254.00	27.93	283.00	80.15
	160.00	280.00	214.00	44.50			200.00	490.00	312.00	107.56		

Females
 Males
 Group results

Comparative analysis

Comparative analysis between the first, and fourth and final year students allows examining the participants' preferences for utilising the four types of macro strategies associated with Wholistic, Analytic, Visual, and Imagery learning styles (Figure 16).

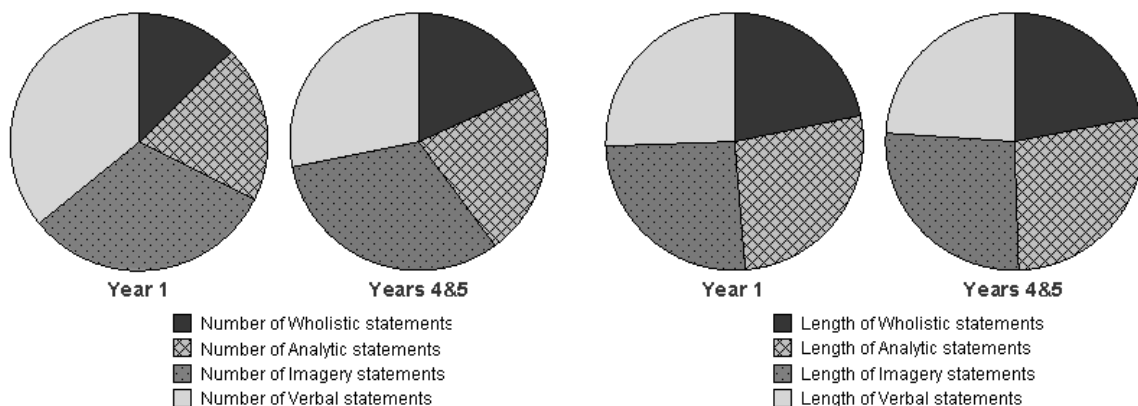


Figure 16. Frequencies of prevailing approaches: Year 1 (left), Years 4&5 (right)

Figure 16 (left) demonstrates relations between the percentages of different macro strategies (i.e. frequencies of means) based on the group (i.e. year 1 and years 4&5) mean values of their cumulative (for each individual session) numbers, calculated for all design sessions, split by the two groups of subjects. Figure 16 (right) demonstrates relations between the percentages of different macro strategies (i.e. their frequencies relative of the protocol session duration) based on the group mean values of their cumulative (for each individual session) lengths in seconds.

Figure 16 and Table 55 indicate that there similarities are as well as differences within and between the sample. The left chart shows that the largest amount of strategies reported by both groups of students were verbal and imagery, and the smallest - wholistic. Different from the first year designers, the fourth and final year architects made more statements related to wholistic, imagery and analytic styles; and had the highest proportion of imagery statements relative of their own group. Whereas the first year students reported more verbal strategies than the fourth and final year students, which is also the highest proportion of statements relative of their own group. There could be many reasons for this, including the formerly mentioned influence of the secondary education supporting verbal analytical learning and problem solving (Coffield, *et al.*, 2004). The verbal nature of retrospection may have also contributed to the observed situation especially as it is equally characteristic of both groups of students.

The observations from the left chart are only in part confirmed by the right chart indicating similar frequencies of the four types of macro strategies when it concerns their duration; this suggests a better balance between the four types of thinking. However, a high variability in the lengths of wholistic and imagery strategies (first year $SD_{Wh}=90.00$; $SD_{Im}=114.81$; fourth and final year $SD_{Wh}=111.50$; $SD_{Im}=103.84$; Table 55) indicate a complex picture. A closer look at the quality of cognitive processing has to be taken (including the integration of thinking processes) before any conclusions are drawn. A further examination of its association with the measurements of learning style may help understanding the observed situation (Tables 60, 61).

Structure of problem-solving

This part of the study was aimed at determining whether the overall high-level structure of individual problem-solving could be classified as representative of a particular learning style. For this purpose, a number of well-known design process models (or methods of designing) have been selected in accordance with the learning style theories as being characteristic of wholistic or analytic thinking²³. Subsequently, the general structure of each design session was identified by extracting and noting down a sequence of macro strategies. As an alternative approach, all macro strategies denoting a particular style, their numbers and lengths, were analysed by comparing their frequencies to identify a group of prevailing strategies (i.e. irrespective of the sequence of occurrence). Then, the data resulting from both approaches was mapped onto the chosen design methods to determine if there were observable similarities. The following models were considered representative of analytical or wholistic thinking:

Working-Backward method is characterised by working back from the goal. The key is to decompose the initial goal into a set of subgoals that imply solutions of the original goal. Thus, the solver can focus on solving each of the subgoals independently (Anderson, 1990).

The Goal-Directed Action of Problem Solver (Rouse, 1985). This model features the extensive use of rule-based strategies. In order to describe multiple modes of problem-solving, various dichotomies have been suggested, such as, intuition vs. analysis, remembering vs. solving, retrieval vs. search, and symptomatic vs. topographic strategies.

Bottom-up Composition methods involve configuration of an overall design solution by successive (i.e. abstraction-forming) or recursive combination of basic design components (Mitchell, 1998). As with top-down decomposition, the individual design components must be well-known and amendable to designers that integrate them into new assemblies.

²³ The association with Imagery or Verbal cognitive styles (or macro approaches) has not been addressed in these models. It is assumed in relation to the nature of a particular design task, or its aspects.

Problem-Solving by Analogy method uses the structure of a solution to one problem (or a combination of structures and solutions) to guide the solution to another problem (Anderson, 1990). In this method the users' knowledge and experience are essential for designing.

The General Problem Solver (GPS) contains four basic steps: (1) problem-finding – moving from an ill-defined to a well-defined problem; (2) working out a detailed solution for the abstract formulation of the problem; (3) applying the solution as a plan in the original problem; and (4) executing this plan to solve the original problem (Newell & Simon, 1972).

Top-down Decomposition (Lawson, 1980) is a method that begins with a concrete aim; it incrementally leads to the production of a fully specified design conception by dismantling the problem into sub-problems. The procedure requires abstract and well-defined problem specifications, which can be recursively divided into smaller section specifications.

Hierarchical Planning Method (Sacerdoti, 1974, 1977) is a search process through a space of possible models for a solution state, or through a plan to satisfy the external imposed criterion (problem). The process of problem-solving refers to a development of constraints that gradually restrict the originally large space of possible models to the solution space which includes only available solutions.

The Opportunistic Planning Model (Hayes-Roth & Hayes-Roth, 1979) suggests that at each point in the process of designing, the planner's current decisions and observations offer various opportunities for plan development. Neither top-down nor bottom-up manner is implied but working on many levels in parallel. There are sets of condition-action rules in this system. A plan is incrementally accumulated, and rarely produced in a systematic manner.

The analysis has indicated that while many students were inclined to using one approach more than another, no model on its own could fully describe the structure of their design processes. For wholistic, brain-gifted and versatile students in both groups design problem-solving was mainly an opportunistically organised type of activity: it did not progress as a series of cycles consisting of actions occurring in a fixed order, such as analysis, synthesis and evaluation as they constantly generated new task goals and redefined task constraints. Yet a higher-order plan, either on the level of maintaining a global overview or following the procedures of the 'standard design practice' was often observed. Analytic students (particularly verbally inclined) did use a more structured approach that could be loosely associated with the first listed method but only on the macro scale. Both wholistic and analytic students resorted to problem-solving by analogy and used top-down and bottom-up approaches (and their combinations), with analytic students being more systematic and less inclined to their simultaneous use (i.e. parallel processing).

In addition to identifying the designer's initial and prevailing approaches, and the general structure of problem-solving associated with a long-term plan or a macro strategy, micro strategies can be identified by looking at the more task specific lower-level aspects of problem-solving to, ultimately, determine their association with individual cognitive abilities and learning styles. A use of micro strategy may be influenced/supported by individual cognitive abilities and may signify no more than a particular way of solving a task, with no requirement that individuals choose or even be aware of the strategies they adopt. In this case, another way to observe cognitive abilities is through consistencies in the application of strategies across tasks or situations. In other cases, the strategy use may not be related to aptitude, while the effectiveness of the implemented strategy could be limited by aptitude. Viewing strategies as exemplars of styles implies the presence of some form of executive or self-regulatory processes. It is possible to assume that due to the nature of designing (as well as introspection), at least some reports of strategy use would imply conscious choice in action or thought. Thus, the range of situations in which particular strategies are used and the flexibility with which they are used may depend on an individual's learning style.

The following two subsections suggest initial steps in the direction of determining a number of links between the further specified micro strategies and individual design abilities.

6.3.2 Analysis of Design Drawings and Annotations

The approach adopted in this part of the study required ‘individuation’ and numbering each sketch in order of their completion. The researcher first went through and identified separate (though still connected) sketching episodes by looking at the videotapes, generated drawings and retrospective verbalisations. Then, similarly to Goel’s (1995) experimental work, the output was ‘individuated’ by placing rectangles around each drawing and numbering them in sequence.

The drawings accompanying each episode were then coded in terms of how the drawing was generated (whether it was a new drawing or a transformation of a previous drawing) and whether or not the drawing was annotated. Duplication or duplication transformations were not considered as their impact on the progression of design problem-solving had no apparent (to us) association with the researched design abilities. Where drawings originated in a previous episode they were coded in terms of whether they were a variation (whether the drawing was recognisably similar to a previous drawing) or whether they were identical to a previous drawing except for specifiable differences. The first code was called *horizontal (lateral) sketch development*, it indicated that the subject was moving from one design idea to another, more or less different, without articulating any of those in depth. The second code was named *vertical sketch development* as it represented moving from one design idea to a more articulated and detailed version of the same idea (Goel, 1995). It was expected for *horizontal* transformations to be associated with wholistic and/or visual thinking and figural ideation abilities.

Two types of annotations were considered relevant due to their association with the design drawings generation. They were also divided into *vertical* (Figure 6, C) and *horizontal* (Figure 6, D) *idea-annotations*. The first type can be related to vertical progression of a design – as it further develops, or adds details, to an already existing idea or a drawing. The second type is used for noting down newly emerging ideas which can be associated with lateral design (i.e. ‘may change the form [of the house] to look more organic’) or sketch (i.e. ‘swimming pool somewhere here?’) development. It was suggested for *horizontal idea-annotations* to be associated with wholistic and/or verbal thinking and verbal ideation abilities.

Descriptive statistics

Table 56 presents descriptive statistics for two types (four categories) of external representations estimated for both test groups split by gender (the original data is included in Appendix B tables containing individual accounts of the analysed variables).

Table 56. Transformational balance of external representations by year and gender: Experiment IV/b

variables	Year 1						Years 4&5					
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Transf.	6.00	46.00	22.60	16.49	24.10	12.88	11.00	53.00	34.20	17.58	29.10	14.86
	15.00	39.00	25.60	9.79			8.00	36.00	24.00	11.07		
Vertical	5.00	31.00	16.00	11.18	17.10	8.90	8.00	35.00	24.00	12.12	20.20	10.49
	10.00	27.00	18.20	7.09			5.00	25.00	16.40	8.02		
Horiz.	1.00	15.00	6.60	5.55	7.00	4.29	3.00	18.00	10.20	5.84	8.90	4.63
	3.00	12.00	7.40	3.21			3.00	11.00	7.60	3.13		
Id-An	0.00	2.00	1.60	0.89	1.40	1.35	0.00	3.00	1.00	1.22	1.70	1.49
	0.00	4.00	1.20	1.79			0.00	4.00	2.40	1.52		
Id-An(v)	0.00	2.00	0.80	0.84	0.60	0.70	0.00	2.00	0.60	0.89	1.20	1.03
	0.00	1.00	0.40	0.55			1.00	3.00	1.80	0.84		
Id-An(h)	0.00	2.00	0.80	0.84	0.80	1.03	0.00	1.00	0.40	0.55	0.60	0.70
	0.00	3.00	0.80	1.30			0.00	2.00	0.80	0.84		

Females
 Males
 Group results

Transf. – overall numbers of transformations (horizontal + vertical); Vertical – vertical transformations;
 Horiz. – Horizontal Transformations; Id-An – overall numbers of idea-annotations (horizontal + vertical);
 Id-An(v) – Idea-annotations (vertical); Id-An(h) – Idea-annotations (horizontal)

It indicates their quantitative characteristics based on the overall numbers of horizontal and vertical transformations and two annotation categories estimated per individual design session (i.e. complete sets of drawings), not on a per page basis.

Comparative analysis

Comparative analysis between the first, and fourth and final year students allows examining the participants' progression in problem-solving, and the structure of reasoning and presenting ideas, conveyed graphically – by sketching, and sententially – by making notes.

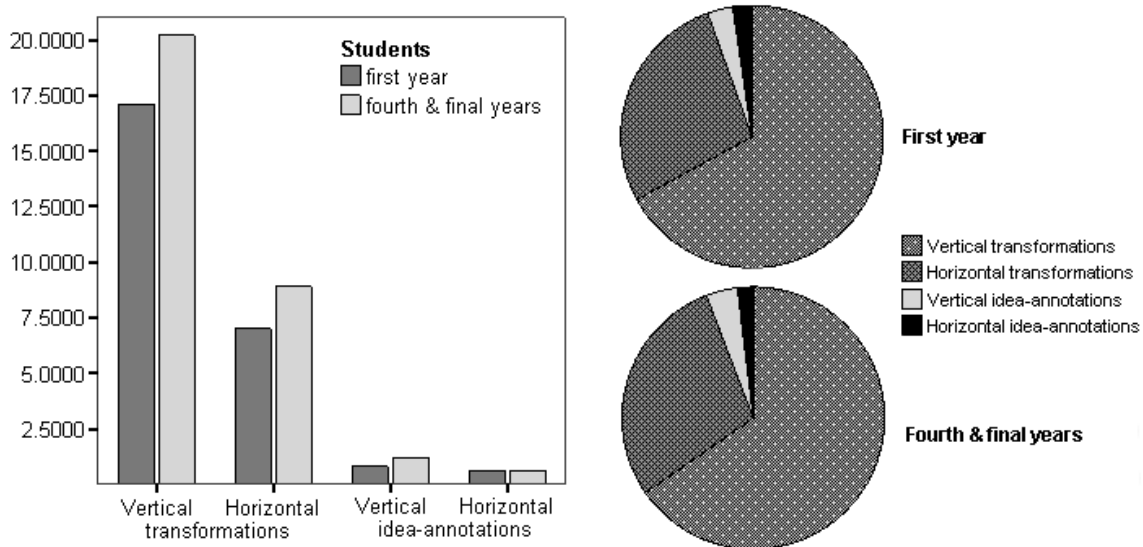


Figure 17. Transformational balance of external representations: Mean (left) and frequencies (right)

Figure 17 demonstrates relations between the average numbers of occurrences (i.e. means and frequencies of means) of horizontal and vertical sketch transformations, and of the two types of sentential representations, estimated for two groups of subjects separately. It indicates that there are differences as well as similarities within and between the sample (see also Table 56).

The left chart shows that the fourth and final year students have higher levels of transformations on both vertical and horizontal dimensions. The vertical dimension suggests higher levels of detailing, while the horizontal dimension indicates that larger numbers of ideas were generated. It is consistent with the data indicating for senior participants to have produced significantly more sketches and diagram-sketches (Figures 8-9). And may be supported by the observations derived from analysing the students' modes of designing, which indicated for the fourth and final year students to have more integrated design processes. That is, it is likely that the knowledge and the skills acquired during design education enabled senior subjects to process more information in parallel, or/and to be more efficient while doing it, and therefore to produce richer (more detailed and more diverse) representations. Further in this study, a closer look will be taken at the transformational balance of sketches and modes of designing in relation to the judges' assessments of the final design solutions to see if there is an association with their (solutions) quality across the sample as well as within each respective group.

Both groups of students have the average balance of around 1:2.5 (horizontal to vertical transformations) with the variation between the two groups being smaller on the horizontal dimension. This is generally consistent with the findings from a relatively recent study of architects indicating that reliance on ideas at the conceptual stage does not appear to result in an over-abundance of horizontal transformations (Suwa & Tversky, 1997). Good design is a result of a balance between horizontal and vertical transformation rather than an extreme horizontal bias (Goel, 1995). It is likely that in the later stages, the balance will shift to an extreme vertical bias as the design representation progresses towards the embodiment and detailing stages.

Further to these comparisons, the right chart suggests a similar overall balance between the two types of transformations and two annotation categories in both groups of students with a slight tendency for the fourth and final year students to produce more vertical idea-annotations.

Figure 18 provides four examples illustrating a range of approaches to producing work with varying horizontal and vertical bias. Each graph breaks down the student's sketching activity and demonstrates the amount of transformations on each page, in relation to each sketch²⁴. It presents them as a sequence that includes intermediate activities of diagramming and idea-annotating (line dropping to zero level) and disregards duplication/duplication transformations.

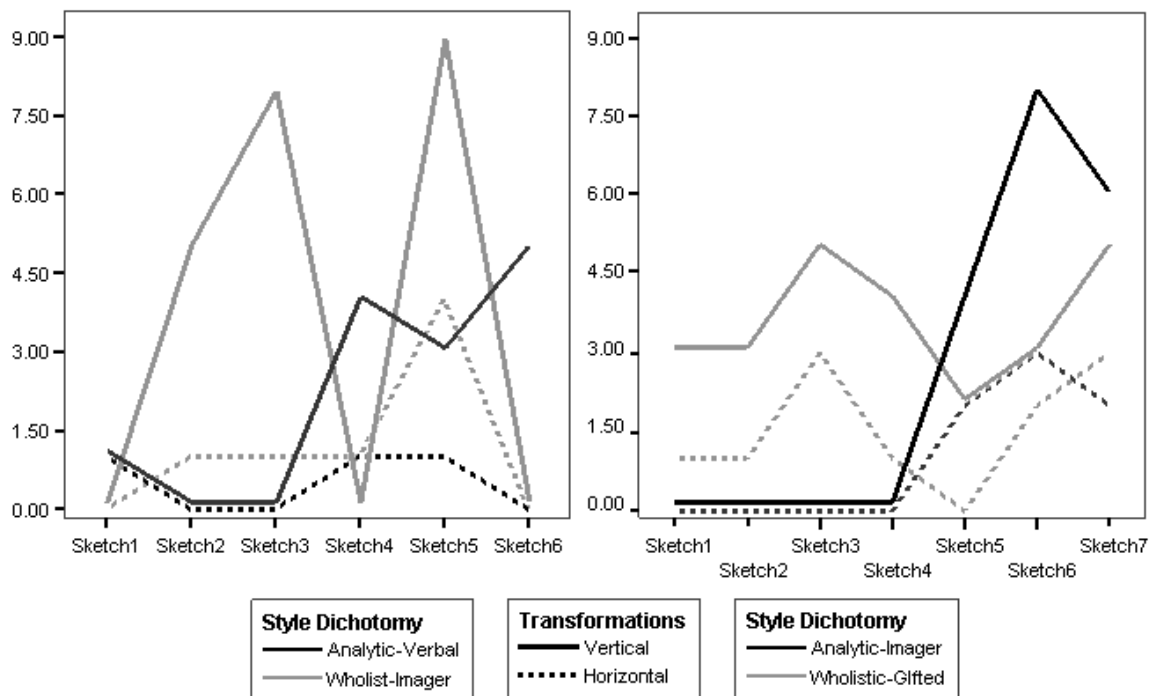


Figure 18. Transformational balance of sketches by style combinations: Year 1(left), Years 4&5 (right)

It is clear from the above the students' structure of sketching activity bears little in common. Among the similarities is the previously mentioned balance between transformations, with an apparent vertical bias present in everyone's sketches. The reasons for this, however, vary. Analytic subjects, both visually and verbally inclined, tended to spend a lot of time in the analysis phase, they structured their problem-solving in a more linear manner and were more concerned with generating a feasible design that accommodated a lot of constraints, than with producing an original solution, or many alternative ideas to choose from. In other words, they built up their solutions gradually by assembling/adding details and responding to local conditions. As a result, horizontal transformations typically peaked in the second quarter, stabilized (or kept increasing and decreasing marginally) in the third, and decreased (in some cases dropped to zero) in the last quarter of design sessions. Vertical transformations followed a similar pattern but with greater values and, therefore, more pronounced rises and declines.

Different to them, many wholistic students, visually inclined in particular, did not start designing till they could fully comprehend the design brief and spent some time on the internal development of conceptual ideas (Figure 13, left graph, Wholistic-Imager). And, as lot of horizontal transformations happened also internally, as a part of visual-verbal ideation, their

²⁴ The examples were chosen from those students whose profiles were not extreme in terms of the overall numbers of transformations. They were close to their respective group mean, with the fourth and final year students, on average having produced higher numbers of transformations.

external activities had a strong vertical bias from the onset. Other wholistic students, flexible in the analytic mode in particular, were more inclined to thinking on paper. Although also guided by an initial high-level conceptual idea, their design solutions developed more gradually, by synthesising solution components, integrating constraints and responding to local conditions. On the whole, wholistic problem-solving was more random and open-ended and, as a result, there were no distinct patterns in the vertical or horizontal transformations, as ideation and detailing could peak and drop at any point in the design process.

The protocol session constraints have also influenced the observed situation (as per cited on pp. 148-149). And, while all students were affected, it occurred to different degrees and in a number of different ways.

As Figure 18 demonstrates, Student S06(I) (Analytic-Verbal) opens with a very brief spell of horizontal and vertical activity after reading the design brief, as he cannot proceed until the problem is broken down into smaller, more manageable components. Thus, he continues with diagramming (site analysis), annotating (listing design concerns and initial low-level ideas/design elements driven by these concerns) and drawing a string of boxes resembling spaces in order to understand dimensions. This is followed by another spell of sketching activity, with a strong bias towards vertical transformations, or as expressed by one of the judges, the subject was 'decorating boxes'. And, as the second spell of lateral sketch work is weak and overtaken by vertical thinking, it suggests problems with ideation and early fixation.

Student's S03(I) (Wholistic-Imager) work is typified by a more random approach. The first spell of diagramming (structural, functional and circulation diagrams) is followed by a period of internal ideation (no drawing activities, no annotating) which is then replaced by an intense period of sketching 'from the head' indicating a strong vertical bias. Thus, the student displays an initial tendency to produce internal lateral work which peaks on paper later in the process when the ideas are too complex to be processed in imagery alone. That time, vertical transformations increase and drop along with horizontal transformations. The final spell of drawing activity includes diagram-like section views and annotations. In real life design, it would be followed by another spell of horizontal and vertical transformations (as S03(I) noted).

Student S012(4) Analytic-Imager begins with an extensive site analysis and structural and functional diagramming. It is followed by a spell of vertical and horizontal activity with a strong vertical bias. It peaks through in the third quarter of the design session to then decline as the subject goes back to revise and refine different aspects of his design solution. The reason for the final drop in horizontal transformations is the same. Largely due to the extended analysis phase, this subject's sketches have progressed well in terms of the complexity level and he managed to accommodate a good number of constraints. The amount of vertical transformations indicate a good level of detailing. However, the student was predominantly concerned with his solution's feasibility than with creativity or originality, which is also clear from the opening spell of lateral sketch work being overtaken by vertical thinking.

Student's S15(V) (Wholistic-Gifted) work is typified by the most balanced approach. While there is a bias towards one type of thinking – vertical, it is relatively slight. Both types of transformations follow the same pattern of increase and decline; this is characteristic of the students who are experienced with 'thinking on paper.' That is, whilst their solutions (solution components) can be synthesised with a varied internal bias, they are externalised by integrating constraints and responding to local conditions. This subjects' sketches also progressed well in terms of the complexity level. A number of horizontal transformations in the transformational activity of S15(V) towards the end of the process were mainly down to generating a number of various layout detail changes.

In view of the above, it can be summarised that there are little similarities in the organization of sketching activity. Analytic students, particularly verbally inclined, on the whole, chose a more structured and linear approach indicating an identifiable progression from the initial analysis that breaks down the problem into its components, to building up ideas in a step-by-step manner (i.e. showing a stable balance of vertical and horizontal transformations, with a clear vertical

bias), followed by gradual (in two cases, abrupt) decline of horizontal transformations, and a continually increasing number of vertical transformations. For wholistic, brain-gifted and versatile students in both groups, design problem-solving was an opportunistically organised type of activity characteristic of parallel processing; it did not follow similar or distinct patterns but was influenced by initial ideation/type of concept and the level of sketching ability/experience with thinking on paper, along with other variables.

In future, it may be easier to understand individual problem-solving and, possibly, discover more common trends that influence/direct transformational activity by looking at the wider range of processes, that is by including the ones that occur internally. It has been noticed, for example, that a lot of wholistic students, whose vertical and horizontal transformations seemed to increase and decrease randomly, and whose reasoning was truly opportunistic, did nonetheless preserve an overview or a high-level plan, and adhered to some global strategy, and that was more apparent from their intro- and retrospective verbalisations. The students were also different in their capabilities of complex integrative reasoning, which affected both the rate/intensity and the pattern of their sketching.

Idea-annotations did not appear to form any distinct trends in terms of their relation to the transformational balance of sketches, or, equally, the general structure of problem-solving. They could appear at any point of time and had a broad range of purposes – from structuring thoughts and planning problem-solving, to explaining and refining ideas, or recording newly emerging ideas on the fly, before having them overlooked or forgotten. Many students chose sentential form of representation when they felt there was not enough time for adequate graphic depictions. While other participants who lacked in sketching ability (or whose ideas were too complex for their levels of sketching) felt it was easier for them to resort to written descriptions.

Learning styles in sketching

Figure 19 illustrates the students' tendency to produce work that is either horizontally or vertically biased relative of their learning styles preferences as assessed by LSA. The vertical axis indicates the mean numbers of occurrence of the two types of transformations and two annotation categories estimated for Wholistic, Analytic, Imagery, Verbal and brain-gifted individuals, for each of these four categories separately (horizontal axis).²⁵

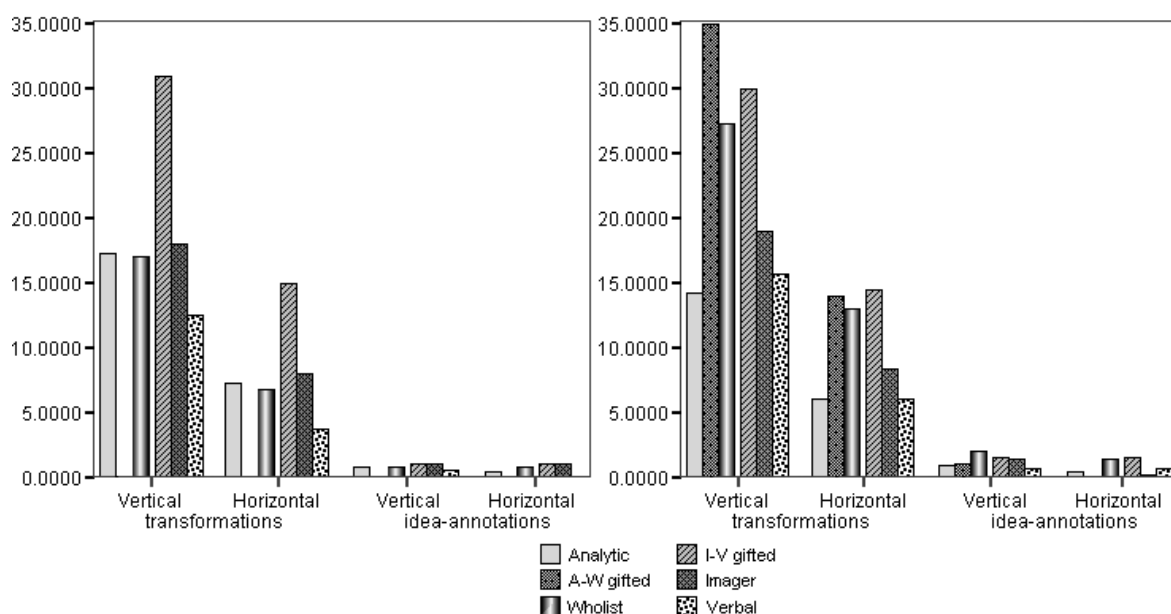


Figure 19. Transformation balance of sketches by W-A and V-I modes: Year 1 (left), Years 4&5 (right)

²⁵ In the left graph, gaps between the bars indicate absence of a particular category (i.e. W-A brain-gifted) as well as zero mean values when the category is present (the latter is also valid for the right graph).

The above indicates differences and similarities in the relationship between learning styles and transformational balance of sketches of the first and the fourth and final year students. As both graphs demonstrate, it is the brain-gifted students in the Imagery-Verbal mode (i.e. equally strong in both visual and verbal processing) who tend to produce the largest numbers of vertical and horizontal transformations. As suggested by the learning style theories, these students are capable of the more integrated parallel processing or/and more swift in alternating between the visual-verbal strategies, and better at translations that govern and transform the meanings of verbal statements into a graphic context (and vice versa) to help them solve problems.

Brain-giftedness in the Analytic-Wholistic mode is also an indicator of a larger number of transformations, vertical in particular, suggesting that being highly integrated in using mental techniques is a definite advantage when it concerns idea-production and detailing. Having preferences in wholistic and analytic brain processing means being able of addressing many different angles of a design task, understanding/accommodating a wider range of constraints, and synthesising solutions into concise logical structures. This, therefore, could be reflected in the quality of the final designs. In this study, however, it remains a mere possibility as the size of the sample does not permit generalisations on the brain-giftedness dimension, although a further look will be taken at the issue of versatility.

The results are not consistent on the Wholistic and Analytic dimensions. With reference to the first year analytic students, there is a tendency for them to generate higher numbers of vertical and horizontal transformations, but only marginally. This may be related to the previously mentioned observation for the wholistic students to start designing after '*absorbing all the information and letting it to sink in,*' and spending more time on the internal development of conceptual ideas (Figure 13, left graph, Wholistic-Imager). Whilst the analytic students were more comfortable with following the known to them (learnt) design routines and 'wasted' much less time waiting for the 'big idea' to emerge. Thus, their solutions indicated early fixation and many lateral transformations were down to generating a number of various detail changes. Correspondingly, one needs to look at assessments of the final design solutions, at the balance of their complexity, functionality and originality to understand these observations better.

The situation is reverse for the fourth and final year students, where wholists appeared to be significantly more productive. It may be supported by the observations derived from analysing the students' modes of designing, which indicated for the fourth and final year students (particularly wholists) to have more integrated design processes. That is, it is likely that the knowledge and the skills acquired during design education enabled senior subjects to process more information in parallel, or/and to be more efficient while doing it, and therefore to produce richer (more detailed and more diverse) representations. Additionally, there are more A-W versatile individuals among the fourth and final year students, as indicated by the LSA.

When it comes to the Imagery dimension, the results are similar for both groups. There is a clear tendency for the visual individuals to generate more horizontal and verbal transformations than was observed among the verbal and analytic students. The reasons are probably related to the visual nature of design problem-solving, both internal (imagery) and external (sketching).

The results vary when it concerns horizontal and vertical idea-annotations (see also Figures 11-12). It is the wholistic, V-I gifted and visual students from the first year, and the wholistic and I-V gifted fourth and final year participants, who were the most productive on these dimensions. There is also a tendency for analytic and verbal individuals in both groups to generate the lowest number of both types of annotations. The reasons for this are likely to be multiple and interacting, and may be indirectly or unrelated to the student's learning styles. That is, as the participants have chosen to convey both visual and verbal ideas and in a written form, it is possible for the observed situation to be less related to the preferences on Visual-Imagery dimension, but to the rate of idea-production, design knowledge, and the very nature of annotations, such as their vagueness and speed of noting down. Additionally, some of the

students used a process of ‘verbal punning’ involving translation between visual and verbal forms of expression – to stimulate the generation of ideas by allowing free associations. It is frequently employed to generate solutions with both visual and verbal resonance (Tomes, *et al.*, 1998). The protocol session constraints may have also influenced the rate of and the type of preference for horizontal and vertical annotations.

In future, a further division of sentential representations into analytical, wholistic, and visually- and verbally-instilled may be more advantageous in identifying their relationship with the *input* the *process* and the *product* of problem-solving.

Cognitive abilities in sketching

Figure 20 illustrates the students’ tendency to produce work that is either horizontally or vertically biased relative of the levels of their visual-spatial (V-S), verbal ideation (VI) and figural ideation (FI) abilities. The vertical axis indicates the mean numbers of the two types of transformations estimated for high, medium-high, medium-low and low ability individuals, for each of the three groups of cognitive abilities separately (horizontal axis)²⁶.

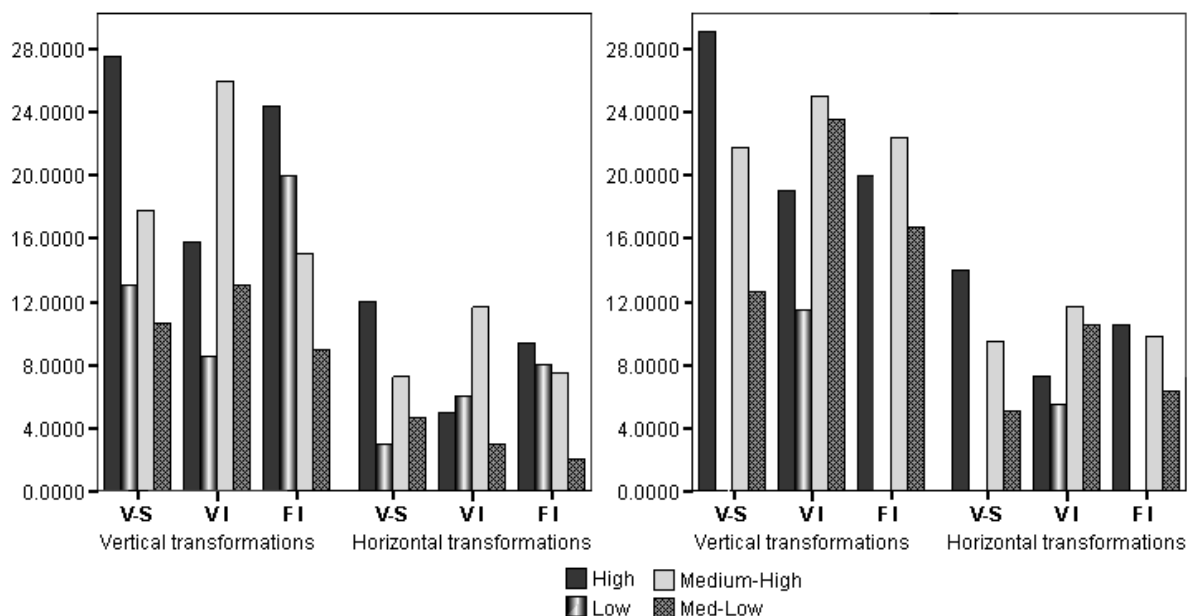


Figure 20. Transformation balance of sketches by cognitive abilities: Year 1 (left), Years 4&5 (right)

It is clear from the above that the first and the fourth and final year students share a lot of similarities in terms of the relationship between their visual-spatial abilities and the transformational balance of sketches. As both graphs indicate the high and the medium-high spatial individuals are inclined to producing the largest numbers of vertical and horizontal transformations; and the medium-low and the low spatial students – the lowest. It is generally consistent with the formerly observed tendency for the high spatial (particularly on the visualisation dimension) in both groups to generate higher numbers of sketches and diagram-sketches (Figure 10; Table 34).

The results are inconclusive on the verbal and figural ideation dimensions. With reference to verbal ideation, there is a tendency for low ability individuals in both groups to generate the lowest number of vertical transformations, but there is a lack of consistency on the horizontal dimension. As to figural ideation abilities, there is a inclination for high ability individuals in both groups to produce more horizontal transformations, while the results are inconsistent on the vertical dimension. This is in general conformity with the earlier analyses (Tables 37, 68-69) that have indicated no significant or moderate correlations between ideational abilities (figural

²⁶ Gaps between the bars indicate absence of a particular category (i.e. *low*) not zero mean values

and verbal), and number and types of external representations generated. However, as the current and the earlier analyses were largely concerned with their quantitative aspects, in future, it may be advantageous to introduce additional coding categories derived from the human ability theories to define design drawings' characteristics in accordance with the chosen cognitive factors (including ideational and associational fluency) to facilitate identifying their relationship with the *input* the *process* and the *product* of problem-solving. One also needs to look into other aspects of drawings and annotations, such as their complexity, levels of abstraction, degrees of detailing, number and quality of constraints integrated, articulation the quality of ideas – to gain a better grasp of what the above results may signify. A measure of sketch ambiguity may also be introduced as an indication of the rate of reinterpretations that occur when the meaning associated with a drawing in one episode has subsequently changed.

On the whole the above results are consistent with the rest of the study, suggesting for visual-spatial abilities to have a greater influence on creativity, academic achievement and performance on design tasks, than visual or verbal ideation (Tables 21, 29, 30).

To understand the reasons for the observed situation better a further look will be taken at the issue of ideational fluency (both the *input* and the *process* aspects) in relation to the judges' assessments of the final design solutions, to ascertain if there is an association with their (solutions) qualities across the sample and within each respective group.

There are no similarities in the character of transformational balance of sketches and annotation categories, suggesting that they do not follow similar patterns. The lack of the association between annotations and individual cognitive abilities has been previously cited (illustrated by Figure 10). The reasons are likely to be multiple and interacting, including the role of personal preferences, learning styles and strategies, knowledge, experience, skills, and more.

In future studies, it may be advantageous to introduce additional coding categories derived from the human ability theories to classify annotations in accordance with the chosen cognitive factors (including *FA* and *FI*) to facilitate correlations with the *input* and the *process*.

A further correlation analyses indicating a range of relationships between the transformational balance of sketches, two types of annotations, learning styles and cognitive abilities is presented in the following Subsection 6.3.3, Tables 59-60.

6.3.3 Analysis of Retrospective Reports

The approach adopted in this part of the study originates from the process oriented scheme proposed by Gero and McNeill (1998). The scheme contained a number of categories (recorded as a micro strategy dimension) concerned with the designer's immediate actions that fit well with the purpose of this research. They could facilitate the exploration of correlations between the lower-level strategies observed during the performance on design tasks, and the measures of individual styles and abilities. These and other formerly used codes that we perceived relevant included (1) divergence (i.e. breaking the design problem into pieces), transformation (putting the pieces together in new ways), and convergence (testing to discover the results of putting the new arrangement into practice); (2) top-down and bottom-up problem-solving; (3) induction and deduction; (4) analysis-synthesis-evaluation; and so on; plus a number of categories that have been used in design studies less frequently and that could be related to cognitive abilities, such as visualisation, mental scanning and mental rotation.

However, as it has been previously mentioned, many of these categories were imprecise in their association with the design ability properties – they merely suggested an approach that pointed towards these factors in a general way. In the process of refining the coding scheme, the search for additional and more specific to this study categories lead us to the learning styles and the human ability theories. They offered a framework that is both model- and data-driven: in that the protocols are the source of the repertoire, while the theories are used to add structure and meaning to the repertoire.

Second-grade strategies in problem-solving and learning styles

Researching the relationship between the lower-level task-specific strategies and the measurements of learning styles is based on the assumption, that the former can be affected by the latter. That is, although strategies may be adapted to be more appropriate to a particular task or situation, the underlying cognitive (preferred learning) style may be much more permanent and persuasive. Therefore, depending on its strength, it may influence the choice of problem-solving strategies that the person tends to adopt over a range of tasks (Pask, 1988).

In agreement with this assumption, the relevant statements were singled out and classified/coded in accordance with characteristics of the four learning styles as suggested by the learning style theories (summarised in Tables 38-39). Several examples are given in Table 57 as an illustration of the range of extracted statements associated with each of the four codes.

Table 57. Retrospective statements associated with W-A & V-I learning styles: Experiment IV/b(process)

Code*	Retrospective statements		
St Wh	I was thinking in 3D about how the levels will be joined	I'm just fixing a few bits together, wanted to make it into one line so it looks like one thing [resolves conflicting boundaries to make them into one shape]	I was kind of concerned with a few things here, so I'm like sketching this wall and thinking I shall not forget that [space], 'cos it changes too
St An	I thought I might check with it to see if it works [reads brief, checks sizes with a ruler]	I'm just checking [constraints against a string of drawn boxes] to see if I put all rooms in	I've divided these spaces up, so now I'm testing if they fit together [by moving boxes]
St Im	Here I'm thinking how the person goes through the space	Here I just change shapes [of the roof] and stuff... just to see	This curved line that I saw in my head, I'm just sketching it
St Ver	It's [building materials] in my head, 'cos I thought about it... and I need to write it down	I'm thinking and putting it [themes] on paper... like every space has a word for it... not just what it is... but like an idea	I'm just writing down a few concerns, like I need to do something about the noise from the main street

* St Wh – Wholistic Strategy; St An – Analytic Strategy; St Im – Imagery Strategy; St Ver – Verbal Strategy

As it is clear from Table 57, some of the examples of micro strategies denoting one style are associated with another style/s, as neither Verbal nor Imagery strategies occurred in isolation from Wholistic or/and Analytic problem-solving (and vice versa). Correspondingly, depending on the context, they could have been ascribed one, two and, sometimes, more codes.

The data, resulting from the extraction/coding process, was subsequently converted into the quantifiable format by estimating (1) the number of statements related to each learning style, and (2) the length of reported/observed activities. The total time spent on each micro strategy was calculated by summing up the total coded time from when the subject first reads the problem statement to when the subject notes that he or she is finished.

After that, a series of correlation analysis were performed using the above data and the data on individual learning styles from LSA assessments and introspective reports. They, however, did not yield many consistent/significant correlations on most dimensions, for the exception of the preferred analytic learning style as assessed by LSA to be correlated with the number (first year $r=0.775^*$; fourth and final year $r=0.785^*$ one-tailed) and the length (first year $r=0.692^*$; fourth and final years $r=0.712^*$ one-tailed) of analytic statements. Another correlation was observed on the Verbal dimension as assessed by LSA, concerning the number of verbal statements (first year $r=0.768^*$; fourth and final year $r=0.645^*$ one-tailed) and their length for the first year students only (moderate correlation; $r=0.597$). A moderate correlation was also observed between the Wholistic learning style and the cumulative number of all micro strategies reported for the first year students ($r=0.627$); and a significant – for the fourth and final year participants ($r=0.725^*$ one tailed).

Although there have been correlations observed, their nature (clear from close examination of the retrospective reports) lead us to believe they were heavily affected by the process of post-factum verbalisations. That is, although the students were advised against skimming over the

details of experienced cognitive processing, as well as against creating reasons behind their problem-solving approaches and strategies that sounded plausible, many (and analytic students more so) found it easier to use more generic cognitive structures such as memories, opinions, procedural knowledge, and stereotypes as a basis for their judgements. This was perceived as rather detrimental for the lower-level task-specific strategies, as opposed to proto- and metacognitive statements and macro strategies which were less likely to being affected in a negative way. In this sense, we may have acquired both incomplete and somewhat untrue descriptions of the experienced cognitive processes on a micro level.

And, if there was an influence of individual learning styles, it manifested itself in the imposed structure of these reports (much more logical and consistent with analytical students). It is also possible for the recollection of cognitive events to be different for students with different learning styles as it seemed more difficult for wholists to gain access to their micro strategies as many of them occurred in parallel, while the intuitive processes were not accessible for later retrospection, possibly due to the low(er) degrees of conscious control. Some of the characteristic examples include *'the idea just popped in my head,' 'it just felt right to put it here,' 'I thought of so many things at once, I don't know how I ended up with this shape,'* and *'I just let it [sculpture garden] evolve in my head till it was ready [to put on paper].'*

This brings us to the issue of conscious control or choice in strategy use. Control appears to be a question of degree, ranging from unconscious and automatic control to fully conscious control. Self-regulation suggests a situationally sensitive and adaptable approach to the planning, initiation, and maintenance of context appropriate (or disengagement from context inappropriate) intentions (Kuhl, 1985; Rojas-Drummond, *et al.*, 1998). Analytic (field-independent) and wholistic (field-dependent) learners can be distinguished in this respect. The former are more able to make use of appropriate (inhibitory or facilitatory) strategies. The latter are more oriented toward situational cues and make less use of appropriate strategies, even when they are available. Additionally, the students tend to be in exile with regard to their use of a learning strategy, thus contextual effects of different tasks were found to be less a determiner of choice of strategy than stylistic consistency (Pask, 1976; 1988). Once a strategy has been chosen by a student it is rare that it is relinquished, even if it proves difficult to execute.

In either case, style facilitates cognition and so the type of strategy used can indicate a broader dispositional style. That is, many different strategies could be classified as indicators of a particular style as there are many different ways to solve problems that might be termed 'analytic' or 'wholistic.' Importantly, though, not all of these strategies will represent the style with equal clarity/strength as some strategies are better indicators of particular style constructs. The LSA model suggested different strengths of preferences that we used as a guidance with the analysis of proto- and metacognitive statements. A similar scheme (or a measurement model) is needed whereby different strategies can be mapped on to one or more style constructs.

Considering the complexity of the observed situation, the data on micro strategies denoting the four learning styles is excluded from the further analyses. In future studies, it may be advantageous to adopt the bottom-up approach: to try to determine how individuals process information in particular contexts, and then look for consistencies in the strategies used.

Data extraction: Cognitive abilities

In addition to the information on individual learning strategies, we suggested it was possible to extract data on the students' visual-spatial and ideational abilities to, ultimately, determine their correlations with the measurements of individual cognitive factors.

To identify the prevailing approach we followed a similar to the above process of extracting relevant task-specific (micro) strategies and then classifying/coding them in accordance with the descriptions provided by factor-analytic literature and human abilities theories. Table 58 presents several examples related to each cognitive factor as an illustration of the range of extracted statements – to elucidate the basis for coding.

Table 58. Retrospective statements associated with visual-spatial & ideation abilities: Experiment VI/b

Code*	Retrospective statements		
St IF	...where they [spaces] overlap, there might be potential for something interesting happening	I was thinking of art and its connection with nature, so these organic shapes started to emerge	I thought there has to be a difference between her dancing studio & his art studio, you know he's a male, she's a female... so I came up with this [anthropomorphic shape]
St IV	I was thinking 'observatory' and that sort of leads to 'space'		
St MV	I'm just trying to recall that building I saw before	I'm thinking I forgot how the flame-trees look, so I tried to recall it by sketching [trees]	I was thinking of the nice [building] materials I saw the other day, I wanted to use that
St SO	...and then I thought 'if I turn it around, it may look better'	I'm just moving [and rotating] these boxes to see if they fit	I just drew it upside down 'cos I saw something there
St Vz	What I'm doing there is trying to visualize in my head in 3D...	I'm just trying to imagine the view from the balcony upstairs	In my head I was just trying to walk inside the house there... to see how the spaces open up
St SS	Where my pencil goes... I was just walking with it [pencil movements] through the rooms	I sort of walked the street, looked how the houses look, what's their alignment	

* St IF – Figural Ideation Strategy; St IV – Verbal Ideation Strategy; St MV – Visual Memory Strategy; St SO – Spatial Orientation/Mental Rotation Strategy; St Vz – Visualisation Strategy; St VS – Spatial Scanning Strategy

The data resulting from the extraction/coding process was subsequently converted into the quantifiable format by summing up the statements related to (1) each cognitive ability, and (2) each of the three groups of cognitive factors (i.e. visual and verbal ideation and visual-spatial abilities). The total number of statements in each category was estimated from when the subject first read the problem statement to when the subject noted that s/he was finished. Their length was not included as, in many cases, it was too hard to estimate.

After that, a series of correlation analyses were performed using the above data and the data on the measures of individual cognitive abilities, modes of designing, and the number and type of external representations generated. They did not yield consistent/significant correlations apart from the number of visualisation statements being correlated with general visual-spatial ability (first year $r=0.682^*$ one-tailed; fourth and final year $r=0.659^*$ one-tailed) and the repertoire of external representations (first year $r=0.696^*$ one-tailed; fourth and final year $r=0.753^*$ one-tailed). A range of correlations with the modes of designing were down to the inclusion of micro strategies in estimations of the modes of designing.

A further series of correlation analyses were performed using the data on micro strategies denoting cognitive abilities and the data on individual learning styles from LSA assessments and introspective reports. They did not yield many consistent/significant correlations on any dimension, for the exception of the preferred wholistic learning style as assessed by LSA to be correlated with the cumulative number (first year $r=0.784^*$ one-tailed; fourth and final year $r=0.792^*$ one-tailed) of all statements related to cognitive abilities. A moderate correlation was observed between the number of verbal ideation statements and wholistic dimension as per LSA assessments ($r=0.594$) and introspective reports ($r=0.612$), for the first year students, and no significant or moderate correlations for the fourth and final year students.

These results are also excluded from the subsequent analyses as similar (to learning styles micro strategies) problems were encountered in case with cognitive ability statements. Although the cumulative data was statistically justified, it was unevenly distributed (fluctuations ranging from Min=3 to Max=25 statements denoting the same ability in one individual), largely due to the character of retrospective verbalisations, and not because of the experienced cognitive processing (the reasons previously cited). This may be supported by the observation that many students did have a fairly good understanding of their visual-spatial and ideational abilities as the cognitive testing results confirmed their predictions concerning how well they would perform. However, statements like *'I had several ideas in my head to choose from, I combined three, may be four... or five,' 'I'm not sure how this idea emerged, may be I saw something like*

that before,' 'I guess I'm rotating it in my head or I just looked at the sketch and I saw it,' 'I just saw [imagined] this complex form I kept trying to sort out' and 'I'm not very creative today' did not do justice to individual aptitudes.

As it became clear from the previous analyses, in addition to the encountered difficulties in establishing the association between task-specific strategies, cognitive abilities, and learning styles (as the protocol study did not ensure sufficiently rich and consistent data), it is hard to be certain about the interpretations even with the links having been identified. Linear correlations may not be appropriate as different individuals and skill groups have been shown to use alternative strategies for solving similar problems, and those were not always related to their learning styles or/and cognitive abilities. Strategy shifting, for example, has been found as most prevalent in the novice sample as the less experienced students seemed to be trying the best of all available to them strategies in an attempt to discover the answer (Lajoie, 1986).

In future, it seems advantageous to focus on the precise relationship between the even lower processes required to perform psychometric tests (below referred to as *third-grade strategies*), and higher-level processes required for domain-specific tasks (first- and second-grade strategies) when it concerns the role of cognitive abilities in problem-solving. As for the learning styles directing the choice of micro strategies, one also needs to identify which strategies could be classified as indicators of a particular style and to which degree (as they are unequal in strengths), to be more clear about the observed associations.

Learning styles and cognitive abilities in third-grade strategies in problem-solving

There have been a number of studies that addressed the relationship between cognitive abilities and third-grade strategies in past. A process-analytic approach has been used to examine quantitative differences in observed performance as well as qualitative differences with regard to the strategies used by individuals on spatial visualisation tasks (Shepard & Metzler, 1971; Shepard & Feng, 1972; Cooper, 1975, 1983; Sternberg & Weil, 1980; Pellegrino & Kail, 1981; Lohman & Kyllonen, 1983; Bethell-Fox, *et al.*, 1984; Pellegrino, *et al.*, 1984; Kyllonen, *et al.*, 1984; 1985; Lajoie, 1986). It has shown that there are at least two effective strategies that underlie orthographic projection performance.

One such approach is a *constructive strategy* in which individuals mentally construct visual representations of objects that require transformations necessary for problem solution. Much of this strategy depends on the ability to synthesize two orthographic views into one three-dimensional representation. Visual-spatial abilities of rotation, folding, and orientation are also used in this strategy as some people describe rotating the top, front, and side views together by mentally folding them together. Also, some individuals draw 3D pictures to check their orthographic view, while others use other orthographic views to test their line placement.

Another approach is an *analytic strategy* employing a sequential feature-by-feature method of comparison and transformation. It consists of analysing the orthographic views in terms of lines instead of three-dimensional shapes. This strategy does not consist of visualizing a three-dimensional object, but contains the following components: matching lines from the top to the front view to see how they fit together; extending lines from the top to the front, from the top to the side, and from the front to the side to draw the side orthographic view; and verification to see that all lines are accounted for.

Constructive-analytic strategy combines the two strategies by switching back and forth between the two attempting to solve an item.

Another potentially useful approach investigated sketching of remembered objects to gain an insight into supporting it cognitive processing. (Kavakli, *et al.*, 1998). Researchers suggested that humans mentally recognize the spatial organization of their surroundings by thinking of it as a series of *simple* or *combined* three-dimensional shapes/volumes, or the objects are usually sketched as primitive shapes to which later details are added. When one volumetric part was

drawn in its entirety before moving on to another part, it was described as being *part-by-part*. When just an element of a volumetric part was drawn, before moving on to another volumetric part, then drawing activity was treated as not reflecting the use of geometric structural knowledge, and is classified as *non-part-by-part*. The simplification of scenes into geometric shapes (or volumetric primitive objects) is a feature shared in common with several other research theories (Marr, 1982; Biederman, 1990).

These studies describe very different methods, which, nonetheless, may be useful if one wanted to have a conceptual understanding of the relationship between individual abilities, learning styles, and performance in design tasks. Without such understanding predicting problem-solving behaviour based on the chosen individual characteristics is exceedingly difficult, as one can never be certain about what the observed associations indicate.

Correlation analysis

Correlation analysis was performed to establish how two different accounts of the students learning styles (as derived from LSA assessments and introspective reports) were related to their modes of designing, macro and micro strategies in problem solving.

Tables 59-60 indicate a number of common correlations observed in both test groups, although with varying magnitudes of correlation coefficients. Whilst some correlations are only present in either group of subjects. For the first year they include:

1. *Wholistic Learning Style (LSA)* is correlated with *Wholistic Learning Style (Introspective reports)*, *Imagery Learning Style (Introspective reports)*, *Imagery-Verbal (Mode of designing)*, *Imagery-Graphic (Mode of designing)*, *Number of Imagery statements (Prevailing approach)*, and *Length of Wholistic Statements (Prevailing approach)*
2. *Analytic Learning Style (LSA)* is correlated with *Analytic Learning Style (Introspective reports)*, and *Verbal Learning Style (Introspective reports)*
3. *Visual External Learning Style (LSA)* is correlated with *Vertical Idea-Annotations*
4. *Imagery Learning Style (LSA)* is correlated with *Wholistic Learning Style (Introspective reports)*, *Imagery Learning Style (Introspective reports)*, *Imagery-Verbal (Mode of designing)*, *Imagery-Graphic (Mode of designing)*, *Number of Imagery statements (Prevailing approach)*, *Vertical sketch transformations*, and *Horizontal sketch transformations*
5. *Verbal Internal Learning Style (LSA)* is correlated with *Analytic Learning Style (Introspective reports)* (moderate correlation), *Verbal Learning Style (Introspective reports)*, and *Sentential (Mode of designing)*
6. *Verbal External Learning Style (LSA)* is correlated with *Verbal Learning Style (Introspective reports)*, *Graphic (Mode of designing)*, *Verbal-Sentential (Mode of designing)*, and *Number of Analytic statements (Prevailing approach)* (moderate correlation)
7. *Wholistic Learning Style (Retrospective reports)* is correlated with *Imagery Learning Style (Retrospective reports)*, *Imagery (Mode of designing)* (moderate correlation) *Imagery-Verbal (Mode of designing)*, *Imagery-Graphic (Mode of designing)*, *Number of Imagery statements (Prevailing approach)*, and *Vertical sketch transformations*
8. *Analytic Learning style (Introspective reports)* is correlated with *Sentential (Mode of designing)* (moderate correlation), *Length of Analytic statements (Prevailing approach)* (moderate correlation), and *Length of Wholistic statements (Prevailing approach)* (moderate correlation)
9. *Imagery Learning Style (Introspective reports)* is correlated with *Imagery-Verbal (Mode of designing)*, *Imagery-Graphic (Mode of designing)*, *Number of Imagery statements (Prevailing approach)*, and *Vertical sketch transformations*

10. *Verbal Learning Style (Introspective reports)* is correlated with *Graphic and Verbal-Sentential (Modes of designing)* (moderate correlations)
11. *Graphic (Mode of designing)* is correlated with *Verbal-Sentential (Mode of designing)*
12. *Sentential (Mode of designing)* is correlated with *Imagery-Sentential (Mode of designing)*, and *Length of Verbal statements (Prevailing approach)*
13. *Imagery (Mode of designing)* is correlated with *Imagery-Graphic (Mode of designing)*
14. *Verbal (Mode of designing)* is correlated with *Verbal-Sentential (Mode of designing)*, and *Number of Analytic statements (Prevailing approach)*
15. *Imagery-Verbal (Mode of designing)* is correlated with *Imagery-Graphic (Mode of designing)*, and *Number of Imagery statements (Prevailing approach)* (moderate correlation)
16. *Imagery-Graphic (Mode of designing)* is correlated with *Number of Imagery statements (Prevailing approach)* (moderate correlation)
17. *Imagery-Sentential (Mode of designing)* is correlated with *Length of Verbal statements (Prevailing approach)* (moderate correlation)
18. *Graphic-Verbal (Mode of designing)* is correlated with *Number of Verbal Statements (Prevailing approach)* (moderate correlation)
19. *Verbal-Sentential (Mode of designing)* is correlated with *Number of Analytic statements (Prevailing approach)*
20. *Number of Wholistic statements (Prevailing approach)* is correlated with *Length of Wholistic statements (Prevailing approach)*, and *Horizontal sketch transformations* (moderate correlation)
21. *Number of Analytic statements (Prevailing approach)* is correlated with *Length of Analytic statements (Prevailing approach)* (moderate correlation)
22. *Number of Imagery statements (Prevailing approach)* is correlated with *Length of Wholistic statements (Prevailing approach)* (moderate correlation), *Vertical sketch transformations*, and *Horizontal sketch transformations*
23. *Number of Verbal statements (Prevailing approach)* is correlated with *Horizontal idea-annotations* (moderate correlation)
24. *Length of Imagery statements (Prevailing approach)* is correlated with *Vertical idea-annotations* (moderate correlation), and *Horizontal idea-annotations* (moderate correlation)
25. *Horizontal sketch transformations* are correlated with *Vertical sketch transformations*
26. *Horizontal sketch transformations* are correlated with *Versatility* (moderate correlation)
27. *Horizontal idea-annotations* are correlated with *Versatility*.

For the fourth and final years the correlations include:

2. *Wholistic Learning Style (LSA)* is correlated with *Wholistic Learning Style (Introspective reports)*, *Imagery Learning Style Introspective reports*, *Imagery-Verbal (Mode of designing)*, *Length of Wholistic statements (Prevailing approach)*, *Vertical sketch transformations*, *Horizontal sketch transformations*, and *Horizontal idea-annotations* (moderate correlation)
3. *Analytic Learning Style (LSA)* is correlated with *Analytic Learning Style (Introspective reports)*, and *Imagery-Sentential (Mode of designing)*
3. *Imagery Learning Style (LSA)* is correlated with *Wholistic Learning Style (LSA)*, *Imagery Learning Style (Introspective reports)*, *Imagery-Verbal (Mode of designing)*, *Number of Wholistic statements (Prevailing approach)*, *Length of Wholistic statements (Prevailing approach)*

- approach), *Vertical sketch transformations* (moderate correlation), *Horizontal sketch transformations*, and *Vertical idea-annotations* (moderate correlation)
4. *Verbal Internal Learning Style (LSA)* is correlated with *Verbal Learning Style (Introspective reports)*
 5. *Wholistic Learning Style (Introspective reports)* is correlated with *Imagery Learning Style (Introspective reports, Imagery-Verbal (Mode of designing), Number of Wholistic statements (Prevailing approach), Length of Wholistic statements (Prevailing approach), Vertical sketch transformations, and Horizontal sketch transformations*
 6. *Imagery (Introspective reports)* is correlated with *Imagery-Verbal (Mode of designing), Number of Wholistic statements (Prevailing approach), Length of Wholistic statements (Prevailing approach), Vertical sketch transformations (moderate correlation), and Horizontal sketch transformations (moderate correlation)*
 7. *Verbal Learning Style (Introspective reports)* is correlated with *Number of Verbal statements (Prevailing approach), and Length of Verbal statements (Prevailing approach) (moderate correlation)*
 8. *Graphic (Mode of designing)* is correlated with *Sentential (Mode of designing), Verbal (Mode of designing), Verbal-Sentential (Mode of designing) (moderate correlation), and Number of Verbal statements (Prevailing approach) (moderate correlation)*
 9. *Sentential (Mode of designing)* is correlated with *Verbal (Mode of designing), and Number of Verbal statements (Prevailing approach) (moderate correlation)*
 10. *Imagery (Mode of designing)* is correlated with *Imagery-Graphic (Mode of designing)*
 11. *Verbal (Mode of designing)* is correlated with *Verbal-Sentential (Mode of designing)*
 12. *Imagery-Verbal (Mode of designing)* is correlated with *Number of Wholistic statements (Prevailing approach), Length of Wholistic statements (Prevailing approach), Vertical sketch transformations, Horizontal sketch transformations, and Vertical idea-annotations (moderate correlation)*
 13. *Imagery-Graphic (Mode of designing)* is correlated with *Vertical sketch transformations (moderate correlation), and Horizontal sketch transformations (moderate correlation)*
 14. *Imagery-Sentential (Mode of designing)* is correlated with *Graphic-Verbal (Mode of designing) (moderate correlation), and Verbal-Sentential (Mode of designing)*
 15. *Graphic-Verbal (Mode of designing)* is correlated with *Number of Verbal statements (Prevailing approach) (moderate correlation), Length of Imagery statements (Prevailing approach), and Length of Verbal statements (Prevailing approach) (moderate correlation)*
 16. *Number of Wholistic statements (Prevailing approach)* is correlated with *Number of Imagery statements (Prevailing approach), Length of Wholistic statements (Prevailing approach), and Horizontal sketch transformations*
 17. *Number of Verbal statements (Prevailing approach)* is correlated with *Length of Verbal statements (Prevailing approach)*
 18. *Length of Wholistic statements (Prevailing approach)* is correlated with *Length of Imagery statements (Prevailing approach) (moderate correlation), Vertical sketch transformations (moderate correlation), Horizontal sketch transformations, Vertical idea-annotations (moderate correlation), and Horizontal idea-annotations*
 19. *Length of Imagery statements (Prevailing approach)* is correlated with *Length of Verbal statements (Prevailing approach), and Vertical idea-annotations (moderate correlation)*
 20. *Horizontal sketch transformations* are correlated with *Vertical sketch transformations*.

Table 59. Pearson product-moment correlation coefficients: Year 1, Experiments III/b-V/b

Variables	W	A	VisE	Im	VerI	VerE	W	A	I	V	Gr	St	Im	Ver	Im-Ver	Im-Gr	Im-St	Gr-Ver	Ver-St	NW	NA	NI	NV	LW	LA	LI	LV	VTr	HTr	VIA	HIA	Ver
Year 1																																
Wholistic	1																															
Analytic	-0.241	1																														
Visual External	0.184	-0.218	1																													
Imagery	0.635*	0.265	0.413	1																												
Verbal Internal	-0.578	0.582	-0.286	-0.304	1																											
Verbal External	-0.441	0.167	-0.582	-0.564	0.218	1																										
Wholistic	0.865**	-0.091	0.298	0.751*	-0.417	-0.667*	1																									
Analytic	-0.360	0.871**	0.081	0.358	0.530	-0.101	-0.106	1																								
Imagery	0.691*	0.169	0.483	0.890**	-0.160	-0.761*	0.848**	0.294	1																							
Verbal	-0.474	0.698*	-0.294	-0.219	0.740*	0.639*	-0.536	0.482	-0.310	1																						
Graphic	-0.546	0.359	-0.645*	-0.697*	0.445	0.817**	-0.662*	0.099	-0.708*	0.623	1																					
Sentential	-0.397	0.355	0.328	0.116	0.650*	-0.170	-0.286	0.583	0.175	0.472	-0.176	1																				
Imagery	0.593	-0.570	0.424	0.287	-0.663*	-0.516	0.575	-0.593	0.300	-0.664*	-0.623	-0.453	1																			
Verbal	-0.266	0.020	-0.107	0.000	0.161	0.430	-0.344	0.181	-0.129	0.294	0.128	0.363	-0.630	1																		
Imagery-Verbal	0.715*	0.061	-0.017	0.666*	-0.343	-0.604	0.882**	-0.022	0.680*	-0.503	-0.536	-0.377	0.531	-0.499	1																	
Imagery-Graph.	0.772**	-0.135	0.386	0.665*	-0.497	-0.812**	0.901**	-0.113	0.762*	-0.655*	-0.704*	-0.307	0.739*	-0.636*	0.879**	1																
Imagery-Sent.	-0.591	0.104	0.303	-0.079	0.316	-0.020	-0.512	0.483	-0.109	0.199	-0.076	0.765**	-0.563	0.604	-0.591	-0.500	1															
Graph.-Verbal	0.092	0.317	-0.136	-0.229	0.096	0.438	-0.003	-0.002	-0.152	0.403	0.601	-0.331	-0.176	-0.216	-0.117	-0.098	-0.415	1														
Verbal-Sent.	-0.480	0.183	-0.308	-0.363	0.262	0.780**	-0.669*	0.166	-0.489	0.566	0.646*	0.146	-0.722*	0.780**	-0.753*	-0.856**	0.393	0.192	1													
N Wholistic	0.470	0.099	-0.592	0.186	0.083	0.099	0.231	-0.152	0.172	0.123	-0.009	-0.049	-0.106	0.109	0.352	0.082	-0.311	-0.065	-0.029	1												
N Analytic	-0.471	0.071	-0.503	-0.286	0.092	0.581	-0.420	0.133	-0.446	0.141	0.478	-0.146	-0.614	0.700*	-0.337	-0.620	0.290	-0.064	0.703*	-0.058	1											
N Imagery	0.648*	0.234	0.381	0.918**	-0.086	-0.516	0.744*	0.312	0.925**	-0.090	-0.640*	0.268	0.152	0.157	0.554	0.545	-0.040	-0.170	-0.246	0.307	-0.278	1										
N Verbal	0.092	0.220	-0.220	-0.268	0.287	0.151	-0.080	0.094	0.010	0.257	0.491	0.011	-0.454	0.005	-0.203	-0.149	-0.042	0.619	0.266	0.250	-0.052	-0.075	1									
L Wholistic	0.675*	-0.211	-0.101	0.390	0.005	-0.328	0.595	-0.279	0.566	-0.200	-0.407	0.024	0.208	0.101	0.466	0.376	-0.322	-0.215	-0.219	0.702*	-0.230	0.632	0.145	1								
L Analytic	-0.108	0.378	-0.279	0.268	0.051	0.008	-0.128	0.545	0.161	0.037	0.088	0.169	-0.564	0.496	-0.004	-0.167	0.419	-0.309	0.415	0.249	0.509	0.211	0.184	0.024	1							
L Imagery	-0.028	0.396	0.538	0.335	-0.172	-0.193	-0.051	0.506	0.234	0.116	-0.071	0.181	0.027	-0.206	-0.104	0.167	0.228	0.180	0.010	-0.442	-0.327	0.131	0.083	-0.508	0.214	1						
L Verbal	-0.200	0.213	0.455	0.049	0.413	-0.011	-0.312	0.363	0.151	0.482	-0.004	0.758*	-0.338	0.350	-0.572	-0.330	0.564	-0.005	0.394	-0.130	-0.242	0.234	0.311	0.041	0.122	0.438	1					
Vertical Trans.	0.227	0.391	0.225	0.687*	0.279	-0.379	0.451	0.415	0.650*	0.172	-0.448	0.388	0.143	0.013	0.431	0.340	-0.074	-0.324	-0.235	0.142	-0.244	0.748*	-0.391	0.452	0.047	0.041	0.221	1				
Horiz. Trans.	0.236	0.450	0.321	0.708*	0.107	-0.368	0.366	0.435	0.582	0.187	-0.433	0.315	0.280	-0.202	0.403	0.407	-0.121	-0.251	-0.295	0.052	-0.439	0.636*	-0.424	0.203	0.027	0.392	0.259	0.892**	1			
Vertical Idea-An.	0.254	-0.302	0.724*	0.420	-0.559	-0.553	0.192	-0.208	0.326	-0.460	-0.718	0.197	0.470	-0.148	0.096	0.415	0.329	-0.408	-0.394	-0.243	-0.483	0.228	-0.335	-0.157	-0.006	0.550	0.206	-0.029	0.222	1		
Horiz. Idea-An.	0.393	0.408	-0.089	0.345	-0.245	-0.102	0.260	0.324	0.324	-0.029	0.084	-0.193	-0.177	-0.151	0.300	0.301	-0.110	0.403	-0.047	0.286	-0.115	0.224	0.559	-0.050	0.479	0.502	-0.039	-0.239	-0.050	0.185	1	
Versatility	0.575	0.481	0.218	0.785**	-0.339	-0.259	0.535	0.399	0.645*	-0.008	-0.244	-0.140	0.162	-0.191	0.516	0.542	-0.270	0.231	-0.171	0.160	-0.293	0.626	0.089	0.084	0.327	0.649*	0.055	0.359	0.573	0.302	0.726*	1

LSA assessments
 Introspective reports
 Modes of designing
 Prevailing approach (N – number of statements; L – length of statements)

* Correlation is significant at the 00.05 level 2-tailed.

** Correlation is significant at the 00.01 level 2-tailed.

Table 60. Pearson product-moment correlation coefficients: Years 4&5, Experiments III/b-V/b

Variables	W	A	VisE	Im	VerE	VerI	W	A	I	V	Gr	St	Im	Ver	Im-Ver	Im-Gr	Im-St	Gr-Ver	Ver-St	NW	NA	NI	NV	LW	LA	LI	LV	VTr	HTr	VIA	HIA	Ver
Years 4&5																																
Wholistic	1																															
Analytic	-0.756*	1																														
Visual External	0.031	-0.156	1																													
Imagery	0.877**	-0.479	-0.175	1																												
Verbal External	0.043	-0.218	0.034	-0.244	1																											
Verbal Internal	0.120	-0.175	-0.064	0.000	0.356	1																										
Wholistic	0.929**	-0.642*	0.140	0.913**	-0.018	0.000	1																									
Analytic	-0.619	0.959**	-0.012	-0.333	-0.321	-0.130	-0.490	1																								
Imagery	0.909**	-0.605	-0.027	0.953**	-0.139	-0.120	0.971**	-0.473	1																							
Verbal	-0.403	0.280	-0.044	-0.501	0.387	0.801**	-0.499	0.223	-0.618	1																						
Graphic	-0.714*	0.399	-0.513	-0.570	0.240	-0.033	-0.660*	0.170	-0.575	0.280	1																					
Sentential	-0.574	0.358	-0.577	-0.449	0.280	0.141	-0.568	0.115	-0.521	0.485	0.862**	1																				
Imagery	0.364	-0.248	0.597	0.220	-0.253	-0.142	0.422	-0.101	0.352	-0.303	-0.675*	-0.748*	1																			
Verbal	-0.688*	0.378	-0.398	-0.623	0.241	-0.157	-0.701*	0.179	-0.603	0.184	0.876**	0.695*	-0.737*	1																		
Imagery-Verbal	0.874**	-0.626	-0.190	0.904**	-0.087	0.130	0.813**	-0.503	0.829**	-0.387	-0.535	-0.369	0.013	-0.551	1																	
Imagery-Graph.	0.491	-0.297	0.458	0.273	-0.139	0.195	0.390	-0.151	0.274	0.036	-0.834**	-0.623	0.772**	-0.876**	0.248	1																
Imagery-Sent.	-0.557	0.655*	-0.505	-0.281	-0.158	-0.250	-0.562	0.566	-0.442	0.053	0.545	0.513	-0.792**	0.676*	-0.201	-0.689*	1															
Graph.-Verbal	-0.375	0.411	-0.427	-0.158	-0.134	0.491	-0.420	0.438	-0.378	0.445	0.378	0.266	-0.481	0.295	-0.067	-0.368	0.506	1														
Verbal-Sent.	-0.681*	0.596	-0.326	-0.667*	0.195	-0.278	-0.769**	0.449	-0.681*	0.143	0.607	0.434	-0.533	0.817**	-0.607	-0.572	0.728*	0.275	1													
N Wholistic	0.717*	-0.641*	0.493	0.669*	-0.036	0.068	0.812**	-0.449	0.719*	-0.388	-0.661*	-0.620	0.343	-0.653*	0.718*	0.344	-0.491	-0.282	-0.779**	1												
N Analytic	-0.283	0.048	0.017	-0.174	-0.315	-0.408	-0.256	0.013	-0.208	-0.343	0.179	0.040	-0.108	0.074	0.017	-0.153	0.279	0.163	0.085	0.070	1											
N Imagery	0.175	-0.188	0.507	0.263	-0.216	0.163	0.304	-0.006	0.201	-0.088	-0.378	-0.389	0.106	-0.430	0.388	0.155	-0.114	0.196	-0.534	0.759*	0.429	1										
N Verbal	-0.548	0.259	-0.378	-0.591	0.022	0.524	-0.737*	0.142	-0.708*	0.720*	0.517	0.529	-0.383	0.475	-0.468	-0.195	0.256	0.604	0.407	-0.687*	-0.050	-0.337	1									
L Wholistic	0.858**	-0.624	-0.042	0.811**	-0.214	0.362	0.729*	-0.439	0.723*	-0.185	-0.706*	-0.561	0.220	-0.656*	0.872**	0.472	-0.367	0.042	-0.650*	0.655*	-0.194	0.360	-0.221	1								
L Analytic	0.046	-0.022	-0.488	0.244	-0.545	-0.335	0.018	-0.017	0.230	-0.514	0.182	-0.108	-0.081	0.277	0.120	-0.389	0.266	0.269	0.195	-0.177	0.108	-0.241	0.120	0.177	1							
L Imagery	0.086	0.151	-0.289	0.306	-0.647*	0.361	-0.007	0.286	0.060	0.165	-0.225	-0.141	-0.129	-0.203	0.318	0.112	0.267	0.647*	-0.165	0.037	0.009	0.285	0.359	0.555	0.396	1						
L Verbal	-0.320	0.419	-0.368	-0.206	-0.227	0.451	-0.442	0.419	-0.388	0.574	0.210	0.304	-0.415	0.342	-0.229	-0.198	0.443	0.588	0.334	-0.492	-0.428	-0.255	0.704*	0.061	0.251	0.674*	1					
Vertical Trans.	0.649*	-0.213	0.069	0.618	0.206	0.373	0.632*	-0.079	0.515	0.100	-0.623	-0.302	0.195	-0.735*	0.650*	0.574	-0.305	-0.093	-0.553	0.528	-0.246	0.325	-0.426	0.585	-0.518	0.132	-0.191	1				
Horiz. Trans.	0.706*	-0.296	0.260	0.687*	0.114	0.390	0.735*	-0.096	0.610	0.028	-0.723*	-0.479	0.235	-0.741*	0.692*	0.515	-0.346	-0.080	-0.647*	0.730*	-0.326	0.517	-0.509	0.698*	-0.418	0.227	-0.122	0.921**	1			
Vertical Idea-An.	0.380	-0.262	-0.255	0.571	-0.356	0.042	0.367	-0.195	0.437	-0.210	-0.164	0.016	-0.438	-0.049	0.670*	-0.211	0.314	0.135	-0.287	0.441	0.045	0.389	-0.165	0.577	0.271	0.551	0.260	0.191	0.353	1		
Horiz. Idea-An.	0.503	-0.517	-0.188	0.337	0.066	0.492	0.271	-0.413	0.299	0.056	-0.283	-0.364	-0.017	-0.101	0.446	0.109	-0.194	0.313	-0.116	0.200	-0.335	-0.014	0.258	0.704*	0.412	0.453	0.361	0.088	0.227	0.277	1	
Versatility	0.419	-0.038	0.125	0.448	-0.117	-0.055	0.437	0.149	0.423	-0.374	-0.534	-0.711*	0.511	-0.578	0.367	0.414	-0.243	0.139	-0.222	0.355	0.119	0.277	-0.424	0.398	0.125	0.147	-0.341	0.462	0.450	-0.218	0.242	1

LSA assessments
 Introspective reports
 Modes of designing
 Prevailing approach (N – number of statements; L – length of statements)

* Correlation is significant at the 00.05 level 2-tailed.

** Correlation is significant at the 00.01 level 2-tailed.

6.3.4 Conclusions

This subsection is concerned with the results of the above correlation analyses; it does not review the broad range of observations derived from the earlier qualitative and quantitative (comparative) analyses for the purpose of clarity and conciseness. A summary of all results discussed in Section 6.3 is presented in Chapter 7.

The results generally confirm the earlier comparative, and are in conformity with the results and observations derived from the previous correlation analyses suggesting that Wholistic and, more so, Imagery learning styles are likely to be the best predictors of the design performance.

Modes of designing. Correlation analysis between the first, and fourth and final year participants allowed examining the participants' preferences for reasoning and presenting information in relation to individual learning styles as assessed by LSA. The results suggested that the first year Wholistic and Visual students are likely to resort to imagery, imagery-verbal and imagery-graphic modes of designing, while verbal students prefer sentential and verbal-sentential modes of representation. When it concerns the fourth and final year Wholistic students, they are inclined to imagery-verbal, and less so imagery-graphic modes of designing. Analytic students from the same year prefer imagery-sentential mode of designing, while Imagers resort more to the imagery-verbal reasoning and representations. The results are generally consistent with both LSA assessments and introspective reports.

Prevailing approach. The four types of macro strategies were suggested to be associated with the four learning styles or metacognitive reasoning executed in planning, monitoring or global approaches to problem-solving situations. The results of correlation analyses suggest that this link is present when it concerns Wholistic and Imagery dimensions for both groups of students (confirmed by LSA assessments as well as introspective reports). In other words, it is the wholistic and visual students in both the first and the fourth and final years of study who prefer to resort to wholistic and visual reasoning on the level of macro strategies.

There is no significant correlations with Verbal or Analytic learning styles, and only a weak correlation between Analytic and Verbal learning styles as assessed by LSA and the length of verbal statements for the fourth and final year students, and between the Verbal learning style and the length of verbal statements for the fourth and final year students. The reasons for the latter lack of correlation are not entirely evident. Our observations and the earlier statistical analyses suggest that analytic, as well as verbal students tend to report more on their micro strategies, and, correspondingly, the correlations are strong there. This could be due to the nature of analytic problem-solving concerned with addressing small(er) chunks of information (design concerns) and one at a time. This issue, however, requires further research.

Additionally, correlation coefficients vary when it concerns the type of analysed statements. Among the first year students, it is the number of these statements that is correlated with the highest amount of other variables (ten significant and moderate correlations), and not their length (nine significant and moderate correlations). The situation is reverse for the fourth and final year students (nine and eleven significant and moderate correlations respectively). The observation is especially apparent when only significant correlations are considered. The reasons are not entirely clear; they may be related to the differences in the students cognitive processes as the first year students tended to move more between design episodes and address a smaller number, or less complex, issues at a time, but at a faster pace. Or there may be reasons related to the quality of retrospective verbalisations, as the number of recollected cognitive processes is in direct relationship with other variables and may, therefore, reflect a real design process better. In future, one needs to address both the duration and the frequency of cognitive events to obtain a fuller account of the researched issue.

Horizontal and vertical transformations. A correlation analysis indicated the students' tendency to produce work that is either horizontally or vertically biased relative of their learning styles preferences as assessed by LSA and of their introspective reports. No correlations have been observed on the Analytic and Verbal dimensions, with only a weak tendency for the first year analytic students to produce more horizontal and vertical transformations (consistent across LSA assessments and introspective reports). This may be related to the observation for the wholistic students to start designing after absorbing information and spending more time on the internal development of conceptual ideas. Whilst the analytic students were more comfortable with following the learnt design routines and spent much less time trying to come up with an interesting concept. Thus, their solutions indicated early fixation and many lateral transformations were down to generating a number of various detail changes.

The situation was reverse for the fourth and final year students, where wholists appeared to be significantly more productive (consistent across LSA assessments and introspective reports). It may be supported by the observations derived from analysing the students' modes of designing, which indicated for the fourth and final year students (particularly wholists) to have more integrated design processes. That is, it is likely that the knowledge and the skills acquired during design education enabled senior subjects to process more information in parallel, or/and to be more efficient while doing it, and therefore to produce richer (more detailed and more diverse) representations. Additionally, there are more A-W versatile individuals among the fourth and final year students, as indicated by the LSA.

On the Imagery dimension, the results are similar for both groups. They are consistent for both LSA assessments and introspective reports although the correlation coefficients vary. There is a clear tendency for the visual individuals to generate more horizontal and verbal transformations than was observed among the verbal and analytic students. The reasons are probably related to the visual nature of design problem-solving, both internal (imagery) and external (sketching).

In future, it may be easier to understand individual problem-solving and, possibly, discover more common trends that influence/direct transformational activity by looking at the wider range of processes, that is by including the ones that occur internally. As well as at the differences in individual capabilities for complex integrative reasoning, which is likely to affect both the rate/intensity and the pattern of sketching.

Horizontal and vertical idea-annotations. There were no significant correlations observed apart from the association vertical idea-annotations with Visual External learning style (as assessed by LSA) for the first year students. The nature of this link is not clear.

Other results varied on horizontal and vertical idea-annotations. It is the wholistic, and visual students among the first year participants, who were the most productive on both dimensions, but the correlation coefficients are weak. While the fourth and final year wholists had a slight tendency to produce more horizontal idea-annotations, and the imagers were inclined to more vertical idea-annotations. There was also a tendency for analytic and verbal individuals in both groups to generate the lowest number of both types of annotations.

The reasons for the lack of correlations are likely to be multiple and interacting. As the participants have chosen to convey both visual and verbal ideas and in a written form, it is possible for the observed situation to be less related to the preferences on Visual-Imagery dimension, but to the rate of idea-production, design knowledge, and the very nature of annotations, such as their vagueness and speed of noting down. They could appear at any point of time and had a broad range of purposes – from structuring thoughts and planning problem-solving, to explaining and refining ideas, or recording newly emerging ideas on the fly, before having them overlooked or forgotten. Many students chose sentential form of representation when they felt there was not enough time for adequate graphic depictions. While other participants who lacked in sketching ability (or whose ideas were too complex for their levels of sketching) felt it was easier for them to resort to written descriptions. The protocol session constraints may have also influenced the rate of and the type of preference for annotations.

Versatility. As Tables 60-61 indicate, the broader repertoire of learning styles may have an influence on the rate of horizontal sketch transformations and horizontal idea-annotations but mainly for the first year students. The correlation magnitudes are low(er) for the fourth and final year as, perhaps, there are lower score fluctuations (i.e. more students with similar strengths of learning style preferences). This is generally consistent with our previous results concerning versatility (Table 37). In other words, being flexible in utilising different approaches to problem solving may have an advantage in terms of the levels of ideation and detailing, but not necessarily in a form of a linear relationship.

W-I, W-V, A-I, and A-V learners. There have also been a few associations observed between the four style combinations as assessed by LSA, and generated external representations. For example, Analytic-Imagers and Analytic-Verbalisers produced the biggest number of idea-annotations ($r=0.756^*$, $r=718^*$, one-tailed), while Wholistic-Imagers tend to produce the highest numbers of horizontal transformations ($r=0.688^*$ one-tailed). However, there are two important considerations that do not permit discussing these as valid trends. Firstly, it is the size of the sample. That is, while there may be some reliable associations observed between single styles and external representations, when style combinations are considered, there is not enough data for statistical analyses on some of the dual dimensions. Additionally, the issue of brain-giftedness need being understood further before any conclusions are drawn, as these students (and this is generally true for versatile subjects as well) tend to generate higher numbers of external representations (Figures 11-12), broader repertoires of schema for external representations (Table 37), and more horizontal and vertical sketch transformations. In other words, it is possible that the (potential) ability of these students to be more flexible in utilising different approaches in design tasks, has resulted in differences in the process and the outcome of individual problem-solving.

6.4 Design Solutions Assessment

Experiment VI/b is concerned with the students' final products of individual problem-solving as assessed by three independent evaluators. The method used is derived from the by procedures initially outlined by Winer (1971) and a number of taxonomies used in earlier design studies (Amabile, 1996). The ultimate purpose of this part of the thesis is providing the basis for inter-relations and correlations between the data acquired through it, and various aspects of the *input* and the *process* of designing, obtained through all administered experiments.

On a more detailed level, this part of the research aims at: **(1)** establishing a taxonomy that allows generating data that can be related to the differences in design abilities; **(2)** collecting assessments of individual design solutions, and exploring relationships and correlations among them, including (a) variability attributed to gender and ethnic origin, and (b) differences/similarities in the learning styles and cognitive abilities of the first and fourth-final years students; and **(3)** exploring a range of links between the measures of academic performance and creativity, learning styles, cognitive abilities, internal and external representations, characteristics of the design process, and the design solutions assessments.

The above parameters are similar to those analysed in Experiments I/b-V/b. The data from the current experiment, along with an extended multivariate data analysis involving Experiments I/b-VI/b, is discussed in Subsection 6.4.1, whereas Subsection 6.4.2 presents a list of conclusions pertaining to all experiments and major datasets.

6.4.1 Experiment VI/b: Assessment, Analysis and Findings.

The reasoning behind conducting Experiment VI is related to the proposition that certain qualitative and quantitative characteristics of generated diagrams, sketches and annotations may be associated with the differences in individual learning styles and cognitive abilities. It was

expected, for example, from designers with wholistic approach, who are viewed as individuals with innovator traits, to produce designs, assessed as original, attractive and transformational. While analytic individuals, seen as adaptors, were expected to produce designs which were more logical, functional and useful. Similarly, the data from this experiment was aimed at determining whether the students' ideational and spatial abilities had an affect on the quality and quantity of ideas present in design drawings, and on other characteristics of generated sketches. The procedure and the dimensions of the design product assessment are outlined below.

Judges

The three judges rating design drawings included representatives from education and practice. They were familiar with the domain, to have developed, over a period of time, some implicit criteria to assess creativity and other measures of professional merit. They were also accustomed with the educational requirements in the first, and fourth and final years of study.

The first judge is a course supervisor currently professionally involved with the Faculty of Architecture, who has worked on studio projects both with pre-architecture and architecture students. The second judge is a university graduate and a professional architect with over than ten years of domain experience. The third judge is the graduate of the Faculty of Architecture, The University of Sydney, who had completed his course of study three years prior to the assessment, and has been working in architecture since then. It was expected that inviting three judges with somewhat dissimilar backgrounds would elicit a richer, and perhaps a more plausible account of the explored issue. There was a danger for the consensus score to appear unacceptably low (i.e. with the average agreement below 60% across all items) due to these differences. If this proved to be the case, we were prepared to identify reasons for the lack of consensus, invite more evaluators, and/or improve the research methodology.

Procedure

The judges were provided with rating sheets, containing descriptions of the assessment dimensions; they also received verbal and written instructions to get accustomed with – prior to commencing the rating process. The instructions express a number of requirements as listed in Table 61 and appearing on the distributed hand-outs.

Table 61. The creative product assessment instructions: Experiment VI/b

Assessment Guidelines
All dimensions are included on each rating sheet; there are twenty sheets to rate. Please complete the ratings proceeding at your own pace. 1. Before beginning the rating process, please accustom yourself with the design brief 2. Browse through the range of student drawings to familiarize yourself with the projects and establish your own impression of the overall range of project merit represented 3. It is important that you rate the projects relative to one another (for each of the two student groups separately) and <u>then</u> with respect to the design brief and your domain expertise, and <u>not</u> according to some absolute standard for excellence 4. Rate all projects according to the dimensions described on each sheet before moving to the next rating sheet 5. The projects may be selected for rating in any random order and the order may be different for each sheet as you go through the rating process 6. When you have finished the ratings, please make sure that all project numbers and ratings are complete, and return the forms 7. Any additional comments or observations arising during the rating process are welcome and will be noted down by the researcher <u>Please remember</u> that the difficulty of a design task varies with the background and repertoire of the designer. A pre-architect may not perform well on architectural design briefs as the performance is affected by their prior learning experience. Please make your judgements in terms of the measurement of achievement (or how well the relevant skills and knowledge have been learned) <u>or/and</u> considering the individual's natural potential.

The bottom note was included in the guidelines as a reminder – whereas the assessments were to be done from the perspective of architectural education and by experienced architects, fifty percent of the sample were pre-architecture students. Evidently, the knowledge of freshmen and fourth and final year students in dealing with architectural design problems varied significantly, while both groups did not have the expertise of a professional architect. Additionally, the requirements to design solutions established in education (and most familiar to the first judge) are different for the architecture and pre-architecture students, and, equally, to the standards adopted in the professional domain. This could translate onto the approaches to problem solving and affect the design solutions as the first year design students are, typically, encouraged to experiment and be creative while learning ‘designerly thinking’. Whereas the final year architecture students are oriented towards making their design solutions not only original or innovative but functional, logical, useful, and so on. Thus, the levels of expertise as well as the specifics of design and architecture education needed being considered in the rating process.

The design product was evaluated with the help of transcripts and video recordings provided by the researcher, as the students’ ideas and intentions became more clear via gaining access to their verbal reports and ongoing sketching activities. The introspective statements and questionnaires also played a part in the design product assessment – they provided additional information on the participants’ experiences and capabilities. To assist with creativity grading, self-reports were examined to help understanding the bases for design solutions – whether they involved adapting or combining formerly seen cases, whether they emerged as complex transformations or a synthesis of remote ideas, were triggered by associative thinking, or other.

Dimensions of judgement

Four sets of criteria have been developed to assess the quality of the students’ designs. The first has three components and is a measure of whether the final design meets a number of constraints specified in the problem statement. The first component is the *client*, it contains 2 constraints and refers to understanding of the nature of the client. The second component is the *site*, containing 2 constraints; it addresses a number of issues related to the site analysis. The third component is the *house* containing 12 constraints. It deals with resolution of 10 functional spaces, their placement and xyz dimensions. The final design could score of 1 to 16 based on the number of constraints met, with subsequent conversion into 4-point scales (i.e. 16-13 – ‘very good’, 12-9 – ‘good; 8-5 – ‘average-good’; 1-4 – ‘average’) used across all other experiments and assessment dimensions.

The second criterion contains three components. As the students’ design solutions can be viewed as artefacts or creative products, they were assessed along a number of parameters typically used for the evaluation of creativity.

Creativity/Originality. The degree to which the design is creative is measured using the judges’ own subjective definitions of creativity. It refers to producing unusual, uncommon and novel ideas, questions, suggestions or solutions, ways of doing things as a result of seeing new relationships among ideas, combining remote ideas, improving things on new lines, etc.

Complexity and Elaboration. Refers to the ability of participants to articulate ideas in terms of related and composite parts; developing the basic idea, figure, object, insight, into details looking into the implications of ideas.

Flexibility and Fluency. Refers to producing a variety of ideas, solutions, possibilities, interpretations, by shifting perspectives, methods, designs, approaches in the direction of thinking and valuing multiple viewpoints and possibilities

The third criterion is *Functionality and General Knowledge of Design Process* evaluating the degree to which the designed space is functional. It also refers to displaying the design process knowledge and skills, including skill in task clarification, concept generation, evaluation and refinement, and overall skill displayed in the execution of design process.

Technical Merit of Design Drawings is the fourth and final criterion assessing the degree to which the project, overall, is good technically. Analysing the levels of students' graphical proficiency helped understanding the role of sketching in problem solving – whether it served as a good/bad interactive thinking tool, a mere means of the imagery externalisation, etc. Whilst the speed and accuracy in design drawing could facilitate or impede the process of ideation.

Scoring

The final result involving all four criteria was obtained by weighting all of its parts equally to obtain an average score ranging from 4 to 1 (corresponding to 'very good', 'good', 'average-good' and 'average') to enable comparisons and correlations with different measures of this and other experiments utilising 4-point scales. The consensus score (counted as a mean for each student on the basis of the three judges assessments) was prepared for the use in subsequent analyses. All additional notes and observations produced by the judges (illustrated by Tables 62 and 63) were taken into account to assist with data interpretations.

Collected data

In addition to completing rating sheets, the judges shared their observations pertaining to the participants' styles of problem solving, probable learning issues, strengths and limitations (where found appropriate). These comments were noted down by the researcher to gain a more informed opinion and a better understanding of the applied assessment principles and grounds for judgements. The evaluators' scores were derived from looking at the final solutions as well as at the video tapes and transcripts of design sessions. This was done with the purpose of reconstructing the discourse within which different aspects of design solutions were generated to establish a bridge between a design product and the thought which led to its creation.

Table 62 contains two examples of the judges' assessments and observations concerning the first year students. S02(I) – is a learner with Wholistic-Visual preferences, and flexibilities in Analytic and Verbal modes. S06(I) is an learner with Analytic flexibility, strong preference in Verbal mode, and adaptabilities in Wholistic-Imagery modes – as reported by LSA profiles.

Table 62. Sample combined rating sheets for students S02(I) and S06(I)

Rating Sheet * Student S02(I) Wholistic-Visual Learner **								
Name of the Judge <u>XXXXXXXX XXXXXXXXXX</u> Student's Name <u>XXXXXXXX XXXXXXXXXX</u> S02(I)								
Constraints	Score			Assessment Dimensions	Score			
Client: (1) dancer; (1) painter	2	2	2	Constraints met ***	3	3	3	
Site analysis: (1) orientation (north, sun, noise, etc); (1) slope	1	1	1	Creativity/Originality	3	3	3	
House: (10) incorporation of 10 functional spaces; (1) views/placements; (1) dimensions (vertical & horizontal)	8	7	8	Complexity/Elaboration	2	1-2	2	
				Flexibility and Fluency	3	2-3	3	
				Functionality and Knowledge	2	1	2	
				Technical Merit	2	2	2	
Additional observations (Judge 1): Good understanding of functions and zones. Good go at outdoor and indoor spaces. The overall look is clear from sketches, but the organising principle or conceptual idea are not articulated enough graphically, although verbal attempts were made to express it (judging by transcripts as well as annotations). Three-dimensional forms are drawn to see if mental images could be externalised on paper, but may be inhibited by insufficient sketching ability. More visually than verbally oriented. Additional observations (Judge 2): Prefers complex functional diagrams that he tries to translate directly into 3D shapes. Mostly working on a macro-level. Could be forced to simplify pre-visualised ideas by the lack of graphical skill. A wholistic thinker who deals well with identifying key relations and properties and giving the overall form, but lacks in ability to integrate them when it comes to developing plans. Annotations are informative but scarce, which suggests a visual person with moderate verbal orientation. Additional observations (Judge 3): Good understanding of volumes and spaces. Confident with expressing ideas in 3D, despite somewhat limited graphical skill. Not enough interaction with paper when it comes to plans or 2D and 3D views, robust ideas are drawn from the head, then adjusted and decorated on paper. May find it difficult to perform the 'routine' design.								

Student S06(I) Analytic-Verbal Learner							
Constraints	Score			Assessment Dimensions	Score		
Client: (1) dancer; (1) painter	0	0	0	Constraints met	3	3	3
Site analysis: (1) orientation (north, sun, noise, etc); (1) slope	1	1	1	Creativity/Originality	1-2	2	2
House: (10) incorporation of 10 functional spaces; (1) views/placements; (1) dimensions (vertical & horizontal)	8	9	8	Complexity/Elaboration	2	2	2
				Flexibility and Fluency	1	1	1
				Functionality and Knowledge	2	1-2	2
				Technical Merit	1	1	1-2
Additional observations (Judge 1): This is a word-centred thinker arranging boxes. Planning happens on paper only. Doesn't have much of an overview in his head. Shows no presence of a general/conceptual idea (or at least not apparent from his drawings, annotations and verbalisations). Not very confident with graphic expression.							
Additional observations (Judge 2): This student may suffer from teaching limitations, only knows how to organise and decorate boxes. A good go at floor specifications although limited by his knowledge. Simplistic approach, tries to compensate it by the unnecessarily high level of detailing. Seems to be stuck at the preliminary analysis. Possibly likes to follow exact guidelines, afraid to experiment, needs self-assurance.							
Additional observations (Judge 3): The 'box' hasn't relaxed. Not interested in form, fixation on the plan. Lack of understanding of the nature of the client, but tries to accommodate some of the site qualities. Tries to consider a number of issues but the result doesn't quite fit in together.							

- * this sample rating sheet is a combination of three separate hand-completed original sheets supplemented by the judges' observations noted down by the researcher during their post-assessment discussions
- ** data on learning styles as indicated by LSA profiles, was not included on original rating sheets but filled in later
- *** this is the final average score for all constraints met, converted by the researcher into a 4-point scale

Table 63 contains two more examples of the judges' assessments supplemented by their observations concerning the fourth and final year students. S15(V) – is a learner with strong preferences in Wholistic-Visual mode, flexibilities in Analytic, and preferences in Verbal modes. S12(IV) is an learner with preference in Analytic and strong preference in Visual mode, and flexibilities in Wholistic-Verbal modes – as indicated by their LSA profiles.

Table 63. Sample combined rating sheets for students S15(V) and S12(IV)

Student S15(V) Wholistic-Visual Learner							
Constraints	Score			Assessment Dimensions	Score		
Client: (1) dancer; (1) painter	2	2	2	Constraints met (adjusted)	2/3	2	2
Site analysis: (1) orientation (north, sun, noise, etc); (1) slope	2	1-2	2	Creativity/Originality	4	3-4	4
House: (10) incorporation of 10 functional spaces; (1) views/placements; (1) dimensions (vertical & horizontal)	5	4	4	Complexity/Elaboration	4	4	4
				Flexibility and Fluency	4	3-4	4
				Functionality and Knowledge	2	1-2	2
				Technical Merit	2	1-2	2
Additional observations (Judge 1): Modern language approach, very complex. Planning is not helping much, struggling with drawings. Seems like he has it worked out in his head on a macro level, but needs models to see it in detail and make it work by testing. More of a conceptual thinker who is concerned with ideas more than with implementation and representation. Possibly finds it hard to concentrate on one thing or detail at a time, seems struggling to finish what he started.							
Additional observations (Judge 2): This student is a creative thinker but does not seem to follow any specific procedure, randomly externalising pre-existing or emerging ideas. May be sketching is not his/her strongest side. On the whole, seems more concerned with the overall form than with spaces or functions.							
Additional observations (Judge 3): Seems pressed for time, well-rounded in understanding different aspects of the design task, but uses unsystematic, hit and miss approach. May have a complex mental model that is hard to visualise in detail and, therefore, hard to put on paper, especially under time constraints. Seems rather confident with his unusual ideas and approach. Does not resort to much writing.							

Student S12(IV) Analytic-Visual Learner							
Constraints	Score			Assessment Dimensions	Score		
Client: (1) dancer; (1) painter	0	0	2	Constraints met (adjusted)	4	4	4
Site analysis: (1) orientation (north, sun, noise, etc); (1) slope	2	2	2	Creativity/Originality	1-2	2	2
House: (10) incorporation of 10 functional spaces; (1) views/placements; (1) dimensions (vertical & horizontal)	12	11	11	Complexity/Elaboration	2	2-3	2
				Flexibility and Fluency	2	2	2-3
				Functionality and Knowledge	3	3	3
				Technical Merit	3	3	3
Additional observations (Judge 1): Good student, quite analytical, but good. One of the most rounded students. Thorough, with good links. Not very creative but tries to understand the nature of the site. Sketching seems an appropriate tool that helps working out constraints and facilitating design solutions.							
Additional observations (Judge 2): This student has found the key relations and properties and has successfully used them to help with analysis and planning. Started with quantifiable things, not much of a conceptual thinker, but experienced and systematic.							
Additional observations (Judge 3): Useful analysis, applies principles and uses constraints. Has a clear strategy to follow but not very articulated on the main idea, seems to combine several simple ideas. Builds up from details to organise spaces. Does not concentrate on the floor plans only, sketches views, diagrams and perspectives.							

As demonstrated by Tables 62-63, the judges' comments can be viewed as insightful, considering how well most of them match the students' LSA profiles. Although none of the evaluators had been instructed to base their assessments on learning theories, many of the observations contained features associated with either of the four learning styles. That is, the judges were informed on the general nature of the thesis, without referring to the specifics of psychometric testing, as the intention was to look at their perspectives and avoid directing them towards fulfilling the researcher's agenda and include particular types of observations. Experiment VI indicated a possibility to form sound views of the individual learning styles by looking at the students' sketches, transcripts and video records. The comments, however, were not enough for the statistical analyses, as the evaluators were unsystematic in sharing their opinions on the students' psychological profiles or/and capabilities.

As the judges' remarks indicate, being a Wholistic learner does not automatically mean a designing advantage, while being an Analytic learner does not imply a poor(er) performance. The reasons could be many. The evaluators could give equal preferences to wholistic and analytical learners, as both tend to succeed in different aspects of design tasks, especially apparent under artificial conditions of protocol studies. They sought to form balanced views of the (relatively) limited protocol materials, as they understood that there were many ways of approaching and structuring problem solving and one could not expect to find all aspects of a design solution typically addressed in the real life conceptual designing. Also, one shall not forget about the styles' flexibility as the more versatile students tend to be more flexible as well as more efficient with either part of a problem tackled, regardless of what their primary/preferred cognitive styles are. And equally, both wholistic, analytic or versatile learners could suffer from learning limitations, or lack in domain skills or aptitudes.

The situation with the Verbal-Imagery dimension is more straightforward – it is a definite advantage to have a developed visual style. The judges' assessments are consistent with the results of correlation analyses concerned with learning styles and academic performance (Section 5.3); and fit well with the relevant domain assumptions, as visual learners have been reported as the more, or the most, successful in both test groups.

Reliability

Estimates of the average reliability for all judges were calculated. Considerable similarities in opinions, even on subjective parameters of creativity and originality, may be related to the fact that students were evaluated in the context of the sample and group performance (i.e. relative of each other as a whole, and also of the year of study) as suggested by the assessment brief, and less so in accordance with certain personal standards for professional excellence.

Table 64. Inter-judge reliabilities for mean scale ratings on dimensions of judgement: Experiment VI/b

Dimensions of judgement	Year 1	Years 4&5
	Reliability of scale	
Constraints met	0.92	0.85
Creativity & Originality	0.86	0.80
Complexity & Elaboration	0.95	0.93
Flexibility & Fluency	0.90	0.84
Functionality	0.80	0.86
Technical Merit	0.84	0.96

Descriptive statistics

Table 65 contains descriptive statistics for two additional design product assessment dimensions of creativity and performance, as reported by the students at the end of Experiment V (original data is included in Appendix B). It is presented for each test group split by year and gender.

Table 65. Distribution characteristics of the students' assessments by year and gender: Experiment VI/b

variables	Year 1						Years 4&5					
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Creativity	3.00	7.00	5.00	1.58	5.30	1.57	4.00	8.00	6.4	1.71	6.15	1.31
	3.00	7.00	5.60	1.67			5.00	7.00	5.90	0.89		
Performance	5.00	7.50	6.30	0.98	6.10	0.84	4.00	8.00	5.90	2.01	6.10	1.47
	5.00	7.00	5.90	0.74			5.00	7.00	6.30	0.84		

 Females
  Males
  Group results

The participants applied a 10-point scale. As the Table 65 indicates, fourth and final year students ranked their solution quality higher than the first year students. This is probably because they were more experienced and more familiar with the design task, whilst the first year students felt somewhat intimidated by it, which is also clear from the explanations of the scores they ascribed to themselves (some included in Appendix C, questionnaires). The participants' views of problem solving ability (i.e. how well they performed on the design task) are similar, although senior students have a slightly higher variation in their assessments.

Descriptive statistics for all design product assessment dimensions, as reported by the three judges (consensus scores), is presented for each test group split by year and gender (Table 66).

Table 66. Distribution characteristics of the judges' assessments by year and gender: Experiment VI/b

variables	Year 1						Years 4&5					
	Min	Max	Mean	SD	Mean	SD	Min	Max	Mean	SD	Mean	SD
Const.	2.00	4.00	2.60	0.89	2.50	0.71	2.00	4.00	2.20	1.30	2.70	0.95
	2.00	3.00	2.40	0.55			2.00	4.00	2.40	0.89		
Cr-Or	1.00	3.00	1.80	0.84	2.00	0.82	1.00	4.00	2.20	1.30	2.10	1.20
	1.00	3.00	2.20	0.84			1.00	4.00	2.00	1.22		
Co-El	1.00	4.00	2.40	1.14	2.10	0.88	1.00	3.00	2.20	0.84	2.20	1.03
	1.00	2.00	1.80	0.45			1.00	4.00	2.20	1.30		
Fl-Flex	1.00	4.00	2.40	1.14	2.30	0.82	2.00	4.00	2.60	0.89	2.40	0.97
	2.00	3.00	2.20	0.45			1.00	4.00	2.20	1.10		
Funct.	2.00	3.00	2.40	0.55	2.40	0.52	2.00	4.00	3.00	0.71	2.70	0.68
	2.00	3.00	2.40	0.55			2.00	3.00	2.40	0.55		
Tech. M	1.00	3.00	2.00	0.71	2.10	0.74	1.00	3.00	2.40	0.89	2.40	0.70
	1.00	3.00	2.20	0.85			2.00	3.00	2.40	0.55		

 Females
  Males
  Group results

Const. – Constraints met; Cr-Or – Creativity & Originality; Co-El – Complexity & Elaboration; Fl-Flex – Fluency & Flexibility; Funct. – Functionality; Tech. M – Technical Merit

Comparative analysis

Comparative analysis allows examining the difference in the quality of design solutions of the first, and fourth and final year students. Figure 21 demonstrates relations between the mean scores of six criteria applied in the design product assessment, split by the year of study.

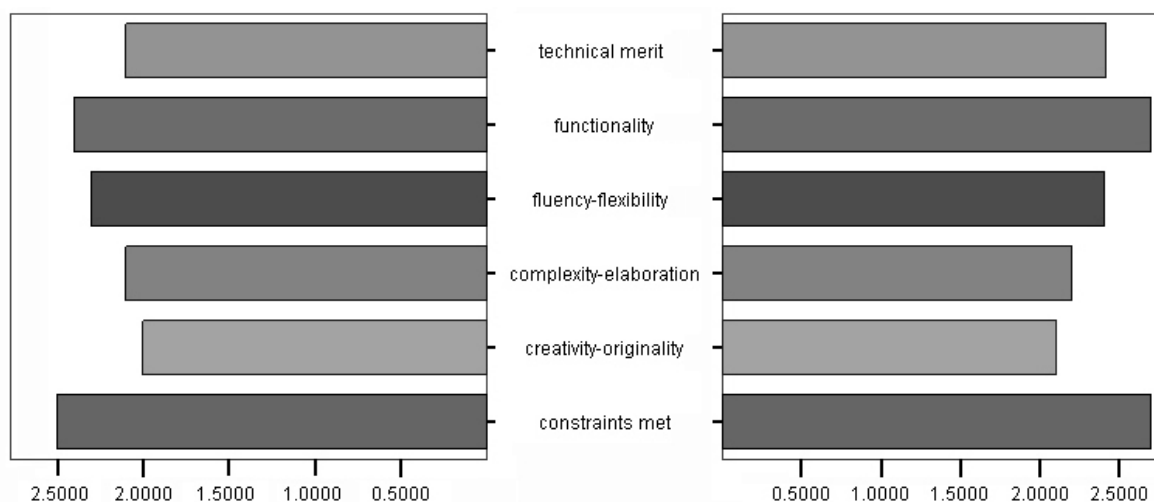


Figure 21. Means of assessments of external representations by year: Year 1(left), Years 4&5 (right)

With the maximum score of 4 on each dimension, the judges rated the quality of design solutions slightly above average. The first year students averaged a quality score of 2.23 across all measures, while the fourth and final year students averaged 2.41. The differences are more (or the most) significant on the *Functionality*, *Technical Merit*, and *Constraints Met* dimensions, and the least on *Complexity-Elaboration*, *Creativity-Originality*, and *Fluency-Flexibility*. The reasons for the differences in the first three dimensions are likely to be related to the more advanced domain knowledge and skills of the fourth and final year students, and also to the fact that there are more analytical students among them. The more important, although connected cause for the observed situation, is that both wholistic and analytic students in the senior group were more capable of developing their ideas interactively, by sketching. Their design solutions evolved gradually and consistently, by synthesising solution components, integrating constraints and responding to local conditions. This is in conformity with the research indicating that sketching may not be as helpful for novices as it is for expert designers in the development of new ideas (Goldschmidt,1991; Goel,1995; Suwa and Tversky,1997).

The obvious result of the comparisons between the two groups of subjects is that the total assessed quality of the students' designs is not significantly different. The considerable similarities in the judges' opinions, however, are down to the fact that students were evaluated in the context of the group performance (i.e. relative of their respective year of study) in the first place – as suggested by the assessment brief, then relative of the sample, and not in accordance with certain arbitrary standards for professional merit.

Learning styles in design product

Figure 22 illustrates the quality of produced design solutions relative of the students' learning styles preferences as assessed by LSA. The vertical axis indicates the mean numbers of the six criteria consensus scores estimated for Wholistic, Analytic, Imagery, Verbal and brain-gifted individuals, for each of these four dimensions separately (horizontal axis).

It shows differences and similarities in the relationship between learning styles and design product assessment scores of the two groups of participants. As both graphs demonstrate, it is the brain-gifted students in the Imagery-Verbal mode (i.e. equally strong in both visual and verbal processing) who tend to produce the highest results on most criteria. For the exclusion of the *Creativity and Originality* measure of the first year students, and technical merit of the

fourth and final year students. As suggested by the learning style theories, these students are better at translations that govern and transform the meanings of verbal statements into a graphic context (and vice versa) to help them solve problems. In this study, it is also the fact that their representations were typically better articulated (graphically or/and sententially) which made it easier for the judges to grasp or gain access to the more complete accounts of design solutions, that may have remained partly concealed in other students.

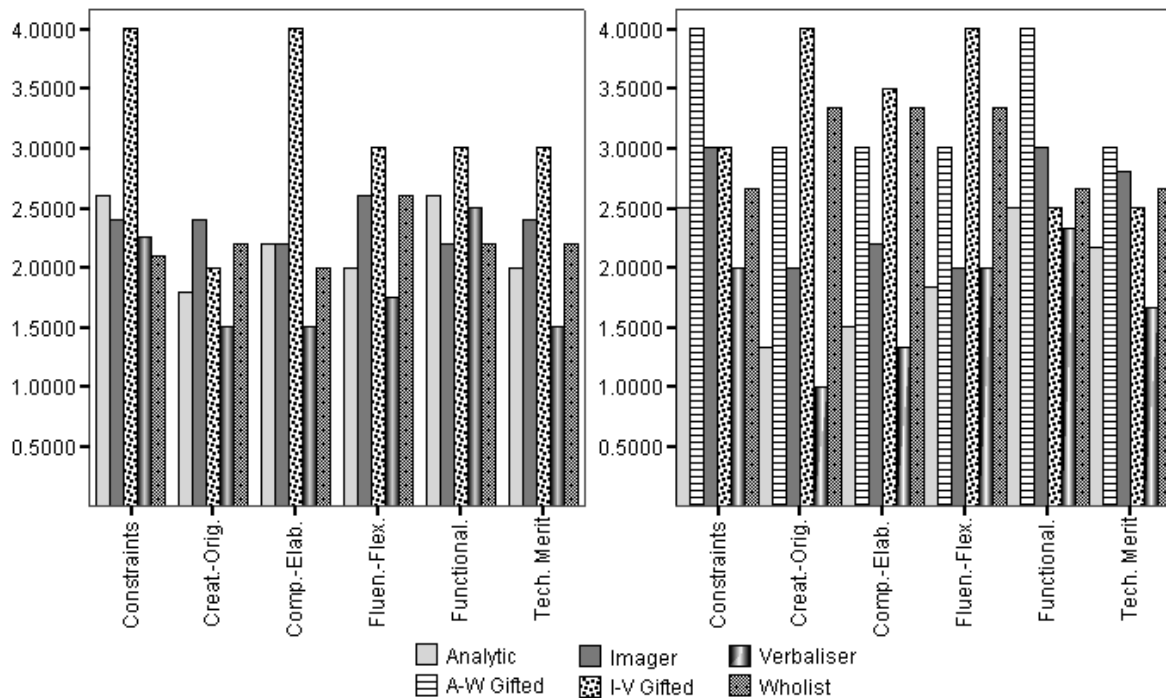


Figure 22. Design product assessments by W-A and V-I modes: Year 1 (left), Years 4&5 (right)

Brain-giftedness in the Analytic-Wholistic mode is also an indicator of the highest (and second highest) scores on all dimensions, *Constraints* and *Functionality* in particular, suggesting that being highly integrated in using mental techniques is a definite advantage when it concerns the quality of design solutions. Having preferences in wholistic and analytic brain processing means being able of addressing many different angles of a design task, understanding/accommodating a wider range of constraints, and synthesising solutions into concise logical structures. It, however, remains only a likely explanation as the size of the sample does not permit generalisations concerning the A-W brain-giftedness.

The results vary across the sample on the Wholistic and Analytic dimensions. With reference to the first year analytic students, there is a tendency for them to be better (than wholists) at meeting specified *Constraints*, at *Complexity and Elaboration* of the final design solutions, and their *Functionality*. Whereas wholists have, on average, higher scores in *Creativity and Originality*, *Fluency and Flexibility*, and *Technical Merit*. These results are in conformity with the learning styles and creativity theories suggesting that it is the wholistic students who are more likely to produce original design solutions, and whose design processes are characterised by high(er) levels of ideation (Fluency-Flexibility measure). Whilst analytic students are more inclined to generating designs that can be judged as logical, feasible and functional.

The results on the Complexity-Elaboration criterion disagree with these theories, which view it as one of the dimensions used in the assessments of creativity (typically associated with wholism). There could be several reasons for that. Firstly, one may need to separate between the two constituents of the measure, as ‘complex’ does not equal ‘elaborate’. Considering the protocol session constraints, high levels of detailing were used as the elaboration measure, and analytic students did succeed in developing their ideas to high(er) levels of detailing. From the

onset, they were more concerned with generating a feasible design that accommodated a lot of constraints, than with producing an original solution, or many alternative ideas to choose from. As a result, many experienced early fixation and moved to the detailing phase much sooner than did the wholists. Different to them, the wholistic students, visually inclined in particular, did not start designing till they could fully comprehend the design brief and spent some time on the internal development of conceptual ideas. Thus, their external representations indicated higher levels of abstraction (and, correspondingly, low(er) levels of detailing). Additionally, while their ideas may have been complex, it was not possible to gain access to internal representations, as post-factum verbalisations of experienced imagery processing were not sufficient.

The technical merit criterion, although not likely to be directly related to learning styles, indicates that wholists were generally better at using design drawings in problem solving. As this measure was not concerned with drawing skills (or not in the first place) but with the students' ability to use sketches as interactive design tools.

The situation is different for the fourth and final year students, where wholists appeared to perform better along all criteria. It may, in part, be explained by the observations derived from analysing the students' modes of designing, which indicated for the fourth and final year students, particularly wholists, to have more integrated design processes. That is, it is likely that the knowledge and the skills acquired during design education enabled senior subjects to process more information in parallel, or/and to be more efficient while doing it, and therefore to produce more balanced (on all measures) representations. Additionally, these students, those flexible in the analytic mode in particular, were more capable of interacting with their drawings than the first year subjects, and also relative of the analytic group (confirmed by the technical merit score). Their design solutions developed on several levels of abstraction by integrating constraints and responding to local conditions. Additionally, there are more A-W versatile individuals among the fourth and final year students, as indicated by their LSA profiles.

The above results may also show that different learning styles enable students to deal more efficiently with different aspects of the design task.

When it comes to the Imagery dimension, the results are similar for both groups. There is a clear tendency for the visual individuals to have a better quality of their design solutions on all criteria than was observed among the verbal students. The reasons are probably related to the visual nature of design problem-solving, both internal (imagery) and external (sketching).

Cognitive abilities in design product

Figure 23 illustrates the quality of produced design solutions relative of the students' levels of visual-spatial and figural ideation abilities²⁷. The vertical axis indicates the mean numbers of the six criteria consensus scores estimated for high, medium-high, medium-low and low ability individuals, for each of the two groups of cognitive abilities separately (horizontal axis).

It shows that the first and the fourth and final year students share a lot of similarities in terms of the relationship between their visual-spatial abilities and the measures used in the assessment of design solutions. As both graphs indicate, the high and the medium-high spatial individuals were ascribed the top scores in *Fluency and Flexibility*, *Creativity and Originality*, and *Technical Merit*; and the medium-low and the low spatial students – the bottom. The results are not consistent on the *Complexity-Elaboration* dimension for the first year students as medium-low spatial students are the second top scorers, possibly due to the reasons quoted above. That is, while complexity measure is likely to be related to visual-spatial abilities, it is not always accessible by retrospection, while elaboration/detailing may be unrelated to the levels of visual-spatial abilities. The results are also inconclusive on the *Constraints Met* criterion (particularly for the first year students), but its relationship with visual-spatial abilities is not likely to be linear. The lack of linearity also applies to the *Functionality* measure, although there is a tendency for high spatial individuals to perform better than low spatial students.

²⁷ Verbal ideation abilities were not included as they did not appear to have any association with the quality of produced design solutions (also see Tables 68-69)

These results are generally consistent with the formerly observed tendency for students with developed visual-spatial abilities (particularly on the visualisation dimension) in both groups to show better results in terms of creativity, academic achievement and performance on design tasks (Table 21, 29, 30).

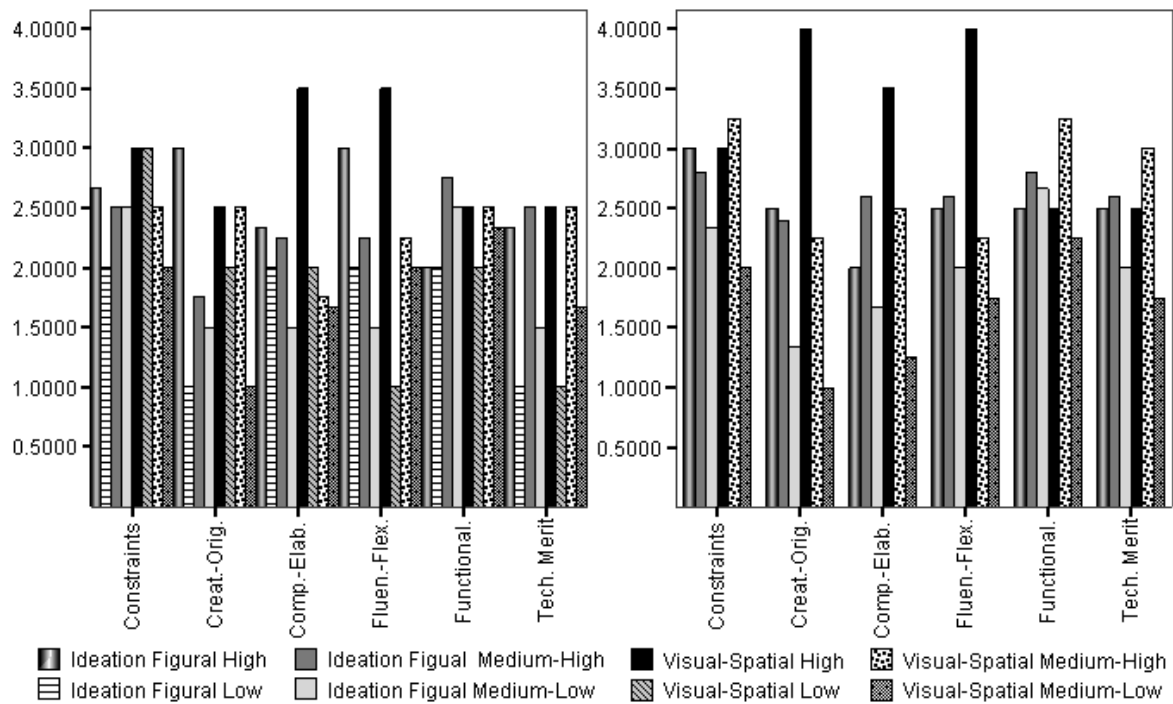


Figure 23. Design product assessments by cognitive abilities: Year 1 (left), Years 4&5 (right)

When it concerns figural ideation, Figure 23 indicates a tendency for high and medium-high ability individuals to have better scores in all (but one) criteria. The only inconclusive result is *Functionality* but its relationship with ideation abilities is not likely to be linear.

These results are more resolute than has been observed in other analyses, indicating a lack of (direct) association between ideation abilities, certain characteristics of external representations, academic achievement, and performance on administered design tasks (Tables 37, 68-69). The reasons are not entirely evident. It is possible that the nature of protocol sessions provided an advantage for the high figural ideation individuals, particularly, among the first year students, much less apparent in real life design not prone to (similar) time constraints.

As the earlier analyses were largely concerned with those aspects of design drawings and reasoning processes that have been previously researched in other studies, in future, it may be useful to introduce new and different coding categories derived from the human ability theories to define criteria in accordance with the chosen ideation factors to facilitate identifying their relationship with the *input* the *process* and the *product* of problem-solving.

Correlation analysis

The following analysis consists of two parts. In the first part, the students' and the judges' evaluations of the final design solutions and creativity are correlated with the assessments of the participants' academic performance and creativity. While the second part is the final multivariate analysis focusing on the four learning styles and three groups of ability factors, and their roles in the design process and the design product.

Students views of produced design solutions

As Tables 65-66 indicate, both the judges' and the students ranked the quality of their solutions above average, yet it is interesting to note that the students' ranking is actually unrelated, or slightly negatively related to the judges' assessments (Table 67).

Table 67. Pearson product-moment correlation coefficients: Years 1 and 4&5, Experiments III/b-VI/b

Variables	C	C-O	C-E	F-F	F	TM	C	P	C	AP
Year 1										
Constraints met	1									
Creativity & Originality	0.385	1								
Complexity & Elaboration	0.628	0.311	1							
Fluency & Flexibility	0.095	0.496	0.570	1						
Functionality	0.000	-0.264	-0.098	-0.052	1					
Technical Merit	0.319	0.369	0.327	0.311	0.467	1				
Creativity	0.150	0.000	0.300	-0.336	-0.027	-0.029	1			
Performance	0.000	0.242	0.286	0.032	-0.102	-0.196	0.395	1		
Creativity	0.325	0.704*	0.342	0.531	0.089	0.873**	-0.161	-0.191	1	
Academ. Performance	0.488	0.563	0.604	0.671*	0.312	0.717*	0.059	-0.123	0.762*	1
Years 4&5										
Constraints met	1									
Creativity & Originality	0.518	1								
Complexity & Elaboration	0.295	0.881**	1							
Fluency & Flexibility	0.388	0.922**	0.802**	1						
Functionality	0.711*	0.316	0.414	0.204	1					
Technical Merit	0.704*	0.478	0.492	0.230	0.753*	1				
Creativity	0.263	0.060	0.098	0.079	0.307	0.411	1			
Performance	0.183	-0.006	-0.015	0.008	0.146	0.227	0.308	1		
Creativity	0.422	0.812**	0.775**	0.592	0.254	0.491	-0.109	-0.350	1	
Academ. Performance	0.345	0.819**	0.886**	0.812**	0.291	0.374	0.025	-0.089	0.740*	1

Judges' assessments
 Students' assessments
 Supervisors' reports

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

That is, neither group of students was able to judge accurately the quality of their final designs. The most apparent explanation is a lack of a good understanding of their ability to produce a quality design, or a lack of knowledge of the grading criteria. However, other factors might have had a strong(er) influence on the participants' judgements. They can be found in the students' comments at the end of the experiment, and are related to individual learning styles. It was noted for the wholists to give low(er) evaluations of their creativity, than did the analytic students, whilst in the judges' assessments within the group context were reverse. This observation may be supported by the study of Runco (1995) who investigated the correlation between job satisfaction and creativity scores. The most creative artists were the least satisfied by their jobs as well as with their performance. Additionally, the participants evaluated their performance relative of how well they would typically perform in real life or could have performed if they were at their personal best.

Table 67 also indicates that there are more and stronger correlations between the six evaluation criteria for the fourth and final year students. And only moderate for the first year participants. This means that the senior students' typically incorporated more factors that have contributed to the final score. That is, if their solutions, for example, were judged as 'good', it is likely that they were very balanced in terms of meeting all assessment criteria. This is likely to be related to the more advanced knowledge, but equally, can be a result of the more integrated design processes (as previously discussed), better cognitive abilities, and higher levels of style flexibility. Additionally, the ability to interact with paper as opposed to trying to externalise imagery or/and 'decorate boxes' is a definite advantage of the senior participants.

Correlation analyses: abilities and styles in design process and design product

Tables 68-69 present the results of the final multivariate analysis focusing on the three groups of ability factors, and their relationships with the design process and the design product.

Table 68. Pearson product-moment correlation coefficients: Year 1, Experiments I/b-VI/b

Variables	Gr	St	Im	Ver	I-V	I-Gr	I-St	Gr-V	V-St	V IA	H IA	3DSk	2DSk	Co-D	Ob-D	V-S	IV	IF	Rep.	Cm3D	Cm2D	Ver.	VT	HT	Co	C-O	C-E	F-F	F	TM	Cr	AP	Cr	P			
Year 1																																					
Graphic	1																																				
Sentential	-0.176	1																																			
Imagery	-0.623	-0.453	1																																		
Verbal	0.128	0.363	-0.630	1																																	
Imagery-Verbal	-0.536	-0.377	0.531	-0.499	1																																
Imagery-Graph.	-0.704*	-0.307	0.739*	-0.636*	0.879**	1																															
Imagery.-Sent.	-0.076	0.765**	-0.563	0.604	-0.591	-0.500	1																														
Graph.-Verbal	0.601	-0.331	-0.176	-0.216	-0.117	-0.098	-0.415	1																													
Verbal.-Sent.	0.646*	0.146	-0.722*	0.780**	-0.753*	-0.856*	0.393	0.192	1																												
Vert. Idea-Ann.	-0.718*	0.197	0.470	-0.148	0.096	0.415	0.329	-0.408	-0.394	1																											
Horiz. Idea-Ann.	0.084	-0.193	-0.177	-0.151	0.300	0.301	-0.110	0.403	-0.047	0.185	1																										
3D-Sketch	-0.287	0.007	0.387	-0.246	0.527	0.372	-0.515	-0.138	-0.339	-0.186	-0.298	1																									
2D-Sketch	-0.716*	0.604	0.002	0.258	0.348	0.311	0.402	-0.640*	-0.252	0.472	0.074	0.337	1																								
Conc.-diagram	0.139	-0.008	-0.168	0.666*	-0.452	-0.558	0.266	-0.201	0.640*	-0.050	-0.442	0.038	-0.028	1																							
Object-diagram	-0.077	0.379	0.012	0.069	-0.599	-0.378	0.601	-0.490	0.094	0.506	-0.342	-0.430	0.031	0.186	1																						
Visual-Spatial	-0.486	0.022	0.138	0.232	0.478	0.392	-0.022	-0.296	-0.030	0.302	0.272	0.453	0.649*	0.296	-0.373	1																					
Ideation Verbal	0.103	-0.277	-0.338	0.289	0.456	0.159	-0.195	0.269	0.155	-0.339	0.563	0.063	0.154	0.017	-0.799*	0.522	1																				
Ideation Figural	-0.758*	-0.318	0.629	-0.156	0.724*	0.766**	-0.271	-0.507	-0.494	0.415	0.087	0.334	0.453	-0.053	-0.237	0.671*	0.238	1																			
Repertoire	-0.703*	0.285	0.293	0.015	0.443	0.590	0.021	-0.132	-0.300	0.546	0.344	0.375	0.723*	-0.146	-0.280	0.736*	0.230	0.543	1																		
3D Complexity	-0.565	0.066	0.451	-0.191	0.677*	0.597	-0.409	-0.233	-0.462	0.000	-0.186	0.913**	0.536	-0.076	-0.510	0.609	0.186	0.581	0.628	1																	
2D Complexity	-0.269	0.596	-0.368	0.220	-0.115	0.013	0.768**	-0.204	0.000	0.506	0.342	-0.430	0.500	-0.093	0.250	0.248	0.114	0.000	0.349	-0.204	1																
Versatility	-0.244	-0.140	0.162	-0.191	0.516	0.542	-0.270	0.231	-0.171	0.302	0.726*	0.282	0.338	-0.167	-0.497	0.753*	0.522	0.436	0.736*	0.406	0.248	1															
Vertical Transf.	-0.448	0.388	0.143	0.013	0.431	0.340	-0.074	-0.324	-0.235	-0.029	-0.239	0.837**	0.648*	0.045	-0.358	0.636*	0.143	0.403	0.598	0.908**	0.053	0.359	1														
Horiz. Transf.	-0.433	0.315	0.280	-0.202	0.403	0.407	-0.121	-0.251	-0.295	0.222	-0.050	0.793**	0.590	0.020	-0.192	0.682*	0.000	0.390	0.660*	0.807**	0.110	0.573	0.892**	1													
Constraints	-0.256	0.397	0.106	-0.147	0.111	0.294	0.033	-0.082	-0.141	0.000	-0.152	0.401	0.271	-0.248	-0.167	0.248	-0.152	0.237	0.466	0.544	0.167	0.248	0.680*	0.622	1												
Creativ.-Origin.	-0.577	-0.094	0.297	-0.095	0.780**	0.640*	-0.231	-0.519	-0.463	0.000	0.000	0.497	0.541	-0.215	-0.433	0.574	0.395	0.821**	0.403	0.707*	0.000	0.287	0.627	0.444	0.385	1											
Compl.-Elabor.	-0.505	0.682*	0.038	0.074	0.111	0.216	0.325	-0.435	-0.124	0.436	0.025	0.454	0.797**	-0.040	0.135	0.575	-0.147	0.268	0.737*	0.549	0.404	0.441	0.740*	0.827**	0.628	0.311	1										
Fluency-Flexib.	-0.496	0.006	0.277	0.205	0.457	0.328	-0.204	-0.360	-0.073	0.232	0.078	0.660*	0.647*	0.299	-0.286	0.839**	0.314	0.584	0.672*	0.701*	-0.143	0.555	0.632*	0.660*	0.095	0.496	0.570	1									
Functionality	0.505	-0.218	-0.434	0.276	-0.270	-0.262	0.073	0.477	0.620	-0.123	0.583	-0.377	-0.297	0.238	-0.228	0.272	0.458	-0.130	0.026	-0.373	0.228	0.499	-0.251	-0.100	0.000	-0.264	-0.098	-0.052	1								
Technical Merit	-0.452	-0.159	0.281	-0.176	0.474	0.643*	-0.062	0.057	-0.268	0.517	0.612	-0.011	0.307	-0.167	-0.319	0.683*	0.408	0.621	0.696*	0.261	0.479	0.841**	0.218	0.386	0.319	0.369	0.327	0.311	0.467	1							
Creativity	-0.692*	-0.222	0.486	-0.228	0.789**	0.856**	-0.270	-0.144	-0.520	0.428	0.423	0.302	0.482	-0.236	-0.488	0.752*	0.468	0.856**	0.764*	0.598	0.244	0.752*	0.447	0.482	0.325	0.704*	0.342	0.531	0.089	0.873**	1						
Academic Perf.	-0.330	0.069	0.067	-0.027	0.577	0.499	-0.189	0.016	-0.152	0.099	0.423	0.554	0.543	-0.055	-0.610	0.873**	0.579	0.509	0.764*	0.697*	0.244	0.873**	0.731*	0.777**	0.488	0.563	0.604	0.671*	0.312	0.717*	0.762*	1					
Creativity	0.079	0.688*	-0.593	0.083	-0.143	-0.215	0.656*	-0.189	-0.010	0.020	0.110	-0.222	0.359	-0.235	0.226	-0.082	0.027	-0.335	-0.067	-0.184	0.752*	-0.082	0.133	0.099	0.150	0.000	0.300	-0.336	-0.027	-0.029	-0.161	0.059	1				
Performance	0.020	0.254	-0.221	0.023	-0.063	-0.149	0.319	-0.635*	0.029	0.075	0.026	-0.106	0.286	-0.146	0.489	-0.028	-0.217	0.079	-0.211	-0.171	0.140	-0.167	-0.009	0.046	0.000	0.242	0.286	0.032	-0.102	-0.196	-0.191	-0.123	0.395	1			

 Modes of designing
  Supervisors' reports
  Students' assessments

* Correlation is significant at the 00.05 level 2-tailed.

** Correlation is significant at the 00.01 level 2-tailed.

Table 69. Pearson product-moment correlation coefficients: Years 4&5, Experiments I/b-VI/b

Variables	Gr	St	Im	Ver	I-V	I-Gr	I-St	Gr-V	V-St	V IA	H IA	3DSk	2DSk	Co-D	Ob-D	V-S	IV	IF	Rep.	Cm3D	Cm2D	Ver.	VT	HT	Co	C-O	C-E	F-F	F	TM	Cr	AP	Cr	P
Years 4&5																																		
Graphic	1																																	
Sentential	0.862**	1																																
Imagery	-0.675*	-0.748*	1																															
Verbal	0.876**	0.695*	-0.737*	1																														
Imagery-Verbal	-0.535	-0.369	0.013	-0.551	1																													
Imagery-Graph.	-0.834**	-0.623	0.772**	-0.876*	0.248	1																												
Imagery.-Sent.	0.545	0.513	-0.792*	0.676*	-0.201	-0.689*	1																											
Graph.-Verbal	0.378	0.266	-0.481	0.295	-0.067	-0.368	0.506	1																										
Verbal-Sent.	0.607	0.434	-0.533	0.817**	-0.607	-0.572	0.728*	0.275	1																									
Vert. Idea-Ann.	-0.164	0.016	-0.438	-0.049	0.670*	-0.211	0.314	0.135	-0.287	1																								
Horiz. Idea-Ann.	-0.283	-0.364	-0.017	-0.101	0.446	0.109	-0.194	0.313	-0.116	0.277	1																							
3D-Sketch	-0.879*	-0.781*	0.572	-0.665*	0.376	0.721*	-0.431	-0.222	-0.472	0.270	0.472	1																						
2D-Sketch	-0.788*	-0.745*	0.669*	-0.703*	0.315	0.778**	-0.415	-0.157	-0.261	-0.174	0.389	0.715*	1																					
Conc.-diagram	0.272	0.034	-0.283	0.117	0.349	-0.426	0.141	0.442	-0.129	0.254	0.147	-0.346	-0.390	1																				
Object-diagram	0.564	0.696*	-0.513	0.319	-0.026	-0.274	0.447	0.336	0.303	0.000	-0.238	-0.571	-0.304	0.257	1																			
Visual-Spatial	-0.793*	-0.762*	0.465	-0.809*	0.792**	0.552	-0.537	-0.082	-0.763*	0.327	0.443	0.611	0.521	0.318	-0.423	1																		
Ideation Verbal	0.132	0.336	-0.042	-0.232	0.407	0.068	-0.348	0.056	-0.585	0.241	0.110	-0.142	-0.155	0.251	0.431	0.170	1																	
Ideation Figural	0.006	0.003	-0.116	-0.117	0.482	-0.305	-0.063	0.108	-0.529	0.612	0.129	-0.017	-0.251	0.364	-0.226	0.344	0.481	1																
Repertoire	-0.764*	-0.594	0.216	-0.647*	0.679*	0.420	-0.249	-0.173	-0.533	0.431	0.242	0.532	0.431	-0.044	-0.556	0.779**	-0.119	0.345	1															
3D Complexity	-0.740*	-0.490	0.194	-0.546	0.587	0.422	-0.058	-0.295	-0.349	0.521	0.186	0.647*	0.566	-0.415	-0.418	0.494	-0.136	0.264	0.805**	1														
2D Complexity	-0.707*	-0.449	0.193	-0.658*	0.534	0.515	-0.072	-0.199	-0.485	0.444	-0.154	0.509	0.289	-0.007	-0.202	0.616	-0.128	0.055	0.746*	0.643*	1													
Versatility	-0.534	-0.711*	0.511	-0.578	0.367	0.414	-0.243	0.139	-0.222	-0.218	0.242	0.290	0.705*	0.246	-0.211	0.643*	-0.194	-0.038	0.443	0.259	0.274	1												
Vertical Transf.	-0.623	-0.302	0.195	-0.735*	0.650*	0.574	-0.305	-0.093	-0.553	0.191	0.088	0.293	0.483	-0.095	-0.079	0.650*	0.225	0.146	0.795**	0.627	0.662*	0.462	1											
Horiz. Transf.	-0.723*	-0.479	0.235	-0.741*	0.692*	0.515	-0.346	-0.080	-0.647*	0.353	0.227	0.463	0.448	-0.041	-0.396	0.785**	0.118	0.355	0.947**	0.724*	0.708*	0.450	0.921**	1										
Constraints	-0.326	-0.313	0.090	-0.411	0.371	0.083	0.063	-0.010	-0.312	0.181	-0.369	-0.040	0.024	0.367	-0.176	0.505	-0.192	0.270	0.637*	0.323	0.697*	0.505	0.554	0.600	1									
Creativ.-Origin.	-0.757*	-0.726*	0.459	-0.808*	0.767**	0.531	-0.514	-0.004	-0.724*	0.252	0.451	0.541	0.590	0.253	-0.418	0.965**	0.184	0.390	0.805**	0.535	0.530	0.729*	0.733*	0.844**	0.518	1								
Compl.-Elabor.	-0.820**	-0.629	0.473	-0.883*	0.820**	0.729*	-0.535	-0.154	-0.722*	0.271	0.431	0.639*	0.724*	0.033	-0.161	0.873**	0.334	0.175	0.687*	0.611	0.575	0.600	0.786**	0.772**	0.295	0.881**	1							
Fluency-Flexib.	-0.641*	-0.593	0.291	-0.661*	0.657*	0.482	-0.425	0.185	-0.521	0.134	0.592	0.447	0.588	0.189	-0.345	0.846**	0.119	0.218	0.757*	0.442	0.391	0.700*	0.759*	0.830**	0.388	0.922**	0.802**	1						
Functionality	-0.490	-0.200	0.199	-0.548	0.318	0.438	-0.010	-0.383	-0.273	0.096	-0.518	0.132	0.292	-0.245	0.000	0.292	-0.128	-0.067	0.581	0.591	0.780**	0.292	0.716*	0.594	0.711*	0.316	0.414	0.204	1					
Technical Merit	-0.624	-0.387	0.262	-0.652*	0.502	0.421	-0.137	-0.313	-0.623	0.492	-0.318	0.436	0.149	0.016	-0.238	0.564	0.027	0.302	0.667*	0.611	0.927**	0.161	0.549	0.632	0.704*	0.478	0.492	0.230	0.753*	1				
Creativity	-0.741*	-0.841*	0.591	-0.725*	0.695*	0.488	-0.460	-0.230	-0.601	0.221	0.327	0.588	0.596	0.323	-0.343	0.870**	0.049	0.232	0.545	0.430	0.486	0.725*	0.382	0.482	0.422	0.812**	0.775**	0.592	0.254	0.491	1			
Academic Perf.	-0.657*	-0.558	0.173	-0.650*	0.835**	0.484	-0.195	0.176	-0.449	0.380	0.561	0.523	0.614	0.302	0.000	0.829**	0.169	0.089	0.623	0.491	0.556	0.663*	0.673*	0.664*	0.345	0.819**	0.886**	0.812**	0.291	0.374	0.740*	1		
Creativity	-0.185	0.021	0.209	-0.380	-0.170	0.474	-0.262	0.070	-0.349	-0.188	-0.351	0.111	-0.075	-0.024	0.063	0.139	0.106	-0.269	0.073	-0.187	0.468	-0.075	0.280	0.222	0.263	0.060	0.098	0.079	0.307	0.411	-0.109	0.025	1	
Performance	0.323	0.617	-0.474	0.045	0.242	-0.247	0.048	0.141	-0.353	0.388	-0.227	-0.424	-0.584	0.226	0.341	-0.029	0.672*	0.523	0.097	-0.070	0.110	-0.461	0.320	0.271	0.183	-0.006	-0.015	0.008	0.146	0.227	-0.350	-0.089	0.308	1

 Modes of designing
  Supervisors' reports
  Students' assessments

* Correlation is significant at the 00.05 level 2-tailed.

** Correlation is significant at the 00.01 level 2-tailed

They indicate a number of common correlations observed in both test groups, although with varying magnitudes of correlation coefficients. Whilst some correlations are only present in either group of subjects. For the first year they include²⁸:

1. *Sentential (Mode of designing)* is correlated with *2D-Sketching* (moderate correlation), *Complexity-Elaboration*, and *Creativity (Self-assessments)*
2. *Imagery (Mode of designing)* is correlated with *Figural Ideation* (moderate correlation), and *Verbal Learning Style (Introspective reports)*
3. *Verbal (Mode of designing)* is correlated with *Concept-diagramming*
4. *Imagery-Verbal (Mode of designing)* is correlated with *3D-Sketching* (moderate correlation), *Visual Ideation*, *3D Complexity*, *Versatility* (moderate correlation), *Creativity-Originality*, *Creativity (Supervisors' assessments)*, and *Academic Performance* (moderate correlation)
5. *Imagery-Graphic (Mode of designing)* is correlated with *Figural Ideation*, *Repertoire* (moderate correlation), *3D Complexity* (moderate correlation), *Versatility* (moderate correlation), *Creativity-Originality*, *Technical Merit*, and *Creativity (Supervisors' assessments)*
6. *Imagery-Sentential (Mode of designing)* is correlated with *2D-Sketching*
7. *Verbal-Sentential (Mode of designing)* is correlated with *Concept-diagramming*
8. *3D-Sketching* is correlated with *3D Complexity*, *Vertical sketch transformations*, *Horizontal sketch transformations*, and *Fluency-Flexibility*
9. *2D-Sketching* is correlated with *Visual-Spatial ability*, *Repertoire*, *2D and 3D Complexity* (moderate correlations), *Vertical sketch transformations*, *Horizontal sketch transformations* (moderate correlation), *Creativity-Originality* (moderate correlation), *Complexity-Elaboration*, and *Fluency-Flexibility*
10. *Visual-Spatial abilities* are correlated with *Verbal Ideation* (moderate correlation), *Figural Ideation*, *Repertoire*, *3D Complexity* (moderate correlation), *Versatility*, *Vertical sketch transformations*, *Horizontal sketch transformations*, *Creativity-Originality* (moderate correlation), *Fluency-Flexibility*, *Technical Merit*, *Creativity*, and *Academic Performance*
11. *Figural Ideation* is correlated with *Repertoire* (moderate correlation), *3D Complexity* (moderate correlation), *Creativity-Originality*, *Fluency-Flexibility* (moderate correlation), and *Technical Merit* (moderate correlation)
12. *Repertoire* is correlated with *3D Complexity* (moderate correlation), *Versatility*, *Vertical sketch transformations* (moderate correlation), *Horizontal sketch transformations*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Technical Merit*, *Creativity (Supervisors' assessments)*, and *Academic Performance*
13. *3D Complexity* is correlated with *Vertical sketch transformations*, *Horizontal sketch transformations*, *Constraints* (moderate correlation), *Creativity-Originality*, *Complexity-Elaboration* (moderate correlation), *Fluency-Flexibility*, *Creativity* (moderate correlation), and *Academic Performance*
14. *2D Complexity* is correlated with *Vertical sketch transformations* (moderate correlation), and *Creativity (self-assessments)*
15. *Vertical sketch transformations* are correlated with *Horizontal sketch transformations*, *Constraints*, *Creativity-Originality* (moderate correlation), *Complexity-Elaboration*, *Fluency-Flexibility*, and *Academic Performance*
16. *Horizontal sketch transformations* are correlated with *Constraints* (moderate correlation), *Complexity-Elaboration*, *Fluency-Flexibility*, and *Academic Performance*

²⁸ The previously cited (discussed) correlations are omitted.

For the fourth and final years the observed correlations included:

1. *Graphic (Mode of designing)* is correlated with *Object-Diagramming*
2. *Sentential (Mode of designing)* is correlated with *Object-Diagramming*
3. *Imagery (Mode of designing)* is correlated with *2D-Sketching*
4. *Imagery-Verbal (Mode of designing)* is correlated with *Vertical idea-annotations*, *Visual-Spatial abilities*, *Repertoire (moderate correlation)*, *2D-Complexity (moderate correlation)* *3D-Complexity (moderate correlation)* *Vertical sketch transformations*, *Horizontal sketch transformations*, *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Technical Merit (moderate correlation)*, *Creativity (Supervisors' assessments)*, and *Academic Performance*
5. *Imagery-Graphic (Mode of designing)* is correlated with *2D-Sketching*, *3D-Sketching*, *Visual-Spatial abilities (moderate correlation)*, *2D Complexity (moderate correlation)*, *Vertical sketch transformations*, *Horizontal sketch transformations*, *Creativity-Originality (moderate correlation)*, and *Complexity-Elaboration*
6. *3D-Sketching* is correlated with *2D-Sketching*, *Repertoire (moderate correlation)*, *3D Complexity*, *Creativity-Originality (moderate correlation)*, *Complexity-Elaboration*, *Creativity (Supervisors' assessments) (moderate correlation)*, and *Academic Performance (moderate correlation)*
7. *2D-Sketching* is correlated with *Visual-Spatial ability (moderate correlation)*, *Repertoire* *3D Complexity (moderate correlation)*, *Versatility*, *Creativity-Originality (moderate correlation)*, *Complexity-Elaboration*, *Fluency-Flexibility (moderate correlation)*, *Creativity (Supervisors' assessments) (moderate correlation)*, and *Academic Performance (moderate correlation)*
8. *Visual-Spatial abilities* are correlated with *Repertoire*, *Versatility*, *Vertical sketch transformations*, *Horizontal sketch transformations*, *Constraints (moderate correlation)*, *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Technical Merit (moderate correlation)*, *Creativity*, and *Academic Performance*
9. *Verbal Ideation* is correlated with *Performance (self-assessments) (moderate correlation)*
10. *Repertoire* is correlated with *2D Complexity*, *3D Complexity*, *Vertical sketch transformations*, *Horizontal sketch transformations*, *Constraints*, *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Functionality (moderate correlation)* *Technical Merit*, *Creativity (Supervisors' assessments) (moderate correlation)*, and *Academic Performance (moderate correlation)*
11. *3D Complexity* is correlated with *2D Complexity*, *Vertical sketch transformations (moderate correlation)*, *Horizontal sketch transformations*, *Creativity-Originality (moderate correlation)*, *Complexity-Elaboration (moderate correlation)*, *Functionality (moderate correlation)*, and *Technical merit*
12. *2D Complexity* is correlated with *Versatility*, *Vertical sketch transformations*, *Horizontal sketch transformations*, *Constraints*, *Creativity-Originality (moderate correlation)*, *Complexity-Elaboration (moderate correlation)*, *Functionality*, *Technical Merit*, and *Academic Performance (moderate correlation)*
13. *Vertical sketch transformations* are correlated with *Horizontal sketch transformations*, *Constraints (moderate correlation)*, *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Functionality*, *Technical Merit (moderate correlation)*, and *Academic Performance*
14. *Horizontal sketch transformations* are correlated with *Constraints (moderate correlation)*, *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Functionality (moderate correlation)*, *Technical Merit (moderate correlation)*, and *Academic Performance*

Table 70. Pearson product-moment correlation coefficients: Year 1, Experiments II/b-VI/b

Variables	W	A	I	V	W	A	I	V	LW	LA	LI	LV	Gr	St	I	V	I-V	I-Gr	I-St	Gr-V	V-St	VT	HT	Vr	Rp	HIA	VIA	Co	C-O	C-E	FF	F	TM	C	AP			
Year 1																																						
Wholistic	1																																					
Analytic	-0.241	1																																				
Imagery	0.635*	0.265	1																																			
Verbal	-0.578	0.582	-0.304	1																																		
Wholistic	0.865*	-0.091	0.751*	-0.417	1																																	
Analytic	-0.360	0.871**	0.358	0.530	-0.106	1																																
Imagery	0.691*	0.169	0.890*	-0.160	0.848*	0.294	1																															
Verbal	-0.474	0.698*	-0.219	0.740*	-0.536	0.482	-0.310	1																														
L Wholistic	0.675*	-0.211	0.390	0.005	0.595	-0.279	0.566	-0.200	1																													
L Analytic	-0.108	0.378	0.268	0.051	-0.128	0.545	0.161	0.037	0.024	1																												
L Imagery	-0.028	0.396	0.335	-0.172	-0.051	0.506	0.234	0.116	-0.508	0.214	1																											
L Verbal	-0.200	0.213	0.049	0.413	-0.312	0.363	0.151	0.482	0.041	0.122	0.438	1																										
Graphic	-0.546	0.359	-0.697*	0.445	-0.662*	0.099	-0.708*	0.623	-0.407	0.088	-0.071	-0.004	1																									
Sentential	-0.397	0.355	0.116	0.650*	-0.286	0.583	0.175	0.472	0.024	0.169	0.181	0.758*	-0.176	1																								
Imagery	0.593	-0.570	0.287	-0.663*	0.575	-0.593	0.300	-0.664*	0.208	-0.564	0.027	-0.338	-0.623	-0.453	1																							
Verbal	-0.266	0.020	0.000	0.161	-0.344	0.181	-0.129	0.294	0.101	0.496	-0.206	0.350	0.128	0.363	-0.630	1																						
Imagery-Verbal	0.715*	0.061	0.666*	-0.343	0.882*	-0.022	0.680*	-0.503	0.466	-0.004	-0.104	-0.572	-0.536	-0.377	0.531	-0.499	1																					
Imagery-Graph.	0.772**	-0.135	0.665*	-0.497	0.901*	-0.113	0.762*	-0.655*	0.376	-0.167	0.167	-0.330	-0.704*	-0.307	0.739*	-0.636*	0.879*	1																				
Imagery.-Sent.	-0.591	0.104	-0.079	0.316	-0.512	0.483	-0.109	0.199	-0.322	0.419	0.228	0.564	-0.076	0.765*	-0.563	0.604	-0.591	-0.500	1																			
Graph.-Verbal	0.092	0.317	-0.229	0.096	-0.003	-0.002	-0.152	0.403	-0.215	-0.309	0.180	-0.005	0.601	-0.331	-0.176	-0.216	-0.117	-0.098	-0.415	1																		
Verbal-Sent.	-0.480	0.183	-0.363	0.262	-0.669*	0.166	-0.489	0.566	-0.219	0.415	0.010	0.394	0.646*	0.146	-0.722*	0.780**	-0.753*	-0.856*	0.393	0.192	1																	
Vertical Transf.	0.227	0.391	0.687*	0.279	0.451	0.415	0.650*	0.172	0.452	0.047	0.041	0.221	-0.448	0.388	0.143	0.013	0.431	0.340	-0.074	-0.324	-0.235	1																
Horiz. Transf.	0.236	0.450	0.708*	0.107	0.366	0.435	0.582	0.187	0.203	0.027	0.392	0.259	-0.433	0.315	0.280	-0.202	0.403	0.407	-0.121	-0.251	-0.295	0.892**	1															
Versatility	0.575	0.481	0.785*	-0.339	0.535	0.399	0.645*	-0.008	0.084	0.327	0.649*	0.055	-0.244	-0.140	0.162	-0.191	0.516	0.542	-0.270	0.231	-0.171	0.359	0.573	1														
Repertoire	0.662*	0.167	0.908**	-0.259	0.659*	0.268	0.881**	-0.126	0.433	0.134	0.441	0.374	-0.703*	0.285	0.293	0.015	0.443	0.590	0.021	-0.132	-0.300	0.598	0.660*	0.736*	1													
Vert. Idea-Ann.	0.254	-0.302	0.420	-0.559	0.192	-0.028	0.326	-0.460	-0.157	-0.006	0.550	0.206	-0.718*	0.197	0.470	-0.148	0.096	0.415	0.329	-0.408	-0.394	-0.029	0.222	0.302	0.546	1												
Horiz. Idea-Ann.	0.393	0.408	0.345	-0.245	0.260	0.324	0.324	-0.029	-0.050	0.479	0.502	-0.039	0.084	-0.193	-0.177	-0.151	0.300	0.301	-0.110	0.403	-0.047	-0.239	-0.050	0.726*	0.344	0.185	1											
Constraints	0.090	0.248	0.371	0.325	0.285	0.383	0.585	0.079	0.275	0.000	0.325	0.552	-0.256	0.397	0.106	-0.147	0.111	0.294	0.033	-0.082	-0.141	0.680*	0.622	0.248	0.466	-0.152	0.000	1										
Creativ.-Origin.	0.466	0.000	0.642*	-0.141	0.704*	0.121	0.698*	-0.504	0.597	0.318	-0.225	-0.318	-0.577	-0.094	0.297	-0.095	0.780**	0.640*	-0.231	-0.519	-0.463	0.627	0.444	0.287	0.403	0.000	0.000	0.385	1									
Compl.-Elabor.	0.130	0.361	0.635*	0.210	0.164	0.511	0.586	0.209	0.259	0.255	0.458	0.637*	-0.505	0.682*	0.038	0.074	0.111	0.216	0.325	-0.435	-0.124	0.740*	0.827**	0.441	0.737*	0.025	0.436	0.628	0.311	1								
Fluency-Flexib.	0.570	0.085	0.752*	-0.307	0.454	0.018	0.507	-0.036	0.526	0.238	0.022	0.009	-0.496	0.006	0.277	0.205	0.457	0.328	-0.204	-0.360	-0.073	0.632*	0.660*	0.555	0.672*	0.078	0.232	0.095	0.496	0.570	1							
Functionality	-0.098	0.408	0.041	-0.134	-0.223	0.372	-0.085	0.261	-0.397	0.535	0.568	0.179	0.505	-0.218	-0.434	0.276	-0.270	-0.262	0.073	0.477	0.620	-0.251	-0.100	0.499	0.026	0.583	-0.123	0.000	-0.264	-0.098	-0.052	1						
Technical Merit	0.499	0.190	0.753*	-0.530	0.584	0.340	0.695*	-0.385	-0.053	0.320	0.695*	0.019	-0.452	-0.159	0.281	-0.176	0.474	0.643*	-0.062	0.057	-0.268	0.218	0.386	0.841**	0.696*	0.612	0.517	0.319	0.369	0.327	0.311	0.467	1					
Creativity	0.736*	0.036	0.890**	-0.548	0.873*	0.148	0.868**	-0.558	0.331	0.199	0.319	-0.198	-0.692*	-0.222	0.486	-0.228	0.789*	0.856**	-0.270	-0.144	-0.520	0.447	0.482	0.752*	0.764*	0.423	0.428	0.325	0.704*	0.342	0.531	0.089	0.873**	1				
Academ. Perf.	0.473	0.582	0.890**	-0.071	0.595	0.555	0.772**	0.081	0.273	0.367	0.429	0.095	-0.330	0.069	0.067	-0.027	0.577	0.499	-0.189	0.016	-0.152	0.731*	0.777**	0.873**	0.764*	0.423	0.099	0.488	0.563	0.604	0.671*	0.312	0.717*	0.762*	1			

Data from LSA assessments
 Data from Introspective reports
 Length of prevailing approaches

* Correlation is significant at the 00.05 level 2-tailed.

** Correlation is significant at the 00.01 level 2-tailed

Table 71. Pearson product-moment correlation coefficients: Years 4&5, Experiments II/b-VI/b

Variables	W	A	I	V	W	A	I	V	LW	LA	LI	LV	Gr	St	I	V	I-V	I-Gr	I-St	Gr-V	V-St	VT	HT	Vr	Rp	HIA	VIA	Co	C-O	C-E	FF	F	TM	C	AP			
Years 4&5																																						
Wholistic	1																																					
Analytic	-0.756*	1																																				
Imagery	0.877**	-0.479	1																																			
Verbal	0.120	-0.175	0.000	1																																		
Wholistic	0.929**	-0.642*	0.913**	0.000	1																																	
Analytic	-0.619	0.959**	-0.333	-0.130	-0.490	1																																
Imagery	0.909**	-0.605	0.953**	-0.120	0.971*	-0.473	1																															
Verbal	-0.403	0.280	-0.501	0.801**	-0.499	0.223	-0.618	1																														
L Wholistic	0.858**	-0.624	0.811**	0.362	0.729*	-0.439	0.723*	-0.185	1																													
L Analytic	0.046	-0.022	0.244	-0.335	0.018	-0.017	0.230	-0.514	0.177	1																												
L Imagery	0.086	0.151	0.306	0.361	-0.007	0.286	0.060	0.165	0.555	0.396	1																											
L Verbal	-0.320	0.419	-0.206	0.451	-0.442	0.419	-0.388	0.574	0.061	0.251	0.674*	1																										
Graphic	-0.714*	0.399	-0.570	-0.033	-0.660*	0.170	-0.575	0.280	-0.706*	0.182	-0.225	0.210	1																									
Sentential	-0.574	0.358	-0.449	0.141	-0.568	0.115	-0.521	0.485	-0.561	-0.108	-0.141	0.304	0.862**	1																								
Imagery	0.364	-0.248	0.220	-0.142	0.422	-0.101	0.352	-0.303	0.220	-0.081	-0.129	-0.415	-0.675*	-0.748*	1																							
Verbal	-0.688*	0.378	-0.623	-0.157	-0.701*	0.179	-0.603	0.184	-0.656*	0.277	-0.203	0.342	0.876**	0.695*	-0.737*	1																						
Imagery-Verbal	0.874**	-0.626	0.904**	0.130	0.813*	-0.503	0.829**	-0.387	0.872**	0.120	0.318	-0.229	-0.535	-0.369	0.013	-0.551	1																					
Imagery-Graph.	0.491	-0.297	0.273	0.195	0.390	-0.151	0.274	0.036	0.472	-0.389	0.112	-0.198	-0.834*	-0.623	0.772**	-0.876*	0.248	1																				
Imagery.-Sent.	-0.557	0.655*	-0.281	-0.250	-0.562	0.566	-0.442	0.053	-0.367	0.266	0.267	0.443	0.545	0.513	-0.792*	0.676*	-0.201	-0.689*	1																			
Graph.-Verbal	-0.375	0.411	-0.158	0.491	-0.420	0.438	-0.378	0.445	0.042	0.269	0.647*	0.588	0.378	0.266	-0.481	0.295	-0.067	-0.368	0.506	1																		
Verbal-Sent.	-0.681*	0.596	-0.667*	-0.278	-0.769*	0.449	-0.681*	0.143	-0.650*	0.195	-0.165	0.334	0.607	0.434	-0.533	0.817**	-0.607	-0.572	0.728*	0.275	1																	
Vertical Transf.	0.649*	-0.213	0.618	0.373	0.632*	-0.079	0.515	0.100	0.585	-0.518	0.132	-0.191	-0.623	-0.302	0.195	-0.735*	0.650*	0.574	-0.305	-0.093	-0.553	1																
Horiz. Transf.	0.706*	-0.296	0.687*	0.390	0.735*	-0.096	0.610	0.028	0.698*	-0.418	0.227	-0.122	-0.723*	-0.479	0.235	-0.741*	0.692*	0.515	-0.346	-0.080	-0.647*	0.921**	1															
Versatility	0.419	-0.038	0.448	-0.055	0.437	0.149	0.423	-0.374	0.398	0.125	0.147	-0.341	-0.534	-0.711*	0.511	-0.578	0.367	0.414	-0.243	0.139	-0.222	0.462	0.450	1														
Repertoire	0.700*	-0.302	0.674*	0.185	0.739*	-0.084	0.634*	-0.160	0.671*	-0.314	0.178	-0.155	-0.764*	-0.594	0.216	-0.647*	0.679*	0.420	-0.249	-0.173	-0.533	0.795**	0.947**	0.443	1													
Vert Idea-Ann.	0.380	-0.262	0.571	0.042	0.367	-0.195	0.437	-0.210	0.577	0.271	0.551	0.260	-0.164	0.016	-0.438	-0.049	0.670*	-0.211	0.314	0.135	-0.287	0.191	0.353	-0.218	0.431	1												
Horiz. Idea-Ann.	0.503	-0.517	0.337	0.492	0.271	-0.413	0.299	0.056	0.704*	0.412	0.453	0.361	-0.283	-0.364	-0.017	-0.101	0.446	0.109	-0.194	0.313	-0.116	0.088	0.227	0.242	0.242	0.277	1											
Constraints	0.196	0.111	0.373	-0.181	0.409	0.252	0.329	-0.301	0.120	-0.347	-0.054	-0.498	-0.326	-0.313	0.090	-0.411	0.371	0.083	0.063	-0.010	-0.312	0.554	0.600	0.505	0.637*	0.181	-0.369	1										
Creativ.-Origin.	0.812**	-0.491	0.787**	0.288	0.827*	-0.259	0.755*	-0.255	0.822**	-0.048	0.282	-0.281	-0.757*	-0.726*	0.459	-0.808*	0.767**	0.531	-0.514	-0.004	-0.724*	0.733*	0.844**	0.729*	0.805**	0.252	0.451	0.518	1									
Compl.-Elabor.	0.881**	-0.554	0.799**	0.250	0.784*	-0.377	0.737*	-0.229	0.881**	-0.072	0.323	-0.236	-0.820*	-0.629	0.473	-0.883*	0.820**	0.729*	-0.535	-0.154	-0.722*	0.786**	0.772**	0.600	0.687*	0.271	0.431	0.295	0.881**	1								
Fluency-Flexib.	0.706*	-0.405	0.610	0.535	0.642*	-0.199	0.545	0.041	0.767**	-0.153	0.292	-0.089	-0.641*	-0.593	0.291	-0.661*	0.657*	0.482	-0.425	0.185	-0.521	0.759*	0.830**	0.700*	0.757*	0.134	0.592	0.388	0.922**	0.802**	1							
Functionality	0.276	0.156	0.349	-0.255	0.370	0.229	0.293	-0.190	0.101	-0.549	-0.124	-0.392	-0.490	-0.200	0.199	-0.548	0.318	0.438	-0.010	-0.383	-0.273	0.716*	0.594	0.292	0.581	0.096	-0.518	0.711*	0.316	0.414	0.204	1						
Technical Merit	0.384	-0.129	0.506	-0.185	0.517	0.024	0.449	-0.310	0.389	-0.330	0.190	-0.321	-0.624	-0.387	0.262	-0.652*	0.502	0.421	-0.137	-0.313	-0.623	0.549	0.632	0.161	0.667*	0.492	-0.318	0.704*	0.478	0.492	0.230	0.753*	1					
Creativity	0.745*	-0.542	0.728*	-0.221	0.753*	-0.345	0.765**	-0.699*	0.696*	0.263	0.176	-0.506	-0.741*	-0.841*	0.591	-0.725*	0.695*	0.488	-0.460	-0.230	-0.601	0.382	0.482	0.725*	0.545	0.221	0.327	0.422	0.812**	0.775**	0.592	0.254	0.491	1				
Academ. Perf.	0.730*	-0.443	0.693*	0.253	0.578	-0.271	0.567	-0.220	0.861**	0.077	0.478	-0.122	-0.657*	-0.558	0.173	-0.650*	0.835**	0.484	-0.195	0.176	-0.449	0.673*	0.664*	0.663*	0.623	0.380	0.561	0.345	0.819**	0.886**	0.812**	0.291	0.374	0.740*	1			

Data from LSA assessments
Data from Introspective reports
Length of prevailing approaches

* Correlation is significant at the 00.05 level 2-tailed.

** Correlation is significant at the 00.01 level 2-tailed

Tables 70-71 present the results of the final multivariate analysis focusing on the four learning style dimensions, and their relationships with the design process and the design product. They indicate a number of common correlations observed in both test groups, although with varying magnitudes of correlation coefficients. Whilst some correlations are only present in either group of subjects. For the first year they include²⁹:

1. *Wholistic learning style (LSA)* is correlated with *Fluency-Flexibility* (moderate correlation), and *Creativity (Supervisors' assessments)*
2. *Imagery learning style (LSA)* is correlated with *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Technical Merit*, *Creativity (Supervisors' assessments)*, and *Academic Performance*
3. *Wholistic learning style (Introspective reports)* is correlated with *Creativity-Originality*, *Technical Merit* (moderate correlation), and *Creativity (Supervisors' assessments)*, and *Academic Performance* (moderate correlation)
4. *Imagery learning style (Introspective reports)* is correlated with *Creativity-Originality*, *Complexity-Elaboration* (moderate correlation), *Fluency-Flexibility* (moderate correlation), *Technical Merit*, *Creativity (Supervisors' assessments)*, and *Academic Performance*

For the fourth and final years the following correlations can be observed:

1. *Wholistic learning style (LSA)* is correlated with *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Creativity (Supervisors' assessments)*, and *Academic Performance*
2. *Imagery learning style (LSA)* is correlated with *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility* (moderate correlation), *Technical Merit* (moderate correlation), *Creativity (Supervisors' assessments)*, and *Academic Performance*
3. *Wholistic learning style (Introspective reports)* is correlated with *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility*, *Creativity (Supervisors' assessments)*, and *Academic Performance* (moderate correlation)
4. *Imagery learning style (Introspective reports)* is correlated with *Creativity-Originality*, *Complexity-Elaboration*, *Fluency-Flexibility* (moderate correlation), *Creativity (Supervisors' assessments)*, and *Academic Performance* (moderate correlation)

6.4.2 Conclusions

This subsection is concerned with the results of the above correlational analyses; it does not review the broad range of observations derived from the earlier qualitative and quantitative (comparative and correlation) analyses for the purpose of clarity and conciseness. A summary of all results discussed in Section 6.3 is presented in Chapter 7.

The general observations derived from the above data (Tables 68-71) indicated that different factors were unequal in terms of the strengths of predictive validity as well as the number and the significance of associations with other variables used in correlation analyses. Visual-spatial abilities, Wholistic and Imagery learning styles appeared to have the strongest influence both on the process and the outcome of individual problem-solving in both groups of students. These results generally confirm the earlier comparative, and are in conformity with the results and observations derived from the previous correlation analyses suggesting that Wholistic and, more so, Imagery learning styles are likely to be the best predictors of the design performance.

Among other factors that show many and/or strong correlations with other variables are *Versatility*, suggesting that flexibility and broader profiles of learning styles are a statistically

²⁹ The previously cited (discussed) correlations are omitted.

significant factor influencing design performance, academic achievement and the quality of final solutions. These students are potentially more able to cope in any learning environment, or more flexible in utilising different approaches to problem solving. Additionally, versatility was correlated with high scores on tests of visual-spatial abilities. One of the possible explanations is that different tests may require different strategies to arrive at correct answers. Or that certain strategies are more efficient for particular tests, while broader repertoires of learning styles may enable students to choose between these strategies more freely, and, therefore, attain higher scores. The same cognitive advantage may also affect non-test situations requiring the use of visual-spatial abilities (such as design tasks).

Another highly correlated with other variables factor is *Repertoire*, it indicates that students who have also produced broader repertoires of schema for external representations (it included a summary of all different types of diagrams, two- and three-dimensional sketches and annotations) were among those who succeeded in terms of the progression and the outcome of design problem-solving. It is related to visual, and, more so, wholistic thinking, probably because they rely upon imagery and ideation, and combine different methods of exploration to achieve understanding by identifying and focusing on many patterns or trends in the task.

When it comes to external representations, sketching has the highest influence on the development of design solutions as well as the quality of final designs, whereas diagramming has the lowest and annotating, though beneficial, is not consistent across the sample.

Cognitive abilities in design solutions. Correlation analyses were performed to determine how different characteristics of the students' design solutions were related to the levels of their visual-spatial, verbal and figural ideation abilities.

They indicated that the first and the fourth and final year students share a lot of similarities in terms of the relationship between their visual-spatial abilities and the measures used in the assessment of design solutions, although the magnitudes of the correlation coefficients vary. The high and the medium-high spatial individuals were ascribed the top scores in *Fluency and Flexibility* (significant correlations), *Creativity and Originality* (moderate and significant correlations), *Complexity and Elaboration* (moderate and significant correlations) and *Technical Merit* (significant and moderate correlations); and the medium-low and the low spatial students – the bottom. Within the above factors, the situation with *Complexity and Elaboration* is the least straightforward. While the complexity measure is likely to be related to visual-spatial abilities, it was not always accessible by retrospection, and elaboration/detailing may be unrelated to the levels of visual-spatial abilities. The results are also inconclusive on the *Constraints Met* criterion, but its relationship with visual-spatial abilities is not likely to be linear. The lack of linearity also applies to the *Functionality* measure.

These results are generally consistent with the formerly observed tendency for students with developed visual-spatial abilities (particularly on the visualisation dimension) in both groups to show better results in terms of creativity, academic achievement and performance on design tasks (Table 21, 29, 30).

When it concerns figural ideation, the above analyses indicate a tendency for high and medium-high ability individuals to have better scores in *Creativity and Originality* (significant correlation), and *Fluency and Flexibility* (moderate correlation), and *Technical Merit* (moderate correlation) measures, but only among the first year students. These results are consistent with other analyses, indicating weak, or a lack of (direct) associations between ideation abilities, certain characteristics of external representations, academic achievement, and performance on administered design tasks (Tables 37, 68-69). The reasons are not entirely evident. It is possible that the nature of protocol sessions provided an advantage for the high figural ideation individuals from the first year of study, much less apparent in real life design not prone to (similar) time constraints. That is, real design exercises are less likely to rely upon abilities emphasizing high speed, as they are not a subject to similar to cognitive tests time constraints. Ideation scores may also be related to speed and control in drawing (Carroll, 1993), and the overall sketching ability (also supported by the *Technical Merit* measure). Whereas in the later

years of study the generally high(er) levels of sketching proficiency may even out the fourth and final year students in terms of the potential advantage figural ideation provides to high scorers.

Thus, to establish reliable correlations between ideation factors and creativity or academic performance in architecture, a measurement beyond the measurement of the quantity of ideas produced need being used. Here, visualisation abilities may be better predictors of academic performance as they involve more complex cognitive processing characteristic of design tasks. It is also likely that other factors relating to teaching, previous instruction and complexity of design tasks, knowledge, experience, and so on, may be of equal or higher importance.

Also, as the earlier analyses were largely concerned with those aspects of design drawings and reasoning processes that have been previously researched in other studies, in future, it may be useful to introduce new and different coding categories derived from the human ability theories to define criteria in accordance with the chosen ideation factors to facilitate identifying their relationship with the *input* the *process* and the *product* of problem-solving.

Verbal ideation does not appear to have any consistent effect on any of the design quality measures and only a weak tendency for the first year students to have higher scores on the *Functionality* criterion. It may be related to the fact that many of them chose sentential form of communicating ideas, different from the fourth and final year students who tended to resort to graphical form of idea-production.

Learning styles in design solutions. The analyses presented in Tables 70-71 showed differences and similarities in the relationship between the two learning styles accounts and design product assessment scores of the two groups of participants. The results vary across the sample on the Wholistic and Analytic dimensions. With reference to the first year analytic students, there is a slight tendency for them to be better (than wholists) at meeting specified *Constraints* (weak correlations), at *Complexity and Elaboration* (weak correlations) of the final design solutions, and their *Functionality* (weak to moderate correlations). Whereas wholists have, on average, higher scores in *Creativity and Originality* (weak to moderate and strong correlations), *Fluency and Flexibility* (moderate correlations), and *Technical Merit* (moderate correlations). These results are in conformity with the learning styles and creativity theories suggesting that it is the wholistic students who are more likely to produce original design solutions, and whose design processes are characterised by high(er) levels of ideation. Whilst analytic students are more inclined to generating designs that can be judged as logical, feasible and functional.

The results on the *Complexity and Elaboration* disagree with these theories, which view it as one of the dimensions used in the assessments of creativity (typically associated with wholism). There could be several reasons for that. Firstly, one may need to separate between the two constituents of the measure, as ‘complex’ does not equal ‘elaborate’. Considering the protocol session constraints, high levels of detailing were used as the elaboration measure, and analytic students did succeed in developing their ideas to high(er) levels of detailing, but many experienced early fixation and moved to the detailing phase prematurely. Different to them, the wholistic students, visually inclined in particular, spent considerable time on the internal development of conceptual ideas. Thus, their external representations indicated higher levels of abstraction (and, correspondingly, low(er) levels of detailing). Additionally, while their ideas may have been complex, it was not always possible to gain access to internal representations.

The *Technical Merit* criterion, although not likely to be directly related to learning styles, indicates that wholists were generally better at using design drawings in problem solving. As this measure was not concerned with drawing skills (or not in the first place) but with the students’ ability to use sketches as interactive design tools.

The situation is different for the fourth and final year students, where Wholists appeared to perform better along all criteria (moderate to strong correlations). It may, in part, be explained by the observations derived from analysing the students’ modes of designing, which indicated for the fourth and final year students, particularly wholists, to have more integrated design processes. That is, it is likely that the knowledge and the skills acquired during design education enabled senior subjects to process more information in parallel, or/and to be more efficient

while doing it, and therefore to produce more balanced (on all measures) representations. Additionally, these students were more capable of interacting with their drawings than the first year subjects, and also relative of the analytic group (confirmed by the *Technical Merit* score).

The above results may also show that different learning styles enable students to deal more efficiently with different aspects of the design task.

When it comes to the Imagery dimension, the results are similar for both groups. There is a clear tendency for the visual individuals to have a better quality of their design solutions on all criteria than was observed among the verbal students (moderate to strong correlations). The reasons are probably related to the visual nature of design problem-solving, both internal (imagery) and external (sketching).

Summarising the results of our study, there are two points to be mentioned. The first one concerns the adequacy of a given problem solving behaviour in a given situation, and the second one concerns the predictability of problem solving behaviour.

With respect to the influence of problem solving styles on design proceeding, the results suggest that diagnosing and training individual problem solving behaviour may be an essential contribution to better domain performance and academic achievement and should therefore be included in design education as well as in further vocational training. As the adequacy of a given style of problem solving depends on the demand characteristics of the situation, a good designer should be able to flexibly use different problem solving strategies and to actually chose the one which best meets the requirements of the situation. Therefore, designers should be trained in the ability to classify problem situations depending on their requirements and in the ability to flexibly adapt their problem solving strategies to the demands of the situation.

A knowledge of learning styles can be used to increase the self-awareness of students and tutors about their strengths and weaknesses as learners. In other words, all the advantages claimed for metacognition (i.e. being aware of ones own thought and learning processes) can be gained by encouraging all learners to become knowledgeable about their own learning and that of others. According to Sadler-Smith (2001) the potential of such awareness lies in enabling individuals to see and to question their ling-held habitual behaviours; individuals can be taught to monitor their selection and use of various learning styles and strategies.

To improve predictability of the problem-solving behaviour, one needs to develop a taxonomy for the field of design and architecture education that can be used as a basis of instruction as well as a basis of assessment procedures. This is evident by the wide range of major objectives and guidelines that evaluators use when grading work. It is almost impossible to acquire a valid consistent picture of the students' academic or creative achievement for comparative (as in case with this thesis) or longitudinal research as different groups of learners are supervised by different instructors who may change during the course of study. Additionally, design and architecture are fields with unique content, whereas the taxonomies currently in use have been developed to assess some generic design product, and are not always appropriate. Thus, assessments of students' work shall be measured against a taxonomy that is suitable for the subject area in order to provide direction and assessment uniformity. That is, it shall be disseminated throughout the field so that instructors have a solid basis for their instruction and assessment. This is also important for the researchers as they need a good understanding of the grading criteria to ensure for their taxonomies to translate well onto the current educational practices and requirements.

Finally, students need being educated on the evaluation principles, because, as this study indicated, they often fail to make accurate judgements concerning the quality of their design products. Or, as summarised by Imrie (1995) '...levels of learning (as well as domains of knowledge) need being identified so that the rationale for assessment is accessible to students for effective learning, to peers (for effective teaching, moderation, and continuity) and for external requirements of quality assurance' (p.180).

Chapter 7. Overview of Results & Future Research

Chapter 7 contains a synopsis of findings brought together with the purpose of articulating the most important conclusions. The discussion capitalises on the relationships between spatial abilities, learning styles, performance and academic achievement, pointing out the limitations of the study and its research methodology, offering some recommendations, and reflecting upon the entire research process.

7.1 Ability factors in design process and product

This thesis was concerned with the exploration of the effect of learning styles and cognitive abilities on problem-solving and academic performance. The idea was instilled by a number of recent studies dedicated to the subject of design ability – a construct that integrates qualities an individual needs to possess to be able to handle a design task, that is potentially useful in predicting design behaviour. Other literature has indicated a growing interest in the subject of cognitive and learning styles and cognitive factors; particularly visual-spatial abilities and wholistic and visual reasoning that have been commonly recognised as crucial for designing. These styles and abilities were chosen for the exploration in the present study as they fit well with the research of design ability being its inherent components.

The main hypothesis proposed that certain differences in designers' problem solving strategies and, ultimately, products of their expertise – designed artefacts – could be correlated with individual differences in learning styles and cognitive abilities.

The study progressed in three major stages associated with the three major areas of research. It began with selecting the *input* – two groups of cognitive styles and abilities contributing to design ability, and their subsequent assessment and relation to academic performance reports. It proceeded with administering design sessions and exploring them as a *process* to see whether and how these abilities and styles were reflected in design problem solving. It then arrived at the assessment of the *product* i.e. final design solutions. And, finally, it explored the correlations between the *input*, the *process* and the *product* to understand the students' preferences in adopting particular problem solving strategies and styles in designing.

The input

The input stage, or the study of design ability, consisted of three experiments. Experiments I/a and I/b were psychometric studies assessing a number of visual-spatial and ideation factors believed to contribute to the design ability. Experiment II/b was another psychometric study evaluating individual positions on Wholistic-Analytic and Visual-Imagery dimensions of learning styles, also believed to be a part of the design ability. Experiment III/a and III/b involved the assessment of academic achievement on design projects reported by course supervisors. The main purpose of this part of the empirical study was to provide the estimates of the students cognitive development and learning preferences, to research interconnections and correlations among the ability factors; and to determine which factors could be regarded as good (better) predictors of the domain performance.

Cognitive abilities and academic performance

The cognitive abilities study contained two major parts referred to as Experiments I/a and I/b as it described two sets of tests administered to 80 (60+20) subjects at two separate stages of this research development. They were similar in terms of the choice of visual-spatial and figural ideation abilities, and differed in two verbal ideation abilities measured in the second experiment only. They generated similar results on both comparative and correlation analyses, suggesting that they were equally characteristic of the student population they drew from.

The results of Experiment I/b (i.e. involving the participants of all six experiments) indicated differences as well as similarities within and between the sample. The ability scores of the first year students were generally lower than of the fourth and final year subjects suggesting that idea production and spatial abilities are not fixed, but involve processes that may be changeable in adulthood. That is, the aptitude may also be a skill which can be improved or developed, and/or there may be learnt strategies that allow achieving higher results on cognitive tests. The idea of ability trainability is supported by factor-analytic research (Carroll, 1993) and a vast number of empirical studies (Piaget 1971; Sorby & Baartmans, 1996; etc).

The improvement in the ability measures varied. The largest gain was on visual memory (MV), and the least on spatial scanning. It was suggested for MV to be highly developed among architects due to a wide range of tasks and activities that both improve the quality of visual memory and depend on its use. This is in conformity with factor-analytical research that has indicated for the visual memory to be one the fundamental lower level factors that support other higher level abilities, such as visualisation (Miyake, *et al.*, 2001; Lohman, 2002). Additionally, spatial learning strategies have also been found to be the cause of superior memory (Maguire, *et al.*, 2002). The transfer-of-training effect between visual memory and other abilities, such as visualisation, has also been reported in earlier studies (Carroll, 1993). Advanced spatial scanning ability, on the other hand, may not be as important in the form it is measured by ability tests – when the speed of performance is emphasized. Not many architectural tasks depend on time-constrained scanning of complex visual material, hence the lowest gain on this factor.

A further comparative analysis indicated for spatial and ideation ability scores to be, on average, higher among the tested architecture and design students than other reported samples of lay population and this observation was valid for each year of education. This is in conformity with the literature indicating for architects to score higher than the general public on visual-spatial tests of mental rotations, mental scanning, constructing spatial analogues, and so on (Ghiselli, 1966; Smith, 1964; Chase and Chi, 1981). And with other research, indicating that they are consistently more accurate at tasks involving spatial visualisation (Salthouse, 1991), and are better than the lay people at ideation and other creativity-related tasks (Yamada & Tam, 1996; De Bono, 1996; Lawson, 1997; Birkhofer, *et al.*, 1998; Plucker, 1999).

The comparative study was followed by correlation analysis concerned with the association between education and design abilities. It indicated for general cognitive development to serve as a consistent predictor of academic performance and creativity in both groups of students, although the magnitudes of correlation coefficients varied.

Other results showed that both visual-spatial and ideation abilities of the first year students were correlated with academic achievement and creativity. Visual-spatial abilities of the fourth and final year students were correlated with creativity and academic achievement, while ideation abilities were not correlated with either.

This suggests that, across the sample, visualisation abilities are better predictors of academic performance, possibly because they involve more complex cognitive processing characteristic of design tasks. The reasons for low(er) predictive effect of ideation may be similar. That is, tasks used in ideation ability tests are relatively simple, they draw on visual/verbal fluency and flexibility more characteristic of the first year design education. Whereas most projects in architecture are multifaceted complex activities, that deal with large numbers of different types of constraints.

As more abilities predicted academic performance and creativity of the first year designers, this suggested their higher importance, possibly due to the fact that the fourth and final year students (a) have succeeded in developing a range of aptitudes necessary for the domain performance (supported by their higher measures relative of the first year participants), or/and (b) acquired certain ways of compensating for ability limitations.

The observed impact of visual-spatial abilities on academic performance suggests that the effect of attrition may also be present; it may be accountable for the differences between the test

scores of the two groups of students. That is, high spatial individuals have a better prospects of fulfilling course requirements and, therefore, to continue education through to the final year.

A further correlation analysis indicated a number of links between and within the three groups of abilities consistent across the sample. The correlations were consistent between visualisation, spatial relations and visual memory. These results are supported by the research that argued for the more complex abilities (such as visualisation and spatial relations) to be partially dependent on, and supported by visual memory (Juhel, 1991). And factor-analytic studies suggesting a transfer-of-training effect between different groups of visual-spatial factors (Carroll, 1993). Other groups of abilities were either inconsistent in terms of observed correlations or unrelated. This is perhaps why seventy percent of the students had uneven ability profiles, scoring high(er) on one or more tests and low(er) on another, even within the same group of cognitive factors. The other explanations for this variability may include: (a) some of the abilities to be more trainable or more likely to be improved via the course of education, (b) the transfer-of-training effect, and (c) the more efficient uses of compensatory strategies during cognitive testing.

Finally, no significant gender or ethnicity-related differences in the ability levels have been detected. The moderate variance suggested that men may be better at visual-spatial abilities. The collective means were equal on ideation, with females scoring marginally higher on figural fluency and marginally lower on figural flexibility tests.

Learning styles and judgements of academic performance

The initial analysis of the learning style scores indicated that: (1) 40% first year designers, and 40% fourth and final architecture students had preferences in Wholistic processing; (2) 30% first year designers, and 70% fourth and final architecture students had preferences in Analytic processing; (3) 50% first year designers, and 60% fourth and final architecture students had preferences in Imagery mode; (4) 20% first year designers, and 40% fourth and final year architecture students had preferences in Verbal mode.

This means that this study's results only partially match domain assumptions in terms of the students' fitting into the prevalent wholistic-visual framework, as both groups consisted of the predominantly visual learners. However, it is not fully evident why there were more analytical learners among architects and designers, and why there was a smaller proportion of wholists in the fourth and final years than in the first year. There could be many reasons for this, including the previous secondary education supporting verbal analytical learning and problem solving. It is also possible that architectural education reinforces analytical thinking because of the associated with it body of technical knowledge. Cultural, racial, environmental aspects, the size of the sample, and other issues could have also contributed to the observed situation.

The joint analysis of the learning style scores has revealed differences in the strengths of learning style preferences within the sample related to: (1) the year of study – there were more of versatile and brain-gifted individuals among the fourth and final year architects, than among the first year designers; (2) gender – females in both groups were more inclined towards the verbal mode and wholistic simultaneous thinking, and males – towards the visual mode, and analytical sequential thinking; and (3) ethnic origin – there are more analytic and visual learners among Australasian students and, correspondingly, more wholistic and verbal students among Australians. Although both gender and ethnicity related differences become marginal when flexibilities are equalised to preferences and strong preferences.

These results suggest that consideration should be given to both the type of learning style preference and the strength of that preference, as no learner fits neatly into one particular style, but rather is inclined towards one area more than another. There are more first year students with flexibilities than with (strong) preferences, which means there are less students with the natural well-developed ability for using different thought processes, and more students that may switch between different modes if necessary.

A training effect may occur as students complete one or more of their major courses. The data in this study suggested a sound possibility for this change as derived from the participants' metacognitive statements, although the observed (i.e. reported by LSA) improvement is mainly related to the strengths of learning styles preferences and their increased versatility. A favourable learning environment catering for the needs of different students could be a key to development of the necessary learning strategies. Design studios have a potential to provide such environments by stimulating and accommodating a broader repertoire of learning styles. At the same time, the students' inability to acquire, or of the education to provide, new and necessary ways of learning may lead into a less effective transition between old – secondary education, and new – university, study environments. This may subsequently lead to the reduced academic learning opportunities and achievement levels, and, ultimately, attrition.

A further correlation analysis of the four learning styles, creativity and academic performance assessments revealed differences and similarities within the sample related to the year of study. For the first year students it indicated for Wholistic and Imagery learning styles to be correlated with creativity, while academic performance could depend on the Imagery learning style. For the fourth and final year students it showed that both creativity and academic performance could be predicted by Wholistic as well as Imagery learning styles.

This suggests that in terms of the roles of learning styles in creativity, this study's sample matched domain assumptions, as Wholistic-Visual learners were the most creative. In academic performance, it is only the Verbal-Imagery dimension that fully met these assumptions for both groups of students as the visual learners were the most successful. It is not fully evident why Wholistic learning style was not associated with academic performance in the first year group (although it was associated with creativity, which, in its turn, was correlated with academic performance). It is possible that, according to the model proposed by Riding and Sadler-Smith (1992), imagery is able to some extent compensate for the absence of wholism for an analytic-imager, as the individual might be able to gain an overall perspective through the application of imagery. Similarly, the wholistic-verbal learner may be able to draw on his verbal thinking to help overcome difficulties arising from the low(er) level of analytic processing.

Other data indicated for Wholistic learning style to be correlated with Imagery learning style, and these correlations were present in both groups. This means that there were more wholistic learners among imagers than there were analytical learners. The wholistic-visual correlation is in agreement with research concerning visual-spatial learners who prefer to think wholistically rather than in a sequential fashion (Silverman, 1998). The magnitude of correlation is smaller for the first year, which may be due to the strength of learning styles preferences (i.e. fourth and final year students possess wider ranges of better developed styles).

Learning styles, cognitive abilities and judgements of academic performance

The first part of the analysis sought to determine the relationship between cognitive styles, cognitive abilities, and academic performance. The correlations were consistent for two accounts of learning styles: (1) proto- and metacognitive reports obtained from introspective reports; and (2) individual learning styles as assessed by LSA. They are discussed further in this section to avoid repetition.

In terms of the strengths of predictive validity, the number and magnitudes of correlation coefficients indicated that, for the first year students, cognitive abilities are essential, while in the later years learning styles gain more importance.

The second part of the analysis indicated for the broader repertoires of learning styles to be a statistically significant factor influencing academic performance. The top students in each group were either versatile or brain-gifted, that is potentially more able to cope in any learning environment, or more flexible in utilising different approaches to problem solving. The correlation magnitudes were lower for the fourth and final year as there were lower score

fluctuations (i.e. more students with similar strengths of learning style preferences). Additionally, versatility was correlated with high scores on tests of visual-spatial abilities. One of the possible explanations is that different tests may require different strategies to arrive at correct answers. Or that certain strategies are more efficient for particular tests, while broader repertoires of learning styles may enable students to choose between these strategies more freely, and, therefore, attain higher scores. The same cognitive advantage may also affect non-test situations requiring the use of visual-spatial abilities (such as design tasks).

Another observation concerning the possible influence of learning styles on ability measures was related to the performance on cognitive tests. Wholistic students were significantly faster (in some cases, used up to 50% less of the allocated time) on visual memory and visualisation tasks. These tasks involve simultaneous processing and/or transformations of visual material and may draw on wholistic processing.

At the same time, analytical students performed better (up to 30% faster and with considerably lower error rates) on tests favouring sequential approaches, such as mental rotations and spatial scanning. These results may partially explain the lack of consistency in test scores of visual-spatial or/and ideation abilities for some subjects – differences in learning styles may have influenced individual performance.

Overall, these results remain tentative, as it has not been possible to determine how the proportion of the variance in achievement outcomes attributable to ability factors fits into other similar research due to the lack of relevant studies involving design students and/or utilising same or equivalent psychometric instruments.

The process

The study of design processes was based on the data from two experiments. In Experiment VI/b, the students solved a design problem after which they were asked to provide retrospective reports of the experienced cognitive processing. Along with these reports, they made unprompted introspective statements, while the researcher drew on the technique of an open interview to help clarifying unclear or ambiguous actions, processes and statements. Introspective claims contained metacognitive data on individual problem solving and the imagery use. In Experiment V/b, the participants were given a questionnaire to complete. It was aimed at obtaining additional accounts of individual design processes.

Protocol studies: Step 1, Experiment IV/b (object)

A series of qualitative and quantitative analyses were performed in two major steps to facilitate comparisons and correlations between different groups of data expected to be indicative of the similar/same types of phenomena (i.e. reflecting particular characteristics of the design ability). In the first step (Experiment IV/b(object)), it was proposed that certain qualitative and quantitative characteristics of generated diagrams, sketches and annotations, as well as of proto- and metacognitive statements from introspective reports and questionnaires, could be associated with the differences in individual learning styles and cognitive abilities.

Demographic analysis indicated that there was no discernible difference in the quality of responses received according to the country from which the respondent originated, or their gender. That is, in what concerned the ability, good or poor, to report experienced cognitive processing, and to articulate proto- and metacognitive ideas. The main distinction pertained to the year of study, with the fourth and final year students being more eloquent, more aware of their learning and problem solving behaviour, as well as more structured with their responses.

Comparative analysis between the first, and fourth and final year students allowed examining the participants' preferences for presenting information and ideas either graphically – by sketching, or sententially – by making notes. It indicated for the fourth and final year students to have produced significantly more sketches, while both groups generated comparable numbers of

annotations and diagrams. Both groups produced the highest amount of annotations, and the lowest – of diagrams.

Cognitive abilities and external representations

Further comparative and correlation analyses were performed to determine how different types of external representations were related to the participants' cognitive abilities.

Preference for Sketching & Diagramming. This part of the study examined the observation from the earlier studies that suggested for problem solving employing sketching and diagramming strategy to be favoured by high spatial ability students (Fennema & Tarte, 1985; Pribyl & Bodner, 1987). The results indicated for high spatial individuals in both groups to have produced, on average, significantly higher amounts of sketches (particularly 2D). Situation with diagramming was less clear – it is only the high spatial students from fourth and final years who generated the largest number of diagrams. There was no link between annotating and visual-spatial ability, despite the possibility for low(er) spatial students to rely more on sentential problem-solving due to, potentially, weaker sketching ability, believed to be supported by visualisation.

Preference for 2D and 3D sketching. Further to the above results, the association between cognitive abilities and preference for 2D and 3D sketching was explored. It was suggested that preference for three-dimensional as opposed to two-dimensional sketching could be a manifestation of a more advanced spatial ability, namely 3D visualisation.

The results indicated that this association may be present. For the first year students 3D sketching was correlated with figural flexibility. It has strong visualisation and reasoning components, and indicates an ability to be flexible in adopting and changing mental sets about figural problems (Carroll, 1993). It also requires fluency in successfully dealing with 3D figural tasks via a search for relevant knowledge in long-term memory, and an ability to rapidly change set and try-out a variety of approaches to solutions for figural problems that have several stated criteria. This fits well with the nature of three-dimensional sketching.

For the fourth and final year students 3D sketching was correlated with advanced spatial relations ability. It is believed to be one of the fundamental lower level factors that support other higher level abilities and one of the subfactors to visualisation (Miyake, *et al.*, 2001; Lohman, 2002). It was also correlated with visualisation which is seen as a more complex and less speeded form of spatial relations, as both require the mental rotation of a spatial configuration in a short term visual memory (Ekstrom, *et al.*, 1976)

The differences in correlations observed among the two groups of participants may be related to the differences in their use of 3D representations. As more architecture students drew three-dimensional objects as an effort to find missing views, while more design students drew three-dimensional shapes in an attempt to externalise pre-visualised ideas.

Levels of ideational ability and external representations. Contrary to the literature linking ideational abilities to sketching and creativity, Experiment IV/a did not yield any new evidence as neither comparative nor correlation analyses have indicated significant or moderate relationships between ideational abilities (figural or verbal), and number and types of external representations generated.

Learning style preferences and external representations

Further comparative and correlation analyses were performed to establish how different types of external representations were related to the participants' learning styles. They were based on the proposition that extensive/redundant annotating, sketching and diagramming may be correlated with Verbal-Imagery learning styles, whereas other characteristics of external representations, such as their complexity and number and quality of ideas generated, could be associated with the Wholistic-Analytic dimension.

Annotations. The correlation analysis indicated a main effect or interaction for the Analytic learning style on the production of object-annotations – for the first year students. And similar, but moderate correlation – for the fourth and final year students. Wholism was associated with idea-annotations in the first group, and idea- and concept-annotations – in the second group, although correlation coefficients were mainly moderate.

On the Verbal-Imagery dimension, the analysis indicated moderate associations between the Visual learning style and idea-annotations for both groups of students, and a moderate correlation between the Imagery mode and concept-annotations for the fourth and final year participants. It has also revealed moderate correlations between object-annotations and the Verbal learning style for design students.

Sketches. The analysis indicated moderate associations between the Wholistic learning style and different types of sketches (2D as well as 3D) for the fourth and final year students, and a low correlation between the wholistic mode and the overall numbers of sketches for the first year participants. No correlations have been observed for the Analytic learning style.

On the Verbal-Imagery dimension, the analysis indicated strong associations between the Imagery learning style and external representations for the first year students (concerning their overall numbers and 2D sketches, in particular), and moderate correlations between the visual mode and sketches (overall, 2D and 3D) for the fourth and final year participants. It has revealed no correlations with the Verbal learning style for either group of students.

Diagrams. The Pearson's product-moment correlation analysis has not indicated any connection between the Wholistic-Analytic and the Visual-Imagery dimensions and the numbers and types of diagrams generated for both groups of students. However, the issue of diagrammatic reasoning needs to be understood further before any conclusions can be drawn.

Levels of complexity, repertoires of external representations, and ability factors

The protocols have revealed that the fourth and final year students had a greater repertoire of schema for external representations, than did the first year students. The differences were more pronounced when it concerned diagrams and sketches (and less so in regards to annotations). The fourth and final year students also generated more complex 3D representations.

Correlation analysis was performed to establish how different levels of complexity, as well as individual repertoires of external representations, were related to the participants' learning styles and cognitive abilities. It was based on the proposition that the high(er) (or low(er)) ranges of all types of annotations, sketches and diagrams used, could be associated with students' preferences on the Wholistic-Analytic and Verbal-Imagery dimensions. Whereas other characteristics of external representations, such as their complexity, could be linked to the Wholistic-Analytic mode and visual-spatial and ideational abilities.

A number of links have been established between learning styles, cognitive abilities and external representations; for the first year students they included: (1) larger repertoires of external representations were correlated with Wholistic and Imagery learning styles, visual-spatial ability, and figural ideation (moderate correlation); (2) 3D-sketches complexity was (moderately) correlated with Wholistic learning style, higher repertoires of external representations, and figural ideation (also moderately); and (3) 3D-sketches complexity was (moderately) correlated with figural ideation

For the fourth and final years they include: (1) larger repertoires of external representations were correlated with Wholistic and Visual Internal (Imagery) learning styles, visual-spatial ability, and 2D-sketches complexity; (2) 3D-sketches complexity was correlated with Wholistic learning style and higher repertoires of external representations; and (3) 2D-sketches complexity was (moderately) correlated with visual-spatial ability

The correlation of larger repertoires of external representations with wholism could be explained by the fact that wholism is commonly associated with fluency (larger proportion) and

flexibility (wider range) in idea production (Williams, 1980). The same reasons may have directed students to producing more complex sketches. That is, as the more versatile ideas are generated in parallel problem-solving and they tend to be interlinked, the more complex external representations emerge. Additionally, the association of the preference for complexity with wholistic learning style is supported by theoretical research and empirical studies in psychology (Pask, 1976; Coffield, *et al.*, 2004).

The imagery link is similar, as visual thinking is believed to involve synthesis, simultaneous processing and interconnecting of concepts; use of imagination and generation of ideas by combining existing facts in new ways – ideation and creative thinking (Lynch, 1986; Silverman, 1998). It may also be supported by the wholistic-imagery correlation. The latter also explains the link between complexity and visual-spatial ability. It is in conformity with the empirical evidence suggesting that high spatial ability individuals have more highly organized mental representations of objects than low spatial (Lohman & Nichols, 1985).

Ability factors in introspective statements, questionnaires and academic performance

Correlation analysis was performed to establish how three different accounts of the students learning styles (as derived from LSA assessments, introspective reports, and questionnaires) were related to their cognitive abilities, creativity, and academic performance.

LSA assessments and Introspective reports. The results suggested a strong link between the two measures of Wholistic learning style and the preference for wholistic problem-solving on design tasks, present in both groups of participants. A similar association was discovered between the two accounts concerning the Imagery dimension. Another consistent across the sample correlation was found between the Analytic learning style (as assessed by LSA) and the students' reports of experienced (preferred) analytic problem-solving and macro approaches to design tasks. A similar link was present between the two accounts concerning the Verbal dimension. There was also a correlation between the measures of Analytic learning style and the preference for verbal processing for the first year students.

Wholistic learning style was found to be correlated with Imagery learning style within and between LSA assessments and introspective reports, and these correlations were present in both groups of participants, suggesting that there are more wholistic learners among imagers than there are analytical learners. The magnitude of correlation coefficient was lower for the first year students, which, in part, is due to the strength of their learning styles preferences (the fourth and final year students have more developed, i.e. strong, styles). The wholistic-imagery correlation is in agreement with research concerning visual-spatial learners who are inclined to think wholistically rather than in an analytic sequential fashion (Silverman, 1998).

LSA assessments, Introspective reports, and Questionnaires. The link between the students' summaries of their design processes, learning styles as assessed by the LSA, and self-reports was confirmed on both Analytic (significant correlations) and Wholistic dimensions (significant and moderate correlations) for the first year students. The situation with the fourth and final year participants was similar, but there was only one strong (and the rest were moderate) association between the Analytic mode (LSA) and the data from questionnaires. Some of the reasons can be related to individual learning style profiles. As the students' dominant and secondary styles varied in terms of the strengths of preferences, and each individual had a unique repertoire of learning styles, some of the versatile subjects produced reports that contained features that could be associated with each pole of W-A dimension with (almost) equal strength. Other reasons for differences in correlation coefficients could be multiple and interacting, including the perceived (by the students) need to organise their reports in a structured and linear way characteristic of analytical reasoning. This means that the nature of the association between the students' preferences for wholistic or analytic problem-solving and the general, higher-level organisation of their design processes revealed in questionnaires, requires further research.

LSA assessments, Introspective reports, and cognitive abilities. A range of links between the two learning styles accounts, creativity, academic performance and cognitive abilities was established; it indicated differences and similarities within and between the sample.

Visual-spatial ability was correlated with Imagery learning style both in LSA assessments, and in introspective self-reports. It was confirmed for both groups of the participants. The association may be supported by the earlier studies that have argued for a visual style to be beneficial in a range of cognitive tasks, including psychometric tests of visualisation and ideation (Vicente, *et al.*, 1987; Sein & Bostrom, 1989; Schofield & Kirby, 1994). It may also indicate that Imagery draws on high visual-spatial abilities. Spatial visualisation was also correlated with Wholistic learning style, but the magnitudes of correlation coefficients varied across the sample. They were significant for the fourth and final year students and weak for the first year participants. The reasons for the less strong association for the latter group are not entirely clear. Whereas the link between the style and the ability is in agreement with research concerning visual-spatial learners who are inclined to think wholistically (Silverman, 1998).

There were no significant correlations between the measures of verbal ideation and any of the four learning styles from both accounts, i.e. LSA assessments and introspective reports.

The levels of figural ideation ability of the first year students were correlated with Wholistic and Imagery learning styles and creativity. The magnitudes of correlation coefficients were significant on the measures of individual learning styles (LSA) as well as on self-reports. The results suggest that developed ideation is important for design creativity in the first year of education, and that both learning styles are beneficial for, or support ideation. It may also mean that Wholistic learning style draws on advanced ideation abilities.

A similar association was discovered between the measures of figural ideations and two accounts of the Imagery dimension for the fourth and final year students. It is strong when it concerns learning styles as assessed by LSA, and is moderate when it comes to self-reports. The magnitudes of correlation coefficients are weak and moderate on the Wholistic dimension. The association of figural idea-production with creativity is also low.

LSA assessments, Introspective reports, Academic performance, and Creativity. This study also sought to determine whether the results of correlation analyses agreed with the domain assumptions concerning the Wholist-Analytic and the Visual-Imagery dichotomies suggesting that designing is successful when the process is a wholistic experience (McCormick *et al.*, 1993). And that the Imagers make the best designers, as visualisation has been shown to be central to the generation and development of ideas (Glegg, 1986).

The Verbal-Imagery dimension was in conformity with these studies when it comes to the association with creativity. It was confirmed for both groups of students. The magnitudes of correlation coefficients were significant relative of the measures of individual learning styles (LSA) as well as of self-reports. The situation with academic performance was similar. For the first year students, the correlations are significant both in LSA reports and in proto- and metacognitive statements. The magnitudes of correlation coefficients are also high for the fourth and final year students when it concerns LSA assessments, and are moderate relative of the introspective self-reports.

The association between the two accounts of the Wholistic learning style and creativity was confirmed for both groups of participants. Whereas the situation with academic performance was different as the correlations were consistent only for the fourth and final year students; they were strong when it concerned LSA assessments and moderate relative of introspective self-reports. For the first year participants, the link was weak on the measure of individual learning styles (LSA) and moderate on proto- and metacognitive statements. It is not fully evident why Wholistic learning style was not associated with academic performance in the first year group (although it is associated with creativity, which, in its turn, is correlated with academic performance). It is possible that, according to the model proposed by Riding and Sadler-Smith (1992), imagery is able to some extent compensate for the absence of wholism for an Analytic-Imager, as the individual might be able to gain an overall perspective through the application of

imagery. Similarly, the Wholist-Verbal learner may be able to draw on his or her verbal thinking to help overcome any difficulties arising from their lesser level of analytic processing.

Effects of metacognition and versatility of learning styles on academic performance. The results of analyses also indicated for the higher levels of cognitive control to be a statistically significant factor on several dimensions. In both groups of students, self-regulation on the wholistic and visual learning styles had a significant impact on creativity. Imagery also affected academic performance on design projects of the first year participants, and indicated a tendency for the similar effect for the fourth and final year students.

The association between metacognition, academic performance, and creativity is perhaps related to the studies of students' metacognitive strategies indicating that metacognitive capabilities such as self-regulation are keys to the development of appropriate learning strategies (Rojas-Drummond, *et al*, 1998; Schraw, 2001). That is, while learning styles are necessary for performing a task, metacognition is critical to understanding how the task is performed, and self-regulation helps in a more efficient conscious choice of learning strategies.

There was also an association between versatility and visual metacognition for designers, while the correlation magnitudes on the same dimensions were low for the architecture students. This suggests that the learners (especially the less flexible ones) need being encouraged on a metacognitive approach to enable them to choose the most appropriate learning strategy from a wide range of options to fit the particular task in hand.

Step 2: Experiment IV/b (process)

Experiment IV/b(process) was concerned with the process of individual problem solving. It was proposed that certain qualitative and quantitative characteristics of diagrams, sketches and annotations being generated, as well as of retrospective reports and questionnaires denoting the progression of problem solving, could be associated with the differences in individual learning styles and cognitive abilities.

Modes of designing

This study distinguished between design activity statements indicating subjects' *modes of designing*. Mode of designing referred to the nature of design activity associated with each protocol statement, i.e. external – graphical and sentential, or internal, visual and verbal, plus five combinations of these modes introduced to include all observed and reported activities.

Comparative analysis between the two groups of subjects was aimed at examining their preferences for reasoning and presenting information. It indicated similarities as well as differences within and between the sample. All students spent the longest proportion of time on problem-solving that integrated two types of processing: (1) combining internal imagery and external pictorial-diagrammatic reasoning (*imagery-graphic* mode); and (2) combining internal imagery and internal verbal processing (*imagery-verbal* mode). That is, approximately 20% and 25% of the protocol session duration. They spent the shortest proportion of time in *sentential*, *verbal-graphic*, and *verbal-sentential* modes of designing, each not exceeding 5% of the session duration. More time was spent in the *imagery-sentential* mode, i.e. •8%. And still longer and comparable time was spent in the *graphic* and *imagery* modes (i.e. about 10% in each).

Different from the first year designers, the fourth and final year architects allocated more of their time to the *imagery-verbal*, *imagery-graphic* and *graphic-verbal* modes. Whereas the designers spent more time in the *imagery*, *verbal* and *imagery-sentential* modes. A comparable time was spent in the *graphic*, *sentential*, *verbal-sentential* (favouring the first year students) and *graphic-verbal* (favouring the fourth and final year students) modes. This suggested the idea that the architecture students may prefer, or are more familiar with/capable of, integrated design processes than are the design students.

This idea could be supported by the observation that the first year students, on average, moved more frequently between design episodes while trying to tackle a small(er) number or/and of less complex issues at a time. They were less capable of using sketching as the efficient means of problem-solving, believed to enable dealing with several levels of abstraction

in parallel. When addressing complex design concerns, they resorted to the familiar to them mode of expression – writing, more (particularly duration-wise) than did the senior students.

Initial and prevailing approaches in problem-solving. The next part of the analysis was aimed at determining the students' initial and prevailing approaches to problem-solving associated with individual learning styles as per the learning style theories.

The results of comparative analysis indicated differences and similarities in the early stages of designing. All students began with understanding and defining the problem, identifying needs, and gathering information, but with apparent variations in individual approaches. Wholists, spent more time trying to build up an overview of the situation from the brief, and later filled in the details of the problem-solving schema. While analytics preferred to focus on particular features of the design task by consulting with the brief more often, for shorter periods of time, and built up a conception of the situation from these details much later in the process.

After the initial understanding of the problem the students proceeded with designing. Analytics were more systematic in their approaches. They, although to various degrees, exhibited many or most of the features associated with analytical learning style. Including, combining information in a linear sequence, working on well-defined chunks of information that are connected by low-level relations, picking up rules, methods and details, using specific, externally-offered descriptions to assimilate procedures and to build concepts for isolated topics. These students typically addressed one goal at a time which, once achieved, was followed by the next goal. Their ideas were built up slowly from careful analysis.

At the same time, there was no much similarity in approaches to designing among the wholists. Although, after understanding the problem, these students proceeded to ideation preserving broad perspectives and using global strategies, the process and the approaches to ideas development bore little in common. They, generally, had many subgoals under the main topic, and addressed many issues in parallel, which is also clear from their rather sporadic verbalisations. Additionally, many wholists showed a tendency to make hasty decisions based on insufficient information or analysis, which resulted in many ideas abandoned further in the process, much more so than observed among the analytical students. Although guided by some strategy, they were very vague on the applied methods and rules.

In addition to determining the designers' initial approach associated with a long-term plan or learning styles, macro strategies were identified by assessing their behaviour in the context of the whole design solution. To identify the prevailing approach the relevant statements were singled out and classified/coded in accordance with characteristics of the four learning styles as suggested by the learning style theories.

The results indicated that the largest amount of strategies reported by both groups of students were verbal and imagery, and the smallest - wholistic. Different from the first year designers, the fourth and final year architects made more statements related to wholistic, imagery and analytic styles; and had the highest proportion of imagery statements relative of their own group. Whereas the first year students reported more verbal strategies than the fourth and final year students, which was also the highest proportion of statements relative of their own group. The reasons could include the influence of the secondary education supporting verbal analytical learning and problem solving. The generally high numbers of reported verbal strategies in both groups could be, in part, justified by the verbal nature of retrospection.

The next part of the analysis was aimed at determining whether the overall high-level structure of individual problem-solving could be classified as representative of a particular learning style. For this purpose, a number of well-known design process models (or methods of designing) were selected as being characteristic of wholistic or analytic thinking. Subsequently, the general structure of each design session was identified by (1) extracting and noting down a sequence of macro strategies, and (2) analysing all macro strategies denoting a particular style, their numbers and lengths. The data resulting from both approaches was mapped onto the chosen design methods to determine whether there were observable similarities.

The analysis indicated that while many students were inclined to using one approach more than another, no model on its own could fully describe the structure of their design processes. For wholistic, brain-gifted and versatile students in both groups design problem-solving was mainly an opportunistically organised type of activity: it did not progress as a series of cycles consisting of actions occurring in a fixed order as they constantly generated new task goals and redefined task constraints. Yet a higher-order plan, either on the level of maintaining a global overview or following the procedures of the 'standard design practice' was often observed. Analytic students (particularly verbally inclined) did use a more structured approach but largely on the macro scale. Both wholistic and analytic students resorted to problem-solving by analogy and used top-down and bottom-up approaches, with analytic students being more systematic and less inclined to their simultaneous use (i.e. parallel processing).

Transformational balance of sketches

Comparative analysis between the first, and fourth and final year students allowed examining the participants' progression of problem-solving, and the structure of reasoning and presenting ideas, conveyed graphically – by sketching, and sententially – by making notes. It indicated for the fourth and final year students to have higher levels of transformations on both vertical and horizontal dimensions.

There were little similarities in the organization/progression of sketching activity. Analytic students, particularly verbally inclined, adhered to more structured and linear approaches that progressed from initial analysis that broke down the problem into its components, to building up ideas in a step-by-step manner (i.e. showing a stable balance of transformations with a clear vertical bias), followed by the gradual decline of horizontal transformations, and the increase of vertical transformations. For wholistic, brain-gifted and versatile students in both groups, design problem-solving was an opportunistically organised type of activity characteristic of parallel processing; it did not follow similar or recurring patterns but was influenced by initial ideation/type of concept and the level of sketching ability/experience with thinking on paper.

Analysis of retrospective reports

The learning styles and the human ability theories offered a framework that lead to a coding scheme that contained a number of categories (recorded as a micro strategy dimension) concerned with the designer's immediate actions. They could facilitate the exploration of correlations between the lower-level strategies observed during the performance on design tasks, and the measures of individual styles and abilities.

However, close examination of retrospective reports lead us to believe that the lower-level task-specific strategies were heavily affected by the process of post-factum verbalisations. That is, although the students were advised against skimming over the details of experienced cognitive processing, as well as against creating reasons behind their problem-solving approaches and strategies that sounded plausible, many (and analytic students more so) found it easier to use more generic cognitive structures such as memories, opinions, procedural knowledge, and stereotypes as a basis for their judgements. This was perceived as rather detrimental for micro strategies, as opposed to proto- and metacognitive statements and macro strategies which were less likely to being affected in a negative way.

Additionally, while the cumulative data was statistically justified, it was unevenly distributed, largely due to the character of retrospective verbalisations, and not because of the experienced cognitive processing.

Learning styles and cognitive abilities in design problem-solving

Correlation analysis was performed to establish how two different accounts of the students learning styles (as derived from LSA assessments and introspective reports) were related to their modes of designing, macro and micro strategies in problem solving. The results generally confirmed the preceding comparative and correlation analyses suggesting that Wholistic and, more so, Imagery learning styles are likely to be the best predictors of the design performance.

Modes of designing. Correlation analysis between the first, and fourth and final year participants allowed examining the participants' preferences for reasoning and presenting information in relation to individual learning styles as assessed by LSA. The results suggested that the first year Wholistic and Visual students are likely to resort to imagery, imagery-verbal and imagery-graphic modes of designing, while verbal students prefer sentential and verbal-sentential modes of representation. When it concerns the fourth and final year Wholistic students, they are inclined to imagery-verbal, and less so imagery-graphic modes of designing. Analytic students from the same year prefer imagery-sentential mode of designing, while Imagers resort more to the imagery-verbal reasoning and representations. The results are generally consistent with both LSA assessments and introspective reports.

Prevailing approach. The four types of macro strategies were suggested to be associated with the four learning styles or metacognitive reasoning executed in planning, monitoring or global approaches to problem-solving situations. The results of correlation analyses indicated that this link is present when it concerns Wholistic and Imagery dimensions for both groups of students (confirmed by LSA assessments as well as introspective reports). In other words, it is the wholistic and visual students in both the first and the fourth and final years of study who preferred to resort to wholistic and visual reasoning on the level of macro strategies.

There were no significant correlations with Verbal or Analytic learning styles, and only a weak correlation between Analytic and Verbal learning styles as assessed by LSA and the length of verbal statements for the fourth and final year students, and between the Verbal learning style and the length of verbal statements for the fourth and final year students. The reasons for the latter lack of association are not entirely evident. Our observations and the earlier statistical analyses suggest that analytic, as well as verbal students tend to report more on their micro strategies, and, correspondingly, the correlations are strong there. This could be due to the nature of analytic problem-solving concerned with addressing small(er) chunks of information (design concerns) and one at a time. This issue, however, requires further research.

Horizontal and vertical transformations. A further comparative analysis indicated the students' tendency to produce work that was either horizontally or vertically biased relative of their learning styles preferences as indicated by the two learning styles accounts.

The brain-gifted students in the Imagery-Verbal mode (i.e. equally strong in both visual and verbal processing) tended to produce the largest numbers of vertical and horizontal transformations. Brain-giftedness in the Analytic-Wholistic mode was also an indicator of a larger number of transformations, vertical in particular, suggesting that being highly integrated in using mental techniques is a definite advantage.

No correlations have been observed on the Analytic and Verbal dimensions, with only a weak tendency for the first year analytic students to produce more horizontal and vertical transformations (consistent across LSA assessments and introspective reports). This may be related to the observation for the wholistic students to start designing after absorbing information and spending more time on the internal development of conceptual ideas. Whilst the analytic students tended to follow the learnt design routines and spent much less time trying to come up with an interesting concept. Thus, their solutions indicated early fixation and many lateral transformations were down to generating a number of various detail changes.

The situation was reverse for the fourth and final year students, where wholists appeared to be significantly more productive (consistent across LSA assessments and introspective reports). It may be supported by the observations derived from analysing the students' modes of designing, which indicated for the fourth and final year students (particularly wholists) to have more integrated design processes. That is, it is likely that the knowledge and the skills acquired during design education enabled senior subjects to process more information in parallel, or/and to be more efficient while doing it, and therefore to produce richer (more detailed and more diverse) representations. Additionally, there are more A-W versatile individuals among the fourth and final year students, as indicated by the LSA.

On the Imagery dimension, the results were similar for both groups. They are consistent for both LSA assessments and introspective reports although the correlation coefficients varied. There was a clear tendency for the visual individuals to generate more horizontal and verbal transformations than was observed among the verbal and analytic students. The reasons were probably related to the visual nature of design problem-solving, both internal (imagery) and external (sketching).

Horizontal and vertical idea-annotations. There were no significant correlations observed apart from the association vertical idea-annotations with Visual External learning style (as assessed by LSA) for the first year students. The nature of this link is not clear.

Other results varied on horizontal and vertical idea-annotations. It is the wholistic, and visual students among the first year participants, who were the most productive on both dimensions, but the correlation coefficients are weak. While the fourth and final year wholists had a slight tendency to produce more horizontal idea-annotations, and the imagers were inclined to more vertical idea-annotations. There was also a tendency for analytic and verbal individuals in both groups to generate the lowest number of both types of annotations.

The reasons for the lack of correlations are likely to be multiple and interacting. As the participants have chosen to convey both visual and verbal ideas and in a written form, it is possible for the observed situation to be less related to the preferences on Visual-Imagery dimension, but to the rate of idea-production, design knowledge, and the very nature of annotations, such as their vagueness and speed of noting down. They could appear at any point of time and had a broad range of purposes – from structuring thoughts and planning problem-solving, to explaining and refining ideas, or recording newly emerging ideas on the fly, before having them overlooked or forgotten. Many students chose sentential form of representation when they felt there was not enough time for adequate graphic depictions. While other participants who lacked in sketching ability (or whose ideas were too complex for their levels of sketching) felt it was easier for them to resort to written descriptions. The protocol session constraints may have also influenced the rate of and the type of preference for annotations.

In future, one needs to look into wider range of processes, that is by including the ones that occur internally. As it has been noticed that a lot of wholistic students, whose vertical and horizontal transformations seemed to increase and decrease randomly, preserved an overview or a high-level plan, and adhered to some global strategy, apparent from their intro- and retrospective verbalisations. The students were also different in their capabilities of complex integrative reasoning, which affected both the rate/intensity and the pattern of their sketching.

Micro strategies, learning styles and cognitive abilities. The data on problem-solving strategies was related to individual learning styles from LSA assessments and introspective reports. The analysis, however, did not yield many consistent/significant correlations on most dimensions, for the exception of the preferred analytic learning style as assessed by LSA to be correlated with the number and the length of analytic statements. Another correlation was observed on the Verbal dimension as assessed by LSA, concerning the number of verbal statements, and their length for the first year students only (moderate correlation). A moderate correlation was also observed between the Wholistic learning style and the cumulative number of all micro strategies reported for the first year students; and a significant – for the fourth and final year participants.

A further series of correlation analyses were performed using the data on problem solving strategies associated with cognitive factors, and the measures of individual cognitive abilities, modes of designing, and the number and type of external representations generated. They did not yield consistent/significant correlations apart from the number of visualisation statements being correlated with general visual-spatial ability, and the repertoire of external representations. A range of correlations with the modes of designing were down to the inclusion of micro strategies in estimations of the modes of designing.

The final series of correlation analyses were performed using the data on micro strategies denoting cognitive abilities and the data on individual learning styles from LSA assessments

and introspective reports. They did not yield many consistent/significant correlations on any dimension, for the exception of the preferred wholistic learning style as assessed by LSA to be correlated with the cumulative number of all statements related to cognitive abilities. A moderate correlation was observed between the number of verbal ideation statements and wholistic dimension as per LSA assessments and introspective reports, for the first year students, and no significant or moderate correlations for the fourth and final year students.

It, however, became clear from these analyses that, in addition to the encountered difficulties in establishing the association between task-specific strategies, cognitive abilities, and learning styles (the reasons previously cited), it is hard to be certain about the interpretations even with the links having been identified. Linear correlations may not be appropriate as different individuals and skill groups have been shown to use alternative strategies for solving similar problems, and those were not always related to their learning styles or/and cognitive abilities (Shepard & Feng, 1972; Cooper, 1975, 1983; etc).

The product

Experiment VI/b was concerned with the students' final products of individual problem-solving as assessed by three independent evaluators according to a number of specified parameters.

The judges rated the quality of design solutions in both groups slightly above average. The first year students averaged a quality score of 2.23 across all measures, while the fourth and final year students averaged 2.41. The similarities in the judges' opinions were down to the fact that students were evaluated in the context of the group performance (i.e. relative of their respective year of study) in the first place – as suggested by the assessment brief, then relative of the sample, and not in accordance with certain arbitrary standards for professional merit.

The differences were more (most) significant on the *Functionality*, *Technical Merit*, and *Constraints Met* dimensions, and the least on *Complexity-Elaboration*, *Creativity-Originality*, and *Fluency-Flexibility*. The reasons for the differences in the first three dimensions are likely to be related to the more advanced domain knowledge and skills of the fourth and final year participants, and also to the fact that there are more analytical students among them. The more important, although connected cause for the observed situation, is that both wholistic and analytic students in the senior group were more capable of developing their ideas interactively, by sketching. Their design solutions evolved gradually, by synthesising solution components, integrating constraints and responding to local conditions. This is in conformity with the research indicating that sketching may not be as helpful for novices as it is for expert designers in the development of new ideas (Goldschmidt, 1991; Goel, 1995; Suwa and Tversky, 1997).

There were more and stronger correlations between the six evaluation criteria for the fourth and final year students. And only moderate for the first year participants. This means that the senior students' typically incorporated more factors that have contributed to the final score. That is, if their solutions, for example, were judged as 'good', it is likely that they were very balanced in terms of meeting all assessment criteria. This is likely to be related to the more advanced knowledge, but equally, can be a result of the more integrated design processes (as previously discussed), better cognitive abilities, and higher levels of style flexibility. Additionally, the ability to interact with paper as opposed to trying to externalise imagery or/and 'decorate boxes' is a definite advantage of the senior participants.

Students views of produced design solutions. The students' ranking was unrelated, or slightly negatively related to the judges' assessments as neither group of students was able to judge accurately the quality of their final designs. The most apparent explanation is a lack of a good understanding of their ability to produce a quality design, or a lack of knowledge of the grading criteria. However, other factors might have had a strong(er) influence on the participants' judgements. They can be found in the students' comments at the end of the experiment, and are related to individual learning styles. It was noted for the wholists to give low(er) evaluations of their creativity, than did the analytic students, whilst in the judges' assessments within the group context were reverse.

Correlation analyses: abilities and styles in design process and design product

The general observations derived from correlating the three groups of ability factors, with the design process and the design product indicated that different factors were unequal in terms of the strengths of predictive validity as well as the number and the significance of associations with other variables used in correlation analyses. Visual-spatial abilities, Wholistic and Imagery learning styles appeared to have the strongest influence both on the process and the outcome of individual problem-solving in both groups of students. These results confirmed the earlier comparative and correlation analyses suggesting that Wholistic and, more so, Imagery learning styles are likely to be the best predictors of the design performance.

Among other factors that showed many and/or strong correlations with other variables were *Versatility*, suggesting that flexibility and broader profiles of learning styles are a statistically significant factor influencing design performance, academic achievement and the quality of final solutions. These students are potentially more able to cope in any learning environment, or more flexible in utilising different approaches to problem solving. Additionally, versatility was correlated with high scores on tests of visual-spatial abilities. One of the possible explanations is that different tests may require different strategies to arrive at correct answers. Or that certain strategies are more efficient for particular tests, while broader repertoires of learning styles may enable students to choose between these strategies more freely, and, therefore, attain higher scores. The same cognitive advantage may also affect non-test situations requiring the use of visual-spatial abilities (such as design tasks).

Another highly correlated with other variables factor was *Repertoire*, it indicates that students who have also produced broader repertoires of schema for external representations (it included a summary of all different types of diagrams, two- and three-dimensional sketches and annotations) were among those who succeeded in terms of the progression and the outcome of design problem-solving. It is related to visual, and, more so, wholistic thinking, probably because they rely upon imagery and ideation, and combine different methods of exploration to achieve understanding by identifying and focusing on many patterns or trends in the task.

When it comes to external representations, sketching had the highest influence on the development of design solutions as well as the quality of final designs, whereas diagramming has the lowest and annotating, though beneficial, is not consistent across the sample.

Cognitive abilities in design solutions. Correlation analyses were performed to determine how different characteristics of the students' design solutions were related to the levels of their visual-spatial, verbal and figural ideation abilities.

They indicated that the first and the fourth and final year students share a lot of similarities in terms of the relationship between their visual-spatial abilities and the measures used in the assessment of design solutions, although the magnitudes of the correlation coefficients varied. The high and the medium-high spatial individuals were ascribed the top scores in *Fluency and Flexibility* (significant correlations), *Creativity and Originality* (moderate and significant correlations), *Complexity and Elaboration* (moderate and significant correlations) and *Technical Merit* (significant and moderate correlations); and the medium-low and the low spatial students – the bottom. Within the above factors, the situation with *Complexity and Elaboration* is the least straightforward. While the complexity measure is likely to be related to visual-spatial abilities, it was not always accessible by retrospection, and elaboration/detailing may be unrelated to the levels of visual-spatial abilities. The results are also inconclusive on the *Constraints Met* criterion, but its relationship with visual-spatial abilities is not likely to be linear. The lack of linearity also applies to the *Functionality* measure.

When it concerns figural ideation, the above analyses indicated a tendency for high and medium-high ability individuals to have better scores in *Creativity and Originality* (significant correlation), and *Fluency and Flexibility* (moderate correlation), and *Technical Merit* (moderate correlation) measures, but only among the first year students. These results are consistent with other analyses, indicating weak, or a lack of (direct) associations between ideation abilities,

external representations, academic achievement, and performance on administered design tasks. The reasons are not entirely evident. It is possible that the nature of protocol sessions provided an advantage for the high figural ideation individuals from the first year of study, much less apparent in real life design not prone to (similar) time constraints. That is, real design exercises are less likely to rely upon abilities emphasizing high speed, as they are not a subject to similar to cognitive tests time constraints. Ideation scores may also be related to speed and control in drawing (Carroll, 1993), and the overall sketching ability (also supported by the *Technical Merit* measure). Whereas in the later years of study the generally high(er) levels of sketching proficiency may even out the fourth and final year students in terms of the potential advantage figural ideation provides to high scorers.

Thus, to establish reliable correlations between ideation factors and creativity or academic performance in architecture, a measurement beyond the measurement of the quantity of ideas produced need being used. Here, visualisation abilities may be better predictors of academic performance as they involve more complex cognitive processing characteristic of design tasks. It is also likely that other factors relating to teaching, previous instruction and complexity of design tasks, knowledge, experience, and so on, may be of equal or higher importance.

Also, as the earlier analyses were largely concerned with those aspects of design drawings and reasoning processes that have been previously researched in other studies, in future, it may be useful to introduce new and different coding categories derived from the human ability theories to define criteria in accordance with the chosen ideation factors to facilitate identifying their relationship with the *input* the *process* and the *product* of problem-solving.

Verbal ideation did not appear to have any consistent effect on any of the design quality measures and only a weak tendency for the first year students to have higher scores on the *Functionality* criterion. It may be related to the fact that many of them chose sentential form of communicating ideas, different from the fourth and final year students who tended to resort to graphical form of idea-production.

Learning styles in design solutions. The analyses showed differences and similarities in the relationship between the two learning styles accounts and design product assessment scores of the two groups of participants. The results varied across the sample on the Wholistic and Analytic dimensions. With reference to the first year analytic students, there is a slight tendency for them to be better (than wholists) at meeting specified *Constraints* (weak correlations), at *Complexity and Elaboration* (weak correlations) of the final design solutions, and their *Functionality* (weak to moderate correlations). Whereas wholists have, on average, higher scores in *Creativity and Originality* (weak to moderate and strong correlations), *Fluency and Flexibility* (moderate correlations), and *Technical Merit* (moderate correlations). These results are in conformity with the learning styles and creativity theories suggesting that it is the wholistic students who are more likely to produce original design solutions, and whose design processes are characterised by high(er) levels of ideation. Whilst analytic students are more inclined to generating designs that can be judged as logical, feasible and functional.

The results on the *Complexity and Elaboration* disagree with these theories, which view it as one of the dimensions used in the assessments of creativity (typically associated with wholism). There could be several reasons for that. Firstly, one may need to separate between the two constituents of the measure, as 'complex' does not equal 'elaborate'. Considering the protocol session constraints, high levels of detailing were used as the elaboration measure, and analytic students did succeed in developing their ideas to high(er) levels of detailing, but many experienced early fixation and moved to the detailing phase prematurely. Different to them, the wholistic students, visually inclined in particular, spent considerable time on the internal development of conceptual ideas. Thus, their external representations indicated higher levels of abstraction (and, correspondingly, low(er) levels of detailing). Additionally, while their ideas may have been complex, it was not always possible to gain access to internal representations.

The *Technical Merit* criterion, although not likely to be directly related to learning styles, indicates that wholists were generally better at using design drawings in problem solving. As this measure was not concerned with drawing skills (or not in the first place) but with the students' ability to use sketches as interactive design tools.

The situation is different for the fourth and final year students, where Wholists appeared to perform better along all criteria (moderate to strong correlations). It may, in part, be explained by the observations derived from analysing the students' modes of designing, which indicated for the fourth and final year students, particularly wholists, to have more integrated design processes. That is, it is likely that the knowledge and the skills acquired during design education enabled senior subjects to process more information in parallel, or/and to be more efficient while doing it, and therefore to produce more balanced (on all measures) representations. Additionally, these students were more capable of interacting with their drawings than the first year subjects, and also relative of the analytic group (confirmed by the *Technical Merit* score).

The above results may also show that different learning styles enable students to deal more efficiently with different aspects of the design task.

When it comes to the Imagery dimension, the results are similar for both groups. There is a clear tendency for the visual individuals to have a better quality of their design solutions on all criteria than was observed among the verbal students (moderate to strong correlations). The reasons are probably related to the visual nature of design problem-solving, both internal (imagery) and external (sketching).

The above analyses allowed to establish a number of important correlations between the measurements of learning styles, cognitive abilities, observed problem solving behaviour, and students' design solutions. They revealed fundamentally different ways by which students approach design situations and structure problem-solving; they are positively correlated with individual learning styles. The styles were also observed to have a moderate to strong impact on the students' academic performance and creativity of which it is the Wholistic and Imagery learning styles that appeared to have the strongest influence both on the process and the outcome of individual problem-solving in both groups of students. Correlations between the measures of cognitive abilities and academic performance were moderate to significant for the first year and similar but marginally lower for the final year students. They indicated a tendency for the students with developed visual-spatial abilities (particularly on the visualisation dimension) in both groups to show better results in terms of creativity, and academic performance. Visualisation abilities have also indicated the strongest (among other groups of factors) influence on design problem-solving and the quality of design solutions. Finally, in addition to individual variations in design input, process and product, there were differences observed that related to the year of study, including the fourth and final year students scoring higher on the ability tests and showing better results on the learning styles assessments.

Overall, it has also been demonstrated that the applied methodology, although requiring further refinement, does enable examining and elucidating the influence of learning styles and cognitive abilities on design problem solving and academic performance.

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Appendix A

Cognitive Abilities Tests: Experiment I/a

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items & maximum score N1/No of items not answered N2/No of Right Answers/No of Wrong answers or No of Right Answers /N3=2 items using different solution/N4=1 similar solution/W Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>						
	Clustering	Ornamentation N1/N2/R/W n=1	Elaboration N1/N2/R/W n=1	Storage N1/R/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
01/I/fem	G/G	24/6/18/0 <i>Tts=18</i>	20/6/14/0 <i>Tts=14</i>	13/4/3/1/3 <i>Tts=7</i>	80/3/75/2 <i>Tts=73</i>	10/3/6/1 <i>Tts=5.75</i>	12/0/12/0 <i>Tts=12</i>	24/10/14/0 <i>Tts=14</i>
	Med-High	(G, P, Sm-5)	(G, E, D, Sm-1)	Err-3 (SC)	Err-2	Err-1	(CAP)	
02/I/fem	AG/G	24/4/20/0 <i>Tts=15</i>	20/4/16/2 <i>Tts=12</i>	13/5/3/1/2 <i>Tts=9</i>	80/48/32/0 <i>Tts=32</i>	10/3/4/3 <i>Tts=3.25</i>	12/1/10/2 <i>Tts=8.5</i>	24/8/16/0 <i>Tts=16</i>
	Med-Low	(P, G, D)	(P, G, D)	Err-3		Err-3	Err-2	(SC)
03/I/male	A/A	24/11/12/1 <i>Tts=12</i>	20/12/8/0 <i>Tts=8</i>	13/5/3/2/2 <i>Tts=8</i>	80/24/51/5 <i>Tts=46</i>	10/3/6/1 <i>Tts=5.75</i>	12/3/6/3 <i>Tts=5.25</i>	24/14/10/0 <i>Tts=10</i>
	Med-Low	(G, S, Sm-2, PSA)	(G, Al, S, PSA)	(SC)	Err-5	Err-1	Err-3 (CAW)	
04/I/male	A/A	24/12/12/0 <i>Tts=12</i>	20/10/9/1 <i>Tts=9</i>	13/6/4/2/0 <i>Tts=10</i>	80/33/47/1 <i>Tts=46</i>	10/5/5/0 <i>Tts=5</i>	12/3/7/2 <i>Tts=6.5</i>	24/7/17/0 <i>Tts=17</i>
	Med-Low	(G, P, S, D, PSA)	(G, P, D, PSA)	Mt			(CAP)	
05/I/male	G/AG	24/4/20/0 <i>Tts=15</i>	20/6/14/0 <i>Tts=14</i>	13/5/4/1/1 <i>Tts=9</i>	80/32/48/0 <i>Tts=48</i>	10/5/5/0 <i>Tts=5</i>	12/0/11/0 <i>Tts=11</i>	24/15/9/0 <i>Tts=9</i>
	Med-Low	(P, O, Mt, Sm-8)	(G, U, Sm-7)	Err-1		(Mt)	(CAW, CAP)	(SC)
06/I/fem	G/AG	24/7/17/0 <i>Tts=17</i>	20/3/17/0 <i>Tts=17</i>	13/5/3/2/2 <i>Tts=8</i>	80/20/60/0 <i>Tts=60</i>	10/4/5/1 <i>Tts=4.75</i>	12/0/10/2 <i>Tts=9.5</i>	24/12/12/0 <i>Tts=12</i>
	Med-Low	(G, P, D)	(G, P, D)	Err-2 (SC)	(SC)	Err-1	Err-2 (SC)	(SC)
07/I/male	AG-AG	24/14/10/0 <i>Tts=10</i>	20/10/10/0 <i>Tts=10</i>	13/4/3/1/0 <i>Tts=7</i>	80/35/45/1 <i>Tts=44</i>	10/2/8/0 <i>Tts=8</i>	12/0/8/4 <i>Tts=7</i>	24/6/18/0 <i>Tts=18</i>
	Med-Low	(P, G, D)	(G, U, Sm-1)	(SC)	Err-1 (SC)		Err-4	
08/I/fem	VG/G	24/9/15/0 <i>Tts=15</i>	20/8/12/0 <i>Tts=12</i>	13/6/4/2/0 <i>Tts=10</i>	80/4/76/0 <i>Tts=76</i>	10/1/9/0 <i>Tts=9</i>	12/0/12/0 <i>Tts=12</i>	24/15/9/0 <i>Tts=9</i>
	High	(G, S, Sm-2)	(G, O)					
09/I/male	VG/VG	24/7/16/1 <i>Tts=16</i>	20/8/12/0 <i>Tts=12</i>	13/6/4/2/0 <i>Tts=10</i>	80/0/80/0 <i>Tts=80</i>	10/0/9/1 <i>Tts=8.75</i>	12/0/12/0 <i>Tts=12</i>	24/3/17/0 <i>Tts=17</i>
	High	(G, P, D, O)	(G, P, D)			Err-1		
10/I/male	A/AG	24/16/8/0 <i>Tts=8</i>	20/10/10/0 <i>Tts=10</i>	13/4/3/1/0 <i>Tts=4</i>	80/48/32/0 <i>Tts=32</i>	10/0/8/2 <i>Tts=7.5</i>	12/2/10/0 <i>Tts=10</i>	24/11/13/0 <i>Tts=13</i>
	Med-Low	(G, P, D, E)	(G, P, D)			Err-1		

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items N1/No of items not answered N2/No of Right Answers/No of Wrong answers or No of Right Answers /N3=2 items using different solution/N4=1 similar solution/W Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>						
		Ornamentation N1/N2/R/W n=1	Elaboration N1/N2/R/W n=1	Storage N1/R/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
	Clustering							
11/I/fem	G/AG	24/3/21/0 Tts=21	20/4/16/2 Tts=16	13/5/3/1/2 Tts=9	80/38/42/2 Tts=40	10/2/5/3 Tts=4.25	12/0/10/2 Tts=9.5	24/13/11/0 Tts=11
	Med-Low	(P, G, D)	(P, G, D)	Err-3	Err-2	Err-3	Err-2 (CAW)	(SC)
12/I/male	G/G	24/2/22/0 Tts=22	20/2/18/0 Tts=18	13/8/4/3/0 Tts=11	80/31/48/1 Tts=47	10/1/8/1 Tts=7.75	12/0/11/1 Tts=10.75	24/10/14/0 Tts=14
	Med-High	(P, G, O, D)	(P, G, S, D)		Err-1	Err-1	Err-1	
13/I/fem	A/A	24/15/9/0 Tts=9	20/6/14/0 Tts=14	13/3/2/1/1 Tts=5	80/20/56/4 Tts=52	10/2/7/1 Tts=6.75	12/0/9/3 Tts=8.25	24/11/13/0 Tts=13
	Med-Low	(P, S, PSA)	(G, S, PSA)		Err-2		Err-2	
14/I/male	AG/AG	24/13/11/0 Tts=11	20/12/8/0 Tts=8	13/8/4/4/0 Tts=12	80/31/48/1 Tts=47	10/1/8/1 Tts=7.75	12/0/11/1 Tts=10.75	24/10/14/0 Tts=14
	Med-High	(P, G, D, S)	(G, D, S)		Err-1	Err-1	Err-1	
15/I/fem	G/VG	24/4/20/0 Tts=20	20/6/14/0 Tts=14	13/5/3/3/0 Tts=9	80/0/78/2 Tts=76	10/2/8/0 Tts=8	12/0/9/3 Tts=8.25	24/9/16/0 Tts=16
	Med-High	(P, G, S, D)	(G, S, D)		Err-2		Err-3	
16/I/fem	G/VG	24/2/20/2 Tts=20	20/8/12/0 Tts=12	13/5/3/3/0 Tts=9	80/16/62/2 Tts=60	10/1/9/0 Tts=9	12/0/12/0 Tts=12	24/14/10/0 Tts=10
	Med-High	(P, G, O, D)	(P, G, D)		Err-2		(CAP)	
17/I/fem	A/A	24/11/13/0 Tts=13	20/0/19/1 Tts=19	13/3/3/0/0 Tts=6	80/39/39/2 Tts=37	10/3/6/1 Tts=5.75	12/4/6/2 Tts=5.5	24/4/20/0 Tts=20
	Low	(P, G, A, S)	(G, A, S, PSA)		Err-2	Err-1	Err-2 (CAP)	
18/I/fem	A/A	24/8/16/0 Tts=16	20/8/12/0 Tts=12	13/6/2/2/1 Tts=7	80/42/38/2 Tts=36	10/1/4/5 Tts=2.75	12/0/7/5 Tts=5.75	24/15/9/0 Tts=11
	Low	(G, P, S, Sm-1)	(G, P, S, PSA)	Err-1	Err-2	Err-5	Err-5	
19/I/male	G/AG	24/8/16/0 Tts=18	20/5/15/0 Tts=15	13/5/3/2/0 Tts=8	80/17/63/3 Tts=60	10/4/5/1 Tts=4.75	12/0/10/2 Tts=9.5	24/10/14/0 Tts=14
	Med-Low	(G, P, S, PSA)	(G, P, S, PSA)		Err-3	Err-1	Err-2	(SC)
20/I/male	AG/G	24/8/16/0 Tts=16	20/9/11/0 Tts=11	13/3/3/0/0 Tts=6	80/3/77/0 Tts=77	10/2/7/2 Tts=6.5	12/1/8/3 Tts=7.25	24/7/17/0 Tts=7
	Med-Low	(P, G, S, Sm-2)	(P, G, Sm-1)			Err-1		

Test Date: 2 November, 2000; 10 November, 2000

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items & maximum score N1/No of items not answered N2/No of Right Answers/No of Wrong answers or No of Right Answers /N3=2 items using different solution/N4=1 similar solution/W Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>						
		Ornamentation N1/N2/R/W n=1	Elaboration N1/N2/R/W n=1	Storage N1/R/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
	Clustering							
01/III/male	VG/VG	24/5/19/0 <i>Tts=19</i>	20/3/17/0 <i>Tts=17</i>	13/7/4/2/0 <i>Tts=10</i>	80/0/78/2 <i>Tts=76</i>	10/0/9/1 <i>Tts=8.75</i>	12/0/12/0 <i>Tts=12</i>	24/8/16/0 <i>Tts=16</i>
	High	(P, G, D)	(O, P, G)		(Ht, Err-2)	(Ht, Err-1)	(Ht)	
02/III/male	G/AG	24/0/24/0 <i>Tts=24</i>	20/0/20/0 <i>Tts=20</i>	13/3/3/0/0 <i>Tts=6</i>	80/7/72/1 <i>Tts=71</i>	10/1/7/2 <i>Tts=6.5</i>	12/0/11/1 <i>Tts=10.75</i>	24/6/18/0 <i>Tts=18</i>
	Med-Low	(G, P, O, D)	(G, P, O, D)					
03/III/male	G/G	24/8/16/0 <i>Tts=16</i>	20/8/12/0 <i>Tts=12</i>	13/4/3/2/0 <i>Tts=8</i>	80/1/78/1 <i>Tts=77</i>	10/1/8/1 <i>Tts=7.75</i>	12/0/10/2 <i>Tts=9.5</i>	24/9/15/0 <i>Tts=15</i>
	Med-High	(G, P, O)	(G, P, D)		Err-1	Err-1	Err-2	
04/III/male	G/G	24/9/15/0 <i>Tts=15</i>	20/4/16/0 <i>Tts=16</i>	13/7/4/2/0 <i>Tts=10</i>	80/10/70/0 <i>Tts=70</i>	10/2/8/0 <i>Tts=8</i>	12/0/12/0 <i>Tts=12</i>	24/13/11/0 <i>Tts=11</i>
	Med-High	(P, G, O)	(P, G, D)					
05/III/male	A/AG	24/13/11/0 <i>Tts=11</i>	20/9/11/0 <i>Tts=11</i>	13/4/3/2/0 <i>Tts=8</i>	80/5/75/2 <i>Tts=73</i>	10/1/8/1 <i>Tts=7.75</i>	12/0/10/2 <i>Tts=9.5</i>	24/7/17/0 <i>Tts=17</i>
	Med-High	(G, P, A, S)	(G, A, Sm-2)		Err-2	Err-1	Err-2	
06/III/fem	G/G	24/9/15/0 <i>Tts=15</i>	20/11/9/0 <i>Tts=9</i>	13/4/3/1/0 <i>Tts=7</i>	80/16/62/2 <i>Tts=60</i>	10/1/9/0 <i>Tts=9</i>	12/0/12/0 <i>Tts=12</i>	24/6/18/0 <i>Tts=18</i>
	Med-High	(G, P, D)	(G, E, S-1)		Err-2			
07/III/fem	A/A	24/11/12/1 <i>Tts=12</i>	20/11/9/0 <i>Tts=9</i>	13/5/3/3/0 <i>Tts=9</i>	80/50/30/0 <i>Tts=30</i>	10/3/6/1 <i>Tts=5.75</i>	12/1/8/3 <i>Tts=7.25</i>	24/13/11/0 <i>Tts=11</i>
	Low	(G, P, S, A, Sm-1)	(G, A, PSA, Sm-2)			Err-1	Err-3	
08/III/male	VG/G	24/5/19/0 <i>Tts=19</i>	20/0/20/0 <i>Tts=20</i>	13/5/4/2/0 <i>Tts=11</i>	80/0/80/0 <i>Tts=80</i>	10/0/10/0 <i>Tts=10</i>	12/0/12/0 <i>Tts=12</i>	24/5/19/0 <i>Tts=15</i>
	High	(G, P, D)	(G, E, D, S-1)				(Ht)	
09/III/male	AG/AG	24/12/12/0 <i>Tts=14</i>	20/12/8/0 <i>Tts=8</i>	13/4/3/1/0 <i>Tts=7</i>	80/0/75/5 <i>Tts=70</i>	10/3/6/1 <i>Tts=5.75</i>	12/1/8/3 <i>Tts=7.25</i>	24/12/12/0 <i>Tts=14</i>
	Med-Low	(G, P, S, Sm-2)	(G, S, A, Sm-3)		Err-5	Err-1	Err-3 (CAW)	
10/III/male	A/AG	24/12/12/0 <i>Tts=12</i>	20/8/12/0 <i>Tts=12</i>	13/7/4/3/0 <i>Tts=11</i>	80/30/50/3 <i>Tts=47</i>	10/3/6/1 <i>Tts=5.75</i>	12/0/10/2 <i>Tts=9.5</i>	24/4/20/0 <i>Tts=20</i>
	Med-Low	(G, P, S)	(G, A)		Err-3	Err-1	Err-2	

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items & maximum score N1/No of items not answered N2/No of Right Answers/No of Wrong answers or No of Right Answers /N3=2 items using different solution/N4=1 similar solution/W Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>						
		Ornamentation N1/N2/R/W n=1	Elaboration N1/N2/R/W n=1	Storage N1/R/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
	Clustering							
11/III/fem	G/G	24/7/16/1 Tts=16	20/8/12/0 Tts=12	8/3/3/1 Tts=9	80/16/64/3 Tts=61	10/0/9/1 Tts=8.75	12/0/12/0 Tts=12	24/11/13/0 Tts=13
	Med-High	(G, P, D, O)	(G, P, D)		Err-1	Err-1		
12/III/fem	AG/AG	24/11/13/0 Tts=13	20/9/11/0 Tts=11	13/6/4/2/2 Tts=10	80/14/64/2 Tts=62	10/2/8/1 Tts=7.75	12/1/9/2 Tts=8.5	24/5/19/0 Tts=19
	Med-Low	(P,G, D, S)	(P,G, D, S)	Err-2	Err-2	Err-1	Err-2	
13/III/fem	G/G	24/9/15/0 Tts=15	20/11/9/0 Tts=9	13/4/3/2/0 Tts=8	80/16/62/2 Tts=60	10/1/9/0 Tts=9	12/0/12/0 Tts=12	24/2/22/0 Tts=12
	Med-High	(G, P, D)	(G, E, S-1)		Err-2			
14/III/fem	A/A	24/15/9/0 Tts=9	20/12/8/0 Tts=8	13/2/2/0/2 Tts=4	80/16/74/10 Tts=64	10/3/7/0 Tts=7	12/1/11/0 Tts=11	24/16/8/0 Tts=8
	Med-Low	(G, P, S, Mt)	(G, P, E, Mt)	Err-2	Err-10			Mt
15/III/fem	AG/AG	24/7/17/0 Tts=17	20/10/10/0 Tts=10	13/6/3/1/1 Tts=7	80/42/41/3 Tts=38	10/1/4/4 Tts=3	12/2/5/3 Tts=4.25	24/12/12/0 Tts=12
	Low	(G, P, S, Sm-3)	(G, S, PSA)	Err-1	Err-3	Err-4	Err-3 (CAP)	
16/III/fem	G/G	24/9/15/0 Tts=15	20/12/8/0 Tts=8	5/4/1/0 Tts=9	80/2/76/2 Tts=74	10/0/9/1 Tts=8.75	12/0/10/2 Tts=9.5	24/13/11/0 Tts=11
	Med-High	(P, G, S, Sm-2)	(P, G, A, S)		Err-2	Err-1	Err-2	
17/III/male	A/A	24/12/12/0 Tts=14	20/8/12/1 Tts=11	13/3/3/0/1 Tts=6	80/0/75/5 Tts=70	10/2/8/3 Tts=7.25	12/2/5/3 Tts=4.25	24/10/14/0 Tts=14
	Med-Low	(G, P, S, Sm-3)	(G, S, PSA, S-3)	Err-1	Err-1		Err-3 (CAW)	
18/III/fem	A/AG	24/10/14/0 Tts=14	20/8/12/0 Tts=12	13/3/3/0/2 Tts=5	80/38/39/3 Tts=36	10/2/6/2 Tts=5.5	12/0/10/2 Tts=9.5	24/12/12/0 Tts=12
	Med-Low	(P, G, A, Sm-3)	Err-1	Err-2	Err-3	Err-2	Err-2	
19/III/male	G/AG	24/4/20/0 Tts=20	20/4/16/2 Tts=16	13/5/3/1/2 Tts=9	80/48/32/0 Tts=42	10/2/5/3 Tts=4.25	12/0/10/2 Tts=9.5	24/9/15/0 Tts=15
	Med-Low	(P, G, D)	(P, G, D)	Err-3		Err-3	Err-2	(SC)
20/III/fem	G/G	24/2/22/0 Tts=22	20/8/12/0 Tts=12	13/5/3/2/1 Tts=8	80/34/46/0 Tts=46	10/1/7/2 Tts=6.5	12/0/12/0 Tts=12	24/6/18/0 Tts=18
	Med-High	(P, G, Sm-4)	(G, S, Sm-4)		(SC)	Err-2		

Test Date: 30 October, 2000; 22 November, 2000

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items & maximum score N1/No of items not answered N2/No of Right Answers/No of Wrong answers or No of Right Answers /N3=2 items using different solution/N4=1 similar solution/W Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>						
		Ornamentation N1/N2/R/W n=1	Elaboration N1/N2/R/W n=1	Storage test N1/R/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
	Clustering							
01/IV/fem	G/G	24/11/13/0 Tts=13 (G, D, E)	20/8/12/0 Tts=12 (G, D, E)	13/5/4/1/0 Tts=9	80/0/80/0 Tts=80	10/3/6/1 Tts=5.75 Err-1	12/0/9/3 Tts=8.25 Err-3	24/10/14/0 Tts=14
	Med-Low							
02/IV/male	A/A	24/13/11/0 Tts=11 (G, P, A)	20/13/6/1 Tts=6 (G, A, PSA)	13/4/3/1/0 Tts=7	80/37/43/1 Tts=42 Err-1	10/1/8/1 Tts=7.75 Err-1	12/0/10/2 Tts=9.5 Err-2	24/6/18/0 Tts=17
	Med-Low							
03/IV/male	G/G	24/10/14/0 Tts=14 (G, P, O, D)	20/8/12/0 Tts=12 (G, P, O, D)	13/7/4/2/0 Tts=10	80/4/76/0 Tts=76	10/1/8/1 Tts=7.75 Err-1	12/0/12/0 Tts=12	24/5/15/0 Tts=15
	Med-High							
04/IV/male	G/G	24/7/17/0 Tts=17 (G, S)	20/3/17/0 Tts=17 (G, S, PSA)	13/5/3/2/0 Tts=8	80/1/79/1 Tts=78 Err-1	10/1/7/2 Tts=6.5 Err-2	12/0/11/1 Tts=10.75 Err-1	24/4/20/0 Tts=20
	Med-High							
05/IV/male	VG/VG	24/10/14/0 Tts=14 (P, G, O, Mt)	20/9/15/0 Tts=15 (G, O, Mt)	13/4/3/1/0 Tts=7 N	80/31/49/4 Tts=45 Err-4	10/2/8/0 Tts=8	12/0/12/0 Tts=12	24/10/14/0 Tts=14
	Med-Low							
06/IV/male	A/A	24/0/24/0 Tts=24 (G, P, S, Sm-5)	20/0/20/0 Tts=20 (G, P, S, Sm-5)	13/6/3/2/1 Tts=8 Err-1	80/9/71/6 Tts=65 Err-6	10/0/8/2 Tts=7.5 Err-2 (Ht)	12/0/7/5 Tts=5.75 Err-5 (Ht)	24/4/20/0 Tts=20
	Med-Low							
07/IV/fem	A/A	24/0/24/0 Tts=24 (G, PSA Sm-5)	20/3/17/0 Tts=17 (G, P, PSA, Sm-3)	13/4/3/1/0 Tts=7	80/26/52/2 Tts=38	10/0/8/2 Tts=7.5 Err-1	12/0/11/1 Tts=10.75 Err-1	24/9/15/0 Tts=15
	Med-Low							
08/IV/fem	A/A	24/10/14/0 Tts=14 (P, G, PSA Sm-4)	20/11/9/0 Tts=9 (P, G, PSA)	13/3/3/0/1 Tts=6 Err-1	80/31/49/4 Tts=45 Err-4	10/2/6/2 Tts=5.5 Err-2	12/0/10/2 Tts=9.5 Err-2	24/16/8/0 Tts=8
	Low							
09/IV/fem	AG/AG	24/0/24/0 Tts=24 (P, G, Sm-4)	20/7/13/0 Tts=13 (G, S, Sm-4)	13/5/3/2/1 Tts=8	80/14/66/0. Tts=66 (SC)	10/1/7/2 Tts=6.5 Err-2	12/0/12/0 Tts=12	24/6/18/0. Tts=18
	Med-High							
10/IV/male	A/AG	24/6/18/0 Tts=18 (G, S, Sm-5)	20/9/11/0 Tts=11 (G, PSA)	13/7/3/4/0 Tts=10	80/0/78/2 Tts=78 Err-2	10/0/9/1 Tts=8.75 Err-3	12/0/12/0 Tts=12	24/8/16/0 Tts=16
	Med-High							

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items & maximum score N1/No of items not answered N2/No of Right Answers/No of Wrong answers or No of Right Answers /N3=2 items using different solution/N4=1 similar solution/W Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>						
		Ornamentation N1/N2/R/W n=1	Elaboration N1/N2/R/W n=1	Storage test N1/R/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
	Clustering							
11/IV/fem	G/G	24/12/12/0 Tts=12	20/8/12/0 Tts=12	13/5/2/1/2 Tts=5	80/0/80/4 Tts=76	10/3/7/0 Tts=7	12/0/12/0 Tts=12	24/7/17/0 Tts=17
	Med-Low	(P, G, O)	(G, D)	Err-2	Err-4			
12/IV/fem	G/AG	24/0/24/0 Tts=24	20/9/11/0 Tts=11	13/7/4/3/1 Tts=11	80/48/32/0 Tts=32	10/2/7/1 Tts=6.75	12/0/11/1 Tts=10.75	24/6/18/0 Tts=18
	Med-Low	(G, S, Sm-6)	(G, Sm-3)	Err-1		Err-1	Err-1	
13/IV/fem	AG/G	24/0/24/0 Tts=24	20/5/15/0 Tts=15	13/5/4/1/0. Tts=9	80/31/49/3 Tts=46	10/0/7/2 Tts=6.5	12/0/12/0 Tts=12	24/1/23/0 Tts=23
	Med-Low	(G, P, Sm-5, PSA)	(G, Sm-3, PSA)		Err-3	Err-2		
14/IV/male	G/AG	24/11/13/0 Tts=13	20/7/13/0 Tts=13	13/9/4/5/0 Tts=13	80/4/76/1 Tts=75	10/0/10/0 Tts=10	12/0/12/0 Tts=12	24/9/15/0 Tts=15
	High	(P, G, D)	(P, G, D, Sm-2)		Err-1			
15/IV/male	AG/A	24/9/15/0 Tts=15	20/8/12/0 Tts=12	13/5/4/1/0 Tts=9	80/45/34/1 Tts=33	10/0/4/2 Tts=3.5	12/0/7/5 Tts=5.75	24/15/9/0 Tts=9
	Low	(G, P, S, Sm-1)	(G, P, S)		Err-1	Err-2	Err-5	
16/V/male	G/AG	24/12/12/0 Tts=12	20/11/9/0 Tts=9	13/10/4/3/0 Tts=12	80/5/75/0 Tts=75	10/1/9/0 Tts=9	12/0/12/0 Tts=12	24/8/16/0 Tts=11
	High	(G, P, S, D)	(G, D, S)					
17/V/fem	G/G	24/2/22/0 Tts=9	20/4/16/0 Tts=16	13/10/5/0 Tts=5	80/42/38/0 Tts=44	10/1/6/1 Tts=5.75	12/0/11/1 Tts=10.75	24/15/9/0 Tts=9
	Med-Low	(P, G, O, D, S)	(G, P, O)		(Mt)		Err-1	
18/V/fem	VG/VG	24/7/17/0 Tts=17	20/2/18/0 Tts=18	13/3/2/1/0 Tts=8	80/4/76/0 Tts=76	10/1/8/1 Tts=7.75	12/0/10/2 Tts=9.5	24/10/14/0 Tts=14
	Med-High	(P, G, E)	(P, G, O)				Err-2 (Ht)	
19/IV/fem	A/A	12/12/12/0 Tts=12	20/10/10/0 Tts=10	13/4/3/1/0 Tts=7	80/10/80/0 Tts=80	10/1/8/1 Tts=7.75	12/0/10/2 Tts=9.5	24/7/17/0 Tts=17
	Med-High	(G, P, E)	(G, P, D, S)			Err-1	Err-2	
20/V/male	G/AG	24/18/6/0 Tts=6	20/10/10/0 Tts=10	13/5/4/0/1 Tts=8	80/4/76/1 Tts=75	10/2/8/0 Tts=8	12/0/12/0 Tts=12	24/6/18/0 Tts=14
	Med-High	(P, G, O)	(G, A)	Err-1	Err-1			

Test Date: 4th year 26 October 2000; 5th year 30 October, 2000

Cognitive Abilities Tests: Experiment I/b, Years 1 and 4&5

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items & maximal score N1/No of items not answered N2/No of Right Answers/No of Wrong answers or N1 - maximal score /N3=2 items using different solution/N4=1 similar solution/ No of Wrong answers Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>								
		Symbols N1/N2/R/W n=1	Ornamentation N1/N2/R/W n=1	Arranging Words R/W n=1	Controlled Associations R/W n=1	Storage test N1/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
LSA profile*	Clustering**									
01/I/female	G/VG	15/8/7/0 Tts=7	24/7/17/0 Tts=17	5/0 Tts=5	12/0 Tts=12	13/4/2/0 Tts=10	80/11/69/3 Tts=66 Err-3	10/0/9/1 Tts=8.75 Err-1	12/0/12/0 Tts=12	24/13/11/0 Tts=11
A-IV	High	(S, D)	(Gm, S, D)							
02/I/male	G/G	15/7/8/0 Tts=8	24/7/17/0 Tts=17	4/0 Tts=4	11/0 Tts=11	13/4/4/0 Tts=12	80/31/48/1 Tts=47 Err-1	10/3/7/0 Tts=7	12/0/11/1 Tts=10.75 Err-1	24/10/14/0 Tts=14
W-I	Med-Low	(W, PSA)	(Gm, Al, S, Sm-8)							
03/I/male	VG/G	15/6/9/0 Tts=9	24/13/11/0 Tts=11	4/0 Tts=4	12/0 Tts=12	13/3/2/0 Tts=8	80/0/78/2 Tts=76 Err-2	10/2/8/0 Tts=8	12/0/9/4 Tts=8 Err-4	24/8/16/0 Tts=16
W-I	Med-High	(O, D)	(Gm, hE)							
04/I/male	AG/AG	15/8/7/0 Tts=7	24/12/12/0 Tts=12	5/0 Tts=5	12/0 Tts=12	13/3/1/0 Tts=7	80/16/62/2 Tts=60 Err-2	10/1/9/0 Tts=9	12/0/12/0 Tts=12	24/14/10/0 Tts=10
A-V	Med-High	(D, E)	(Gm, E, O)							
05/I/male	G/G	15/6/9/0 Tts=9	24/16/8/0 Tts=8	5/0 Tts=5	11/0 Tts=11	13/4/2/0 Tts=10	80/19/61/0 Tts=61	10/2/8/0 Tts=8	12/0/12/0 Tts=12	24/13/11/0 Tts=11
A-I	Med-High	(W, D, O)	(Gm, E, O, Sm-1)							
06/I/female	A/A	15/10/5/0 Tts=5	24/13/11/0 Tts=11	3/0 Tts=3	8/0 Tts=8	13/2/1/0 Tts=5	80/50/30/0 Tts=30	10/5/5/1 Tts=4.75 Err-1	12/4/8/0 Tts=8	24/9/15/0 Tts=15
A-V	Low	(U, PSA)	(Gm, P, S, U)							
07/I/female	AG/AG	15/5/10/0 Tts=10	20/15/5/0 Tts=5	5/0 Tts=5	12/0 Tts=12	13/3/1/0 Tts=7	80/32/42/4 Tts=38 Err-4	10/1/6/4 Tts=5 Err-4	12/0/10/2 Tts=9.5 Err-2	24/15/9/0 Tts=9
W-V	Med-Low	(O, D, S)	(E, D)							
08/I/male	A/AG	15/11/4/0 Tts=4	24/14/10/0 Tts=10	6/1 Tts=5	7/0 Tts=7	13/3/2/0 Tts=8	80/16/64/3 Tts=61 Err-3	10/0/8/2 Tts=7.5 Err-2	12/3/9/2 Tts=8.5	24/12/12/0 Tts=12
A-V	Med-Low	(D, Ex)	(Gm, P, D)							
09/I/female	G/G	15/7/8/0 Tts=8	24/1/23/0 Tts=23	5/0 Tts=5	12/0 Tts=12	13/3/3/0 Tts=9 (W)	80/15/63/2 Tts=61 Err-2	10/0/9/1 Tts=8.75 Err-1 (Ht)	12/0/12/0 Tts=12 (Ht)	24/10/14/0 Tts=14
W-I	Med-High	(D, W, E)	(Gm, P, D)							
10/I/female	AG/A	15/9/6/0 Tts=6	20/4/16/2 Tts=14	3/0 Tts=3	9/0 Tts=7	13/3/1/0 Tts=7	0/5/70/5 Tts=65 Err-5	10/1/8/4 Tts=7 Err-4	12/2/10/0 Tts=10	24/12/12/0 Tts=12
W-I	Med-Low	(Gm, S, Sm-3)	(Gm, S, Sm-4)							

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Performance Assessment by Supervisor	Test Description <i>No of items & maximal score N1/No of items not answered N2/No of Right Answers/No of Wrong answers or N1 - maximal score /N3=2 items using different solution/N4=1 similar solution/ No of Wrong answers Tts -Total test score R - W/(n-1) – correction for guessing, where n-No of response options</i>								
		Symbols N1/N2/R/W n=1	Ornamentation N1/N2/R/W n=1	Arranging Words R/W n=1	Controlled Associations R/W n=1	Storage test N1/N3/N4/W n=1	Card rotation N1/N2/R/W n=2	Paper folding N1/N2/R/W n=5	Building memory N1/N2/R/W n=5	Maze tracing N1/N2/R/W n=1
LSA profile*	Clustering									
11/IV/male	A/AG	15/6/9/0 Tts=9	24/14/12/0 Tts=12	3/0 Tts=3	11/1 Tts=11	13/3/2/0 Tts=9	80/22/58/3 Tts=55 Err-3	10/4/6/0 Tts=6	12/0/11/1 Tts=10.75 Err-1 (Ht)	24/5/19/0 Tts=19
A-V	Med-Low	(Ex, S)	(Gm, P, PSA)							
12/IV/male	G/G	15/6/9/0 Tts=9	24/6/18/0 Tts=18	4/0 Tts=4	9/0 Tts=9	13/3/2/0 Tts=8	80/12/68/1 Tts=67 Err-1	10/1/9/0 Tts=9	12/0/11/1 Tts=10.75 Err-1	24/8/16/0 Tts=16
A-I	Med-High	(D)	(O, D)							
13/Vfemale	G/G	15/3/12/0 Tts=12	24/5/19/0 Tts=19	4/1 Tts=4	11/1 Tts=12	13/6/4/2/0 Tts=10	80/0/80/0 Tts=80	10/1/9/0 Tts=9	12/0/12/0 Tts=12 (Ht)	24/5/19/0 Tts=19
W-IV	High	(D, O, W)	(Gm, P, O, D)							
14/V/female	AG/AG	15/10/5/0 Tts=5	24/10/14/0 Tts=14	3/0 Tts=3	12/2 Tts=12	13/3/1/0 Tts=7	80/24/56/1 Tts=55 Err-1	10/3/6/0 Tts=6	12/0/10/2 Tts=9.5 Err-2	24/10/14/0 Tts=14
A-V	Med-Low	(S, Al, U, PSA)	(G, S, Sm-3)							
15/V/male	VG/VG	15/5/10/0 Tts=10	24/9/15/0 Tts=15	5/0 Tts=5	13/1 Tts=13	13/4/1/0 Tts=9	80/0/79/1 Tts=78 Err-1	10/1/8/1 Tts=7.75 Err-1	12/0/12/0 Tts=12 (Ht)	24/9/15/0 Tts=15
W-IV	Med-High	(D, O)	(Gm, D)							
16/IV/female	G/G	15/5/10/0 Tts=10	24/12/12/0 Tts=12	4/0 Tts=4	8/0 Tts=8	13/3/2/0 Tts=8	80/23/57/2 Tts=55 Err-2	10/0/9/1 Tts=8.75 Err-1	12/0/12/0 Tts=12	24/11/13/0 Tts=13
AW-I	Med-High	(D, O)	(Gm, P, D, O)							
17/IV/female	G/AG	15/2/13/2 Tts=11	24/14/10/0 Tts=10	5/0 Tts=5	6/0 Tts=6	13/4/1/0 Tts=9	80/0/78/2 Tts=76 Err-2	10/0/9/1 Tts=8.75 Err-1 (Ht)	12/0/10/2 Tts=9.5 Err-2	24/13/11/0 Tts=11
A-I	Med-High	(D, O, E)	(Gm, P, D, E)							
18/IV/female	A/AG	15/7/8/0 Tts=8	24/14/10/0 Tts=10	5/0 Tts=5	19/1 Tts=15	13/3/2/0 Tts=8	80/33/47/0 Tts=47	10/3/6/0 Tts=6	12/0/10/2 Tts=9.5 Err-2	24/8/16/0 Tts=16
A-V	Med-Low	(D)	(D, S, Sm-2)							
19/IV/male	AG/A	15/1/14/0 Tts=14	12/12/12/0 Tts=12	5/0 Tts=5	11/3 Tts=11	13/4/1/0 Tts=9	80/10/68/2 Tts=66 Err-2	10/1/6/1 Tts=5.75 Err-1	12/3/8/1 Tts=7.75 Err-2	24/12/12/0 Tts=12
A-I	Med-Low	(D, Ex, W)	(Gm, P, E)							
20/V/male	G/G	15/7/8/0 Tts=8	24/9/15/0 Tts=15	4/0 Tts=4	12/0 Tts=12	13/3/1/0 Tts=7	80/8/72/0 Tts=75	10/0/9/1 Tts=8.75 Err-1	12/0/12/0 Tts=12	24/6/18/0 Tts=18
W-I	Med-High	(E,O, D)	(Gm, P, D)							

Test Dates: April-May 2003

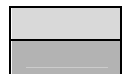
Codes used in Academic Assessment (same coding applies to performance and creativity)

A – Average (for analyses ascribed value 1)
AG – Average- Good (for analyses ascribed value 2)
G – Good (for analyses ascribed value 3)
VG – Very Good (for analyses ascribed value 4)

Codes used in experiments:

AI – Alike
CAG – Cognitive aid graphic (signs, lines, etc. used to facilitate test completion)
CAW – Cognitive aid written (notes, words, etc. used to facilitate test completion)
D – Diverse
E – Elaborate (also **hE** – highly elaborate)
Err – Errors
Ex – expected, falls midway between original and unoriginal
Gm – Geometric Images (abstract – lines, dots, etc.)
Ht – half time required to complete a task
N – Numbers used
Mt – More time required to complete a task
O – Original
P – Pictorial Images (concrete – images or patterns of flowers, people, etc.)
PG – Pictorial-Geometric (combinational type – both types used in *one* drawing)
PSA – Poor sketching ability
SC – Self-correcting
Sm – Similar patterns (and an estimated number of cases using similar patterns)
S – Simple
U – Unoriginal
W – Words used

Colour coding:



High spatial individuals (within their respective group; does not equal general cognitive ability)

Low spatial individuals (within their respective group; does not equal general cognitive ability)

* In LSA profiles **bold** denotes (strong) preference

** When clustering for general cognitive ability , qualitative characteristics of ideation tests were considered alongside their quantitative characteristics

Note: 01/III/male from the first set of tables and 15/V/male from the second are the same student who took two sets of tests two years apart
 On the *Symbols Test* Participants were given 3 minutes to draw 3 rows of symbols (instead of 5 mins for 5 rows)

Appendix B

Final prepared data on Design Drawings, Introspective Reports & Questionnaires: Year 1

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Perform. Assessm. by Supervisor	Test Description														
		p – page; n – number; t – type of diagram or annotation (ob - object; co - concept; i – idea, vertical or horizontal); st – subtype; c – complexity (on a 3-point scale); CoN – number of constraints met (after conversion into a 4-point scale); CrO – creativity & originality; CE – complexity & elaboration; FF – flexibility & fluency; F – functionality; TM – technical merit (4-point scale for all design drawings assessments); LS – learning style; PA – personal assessment;														
LSA profile*	Ability	Sketches, number per page	Sketch transform., number per page		Annotations p/n/t	Diagrams p/n/t/st/c	2D-3D balance n/type/c	Design drawings assessment (consensus)						Intros pect.	Questionnaires	
			Vertical	Horizont.				CoN	CrO	CE	FF	F	TM		LS	P/C
01/I/female	G/VG	2/1/3/1/1/2 /2	6/1/6/7/3/ 5/3	3/1/3/3/1/ 2/2	1/2/ ob + co ;2/1/ ob ;3/ 5/3 ob + co + ih ;4/2/ co + ob ;5/2/ co + ob ;6/4/ 2 iv + ob + co ;7/1/ ob	1/1/ co /C; 2/2/ co + ob /BC;	10/2D/3; 2/3D/2- 3; Elev.	4	2	4	3	3	3	A(W)- IV	A-(I)V	6/6
A-IV	High															
02/I/male	G/G	2/1/1/4	7/4/9/7	3/2/3/4	1/2/ ob + co ;2/2/ ob + co ;3/1/ ob	2/1/ co /E + integrated with sketches, 1/1/ co + ob	4/3D/2-3	3	3	2	3	2	2	W-I	W-I	6/3
W-I	Med-Low															
03/I/male	VG/G	1/2/1/1/1/4	0/5/8/0/9	0/1/1/1/4	1/1/ ob ; 2/2/ ob + iv ; 3/2/ ob + ih ; 4/1/ ob ; 5/2/ ob + co ; 6/2/ ob + co	0 + integrated with sketches, 2/1/ co + ob	9/2D/2-3 1/3D/2	3	3	2	2	2	3	WA-I	AW-I	5/6
W-I	Med-High															
04/I/male	AG/AG	1/2	4/8	1/2	1/4/ o ; 2/2/ o	1/4/ co /C/1; 1/1/ ob /D/1	3/2D/2	2	2	1	2	3	2	A-V(I)	A-IV	6/5
A-V	Med-High															
05/I/male	G/G	4/2	8/2	6/1	1/10/4 ob +5 co + ih ; 2/6/2 ob +3 iv + co	1/1/ ob /B	6/2D/3	2	2	2	2	3	3	A(W)-I	A-I(V)	7/7
A-I	Med-High															
06/I/female	A/A	1/0/1/1/1/1	1/0/0/4/3/5	1/0/0/1/1/0	1/1/ ob ; 3/1/ o ; 4/2/ co + ob ;5/2/ co + ob ; 6/1/ ob	2/1/ ob /D; 3/1/ ob /D	5/2D/2	3	2	2	1	2	1	A-V(I)	A-I	7-8/7
A-V	Low															
07/I/female	AG/AG	0/1	0/5	0/1	1/4/ co + ob +2 iv	1/7/4 co +3 ob / ADC; 2/1/ ob /F	1/2D/1	2	1	1	2	3	2	W-V	W-V	5/3
W-V	Med-Low															
08/I/male	A/AG	1/2/2/2/1	2/4/5/5/4	1/2/2/2/1	1/3/ co +2 ob ;2/3/ co + 2 ob ;3/2/ ob ;4/2/ ob ; 5/1/ ob	1/1/ co /;	2/3D/1 6/2D/1-3	2	1	2	2	2	1	A-V(I)	A(W)- V(I)	5-6/7
A-V	Med-Low															
09/I/female	G/G	1/2/3/3/2/2	3/4/6/5/3 /3	1/1/3/2/1/ 1	1/2/ co ;2/2/ iv + co ;4/2 / ih + co ;6/2/ co + ob ; 7/2/ co + ob	1/ co /C; 2/ co + ob /AD/	2/3D/2; 14/2D/1- 2	2	3	3	4	2	2	W(A)- IV	W-I	7/5
W-I	Med-High															
10/I/female	AG/A	0/0/0/5	0/0/0/7	0/0/0/5	1/6/5 co + ob ;2/3/2 ih + co ; 3/3/2 co + ob ; 4/2/ co + ob	1/1/ co /A; 2/1/ ob /B; 3/3/ co - ob /CB	5/2D/2	2	1	2	2	2	2	WA-I	WA-V	6/4
W-I	Med-Low															

Final prepared data on Design Drawings, Introspective Reports & Questionnaires: Years 4&5

Test Takers Code/ Year of Study/ Gender	Creativity/ Academic Perform. Assessm. by Supervisor	Test Description														
		p – page; n – number; t – type of diagram or annotation (ob - object; co - concept; i – idea, vertical or horizontal); st – subtype; c – complexity (on a 3-point scale); CoN – number of constraints met (after conversion into a 4-point scale); CrO – creativity & originality; CE – complexity & elaboration; FF – flexibility & fluency; F – functionality; TM – technical merit (4-point scale for all design drawings assessments); LS – learning style; P/C – performance/creativity														
		Sketches, number per page	Sketch transform., number per page		Annotations p/n/t	Diagrams p/n/t/st/c	2D-3D balance n/type/c	Design drawings assessment (consensus)						Intros pect.	Questionnaires	
Vertical	Horizont.		CoN	CrO				CE	FF	F	TM	LS	LS		P/C	
LSA profile*	Ability															
11/IV/male	A/AG	0/3/2/2	0/6/3/3	0/3/2/2	1/3/ih+2iv/; 2/3/ob; 3/2/ob; 4/2/ob	1/2/co+ob/BC	1/3D/1; 6/2D/2	2	1	1	2	2	3	A-V	A-IV	6-7/ 6-7
A-V	Med-Low															
12/IV/male	G/G	0/0/0/0/1/1 /2	0/0/0/0/4/ 8/6	0/0/0/0/2/ 3/2	1/1/co;2/1/co;3/2/co +ob;4/2/ob+co;6/3/ 2iv+ob; 7/2/ob+co	1/3/ob/B;1/1/c o/A;3/2/ob/B;4 /1/co-ob/A-D	4/2D/2-3	4	2	2	2	3	3	AW-V	A-IV	7/7
A-I	Med-High															
13/Vfemale	G/G	2/2/2/1/1	4/12/10/5 /4	3/7/4/2/2	1/4/iv+ob+2co;/2/6/ ih+3co+2ob;3/5/2co +2ob+iv;4/1/ob	1/1/co/A;2/2/c o/D + integr. with sketches, 2/2/co+ob	1/3D/2; elevat. +cross	4	4	3	4	3	3	WA-IV	WA-I	8/6-7
W-IV	High															
14/V/female	AG/AG	0/6/2	0/10/7	0/1/2	1/6/5co+1ih;2/2/ob	1/2/co/AC; 2/1/ob/F	8/2D/1-2	2	1	1	2	2	1	AW-V	A-V	4/4
A-V	Med-Low															
15/V/male	VG/VG	1/1/4/3/1/2 /4	3/3/5/4/2/ 3/5	1/1/3/1/0/ 2/3	1/2/co;2/3/2iv+co;4/ 2/ih+co;/6/2/co+ob; 7/2/co+ob; model	1/1/co/A;2/2/c o+ob/AD;/3/1/ co/A;	2/3D/1; 15/2D/1- 2	2	4	4	4	2	2	WA-IV	WA-IV	5/6
W-IV	Med-High															
16/IV/female	G/G	2/1/2/1/2/2 /1/2/2	2/4/3/6/6/4/ 4/6	1/2/1/2/2/2/ 2/2	1/1/ob;2/1/ob;/3/2/ ob+co;4/1/ob;5/2/ ob;6/2/co+ob; model;8/2/ob+iv	1/ob/B/ + integrated with sketches 2/1/co+ob	1/3D/3, 14/2D/2-3 +elev.+ cross.	4	3	3	3	4	3	AW-IV	AW-I	5-6/ 5-6
AW-I	Med-High															
17/IV/female	G/AG	6/6/1	7/8	5/3	1/3/ob; 2/4/ob; 3/1/co	0 + integrated with sketches, 3/2/co+ob	2/3D/1 11/2D/3	3	2	2	2	3	3	AW-I	AW-I	4/8
A-I	Med-High															
18/IV/female	A/AG	2/1/2/1/1	4/4/9/6/4	2/1/2/2/1	1/2/ob;2/2/ob; 3/2/ob; 4/1/ob; 5/2/ob; model	1/2/ob/AC; + integrated with sketches, 2/1/co+ob	7/2D/2-3	2	1	2	2	3	2	A-VI	A-V	8/8
A-V	Med-Low															
19/IV/male	AG/A	0/1/1/2	0/1/2/2	0/1/1/1	1/2/co+ob; 2/2/iv+co/; model	1/2/co+ob/AB; 2/co/E	4/2D/1	2	1	1	1	2	2	A-IV	A-I	7/5
A-I	Med-Low															
20/V/male	G/G	4/2/4/2	12/2/6/2	6/1/2/1	1/9/4ob+5co+ih; 2/5/3iv+co	1/1/ob/B + integrated with sketches, 4/2/co+ob	2/3D/3 10/2D/3	2	2	3	2	3	3	WA-I	WA-I	6/5
W-I	Med-High															

* In LSA profiles **bold** denotes (strong) preference

Appendix C

Selected data from Questionnaires: Years 1 and 4&5

Test Takers Code/ Year of Study/ Gender	Was the assignment we gave you familiar to you?	How would you rate the difficulty of this assignment (use a 1 to 10 scale)	How would you rate your performance on this design task (use a 1 to 10 scale)	How would you rate creativity of your design ideas, solutions (use a 1 to 10 scale)	Did you have any problems expressing your ideas by freehand sketching	What kind of tools/techniques do you generally use to support the expression of your ideas	Please briefly describe the issues that you considered relevant to the design task and the strategies you used in designing	Please briefly step-by-step summarise the process you followed to complete the design task
LSA profile*								
01//fem	Yes – it followed the lines of an assignment I would have in design practice	5, challenging due to requirements but freedom to explore ideas in character	6, I came up with many ideas and sketches so I think I worked out a design to a conceivable level	5, My solutions are logical but my creativity was limited, I concentrated on the solution more	Not at all, the best communicative medium for me The size constraints probably limited my solution but I enjoyed the freedom of the exercise.	Plans, sections (technical drawing skills); mostly line drawings with labels	Light was important firstly, then views and the levels due to slope. The orientation & sequence of spaces evolved from these issues. Levels were first because I had to deal with fitting all the rooms in 65% of site. I sketch an aerial view first to 'see' what I was dealing with.	I worked out the site restrictions, then diagrams of space placement, integrated the living spaces into a plan, took views to visualize it 3 dimensionally and thought about character. I had problems arranging studio spaces but major living spaces I was certain about from the start.
A-IV								
02//male	Haven't designed a house before but I've lived in a house for the past 19 years of my life, so yes I guess Yes, we have had previous drafting assignments of similar criteria	4, incorporates past knowledge which has taken time to collect, but wasn't too stressful; reasonably straightforward 6, time difficulties and hesitation	6, I think I went reasonably, I answered the question, may be not the best answer in the world but it was okay 5, I spent too much time thinking while I should have been sketching my ideas	3, not the most interesting and wild form but I liked the circulation of the courtyard à studios as secluded areas 6, I think since uni has started I have been less creative and more practical. My ideas have sobered and I think more realistically	No, may be they are hard to understand by others though No, I think this is the ideal method for expressing ideas and very useful I sometimes worry that it might seem that my design is just thrown together	I generally like scribbly drawings and am into getting down the concept I like having all my info on a page so I don't miss anything. Axonometric, floor plans, perspective sketches	Creating a hierarchy of spaces was the first thing I considered, so I immediately chose which would be the highest, private spaces and decided they should look down the hill towards the reserve, the rest of the space were created as 'fill'. I noticed a few places where light would be an issue The space was what I thought of first. I wanted to give adequate space to each room. Also because the dance and art studios cannot be cramped. They both need generous amounts of space to function. I think the organisational diagram and the floor plans are the most informative when it comes to space	1. Hierarchy of spaces à studios, master bedroom à linked to each other by courtyard 2. Services à WC, shower, bath allocated à plan à responding to brief 3. Living areas plus garage 4. Considered materials plus facades I first wanted to look at the floor plan and decide on the location and shape of each room. After I finally decided on the organisation, I looked at the exterior and overall shape of the building (roof, walls, windows, doors). I always think of designs at first and then incorporate them with the organisation of the rooms and come up with a final idea
W-I								
03//male								
W-I								

04/I/male	Yes	5, instructions were few, and few restrictions also. And we did not have to accurately seek the design	6	5	No. I feel somewhat comfortable and getting a little better at it. I need to expose myself more to precedents to see how different problems are dealt with	Diagrams and sketches	Spatial layout, I needed to organise the spaces in a logical manner, using diagrams. Views – I decided which spaces would have views of the recreation space Finally, coming up with an interesting plan to fit everything together	First, I set aside space for the parking, because the amount of space available for the building is dependent upon it. Next, I organised all the parts into categories (public-semi public- private) and decided which spaces would have a view of the recreation space (studios, master bedroom, observatory). Then I set aside some space for the sculpture garden, next to the painting studio. Then, I used the rest of the floor plan for semi-public space (living, dining, WC). Finally, I decided on a floor plan design to fit everything together
A-V								
05/I/male	Not entirely, but I have had some influence from friends about architectural designs	6, a lot has to be thought about and fitted in the given space, yet there was freedom to design as we pleased	7, Ok I guess, if I had more knowledge, I would have done a much better job, I think I had some good ideas	7, I think my ideas are creative , but some people can readily come up with things no one could think about, I don't think my ideas are like that	No, I didn't, I tend to make my ideas flow from my sketching, so expressing them isn't hard at all	Paper and pencil, computers, I tend to be exact and I like perfection	Space I firstly considered: I thought I had to know what my constraints were so I calculated how much space I was juggling with, the positioning of key requirements was also important as they had to serve a purpose	Firstly, I tried to understand the task at hand, then I calculated the space and proportions I had to deal with, next came positioning of individual elements (the house, the garden), then how the floors would be arranged and how I would allocate ambiens to floors. Then I would divide the allocated space to create the ambiens
A-I								
06/I/fem	Yes-> houses were done in 2 nd year and process is the same as any other assignment	4, pretty easy as far as site constraints, so can achieve all elements of brief	7 or 8	All criteria fulfilled – and the house will be a nice place to be in all rooms, so 7 Sometimes I feel creativity is difficult for me. Practically I seem to fulfil all elements OK	Didn't have time to express materials, windows, but otherwise, no	Colour, pictures (trees, furniture, people), arrows, sometimes diagrams	Nice spaces Views important – considered first Access/entry points/proximity Noise Wind -> cross ventilation aspect Orientation (considered a bit late)	1) Views 2) Access/Proximity/Noise 3) Size + spaces 4) Checking against brief criteria 5) Checking for wind 6) Firming up and drawing
A-V								

07/I/fem	Yes, because an infill building with some connection with site context, no b/c domestic and parking and studio space	7, design is always challenging. Here there were many things to consider, but the response was open-ended	5, I developed a concept but did not resolve it fully	3, I don't think my response was very creative, I was merely trying to respond practically	No, but I mostly did diagrams and notes. I try to avoid drafting as long as possible	Diagrams and sketches and notes	- Site b/c that what we had to work with - People, to design for painter and dancer and what aspects they needed - Building use: home and studio (what is going on inside the house)	1) Concept: what am I doing and why? What am I trying to achieve? How would I like it? What is my main idea? 2) Spaces and order – how things relate to each other and site, sizes 3) Design of actual rooms
W-V								
08/I/male	Not at all, it was not difficult to generalise design ideas, but the assignment used unfamiliar knowledge	7, location and direction was not difficult, but practical layout was difficult to get working	5 or 6, I didn't have the all-round organisation of spaces needed to make the building work functionally	7, I tried to incorporate the tastes described into the design, keeping it natural and simplistic. This came across in an interesting way, with odd shapes emerging	I found it very difficult to assess the size of what I was sketching to see if I met requirements – this was my problem – scale. I felt ok about initial ideas, but sketching them became a bit difficult because of my lack of training	Computers (3D modelling, 2D plans, etc), but sketches play a major part in my initial planning, etc	Northerly aspect, sea breeze, light-views of the natural, and internal and external aesthetics. I tried to look at the sites positive and negative aspects well, then define spaces within this form for the required functions	I looked at the site, and its natural bonuses, versus its natural flaws, then tried to create an organic form that suited itself to the site's positive points. Then, this form was refined to suit the spaces that would make up the entire space itself. Organisation of these spaces meant the original form was drastically modified by the end
A-V								
09/I/fem	Yes, I have done a house before, seen many of them, and also have lived in one, so yes, rather familiar	6, could not concentrate on the concept in detail because I spent a lot of time trying to understand the site, usually require a more time to digest the brief	7, I think I did well, I tried to resolve functional issues first and to keep a track of the initial concept	5, creativity was ok, but I concentrated more on analysis, drew diagrams	No, but I prefer not being pressed for time	At this stage sketches mainly	Site, i.e. how the house related to context, and how my design fits in the site context Considered environmental issues Consider clients' lifestyle, creating a hierarchy of spaces to fit their needs (drew functional diagrams) Give it a form Allocate spaces that fit into the overall form	1. Interpret/understand the site 2. Calculate areas for each space, give it a shape to relate them in size 3. Think how I imagine the client's lifestyle would be. Arrange spaces on site according to environmental aspects and pattern of use/living
W-I								
10/I/fem	I have done a house before but not to this extent (didn't do all of it)	7, fitting all requirements in was a bit difficult, concept part was ok	5, I think I could have done better on the requirements part	4, It was a nice concept, but I didn't think it was too creative	Yes, a little bit, I could not sketch properly what I visualised	Sketches & models	House, how it represents people who live there, how it fits into the site Concept plan and shape Brief requirements	1. Thought about art and its connection to life and nature 2. Came up with a concept plan and shape 3. Tried to fit brief requirements into that
W-I								

11/IV/male	Yes	6	6-7	6-7 due to limited information and resources	No, designing is a fantastic form of expression	Sketches and annotations	Site analysis Organisation of spaces Circulation Form <- Buildings	1) Site analysis -> on site annotation 2) Responses to site visits 3) Planning and sorting the required rooms 4) Allocation of spaces 5) Form
A-V								
12/IV/male	Yes	3, because although being a house (lots of considerations) the parameters set are basically still loose	7, given the time limits	7, given rather too few constraints to opportunities	No	Pen, trace	Issues: FSR, brief of spatial requirements, light, space, view, noise, street response, circulation, relationship of spaces to each other, relationship of building to surrounds Strategies: 1) Rough feel of size 2) Site opportunities/constraints (1&2 to get a feel of the issues to be tackled) 3) Spatial requirements 4) Spatial layout	Consider site and spatial brief and regulations concurrently, then allocate spaces to respond (in doing so, also relate each spatial regulations to others)
A-I								
13/Vfem	No	4, needed more info on site slope and neighbouring context	8	6 or 7	Sometimes. Spatial sketching perspectives are difficult to put on paper (mind->paper)	Concept sketches and perspectives	1) Line -> line of street and context – draw 2) Where sun is – NSEW and what rooms need what light 3) Slope – how to use to advantage 4) Views to surroundings 5) Living areas & outdoor areas & type/size of spaces needed	First looked at the requirements of brief, then how the house should address the street (looking at sight lines and how to approach entry). Use wall as 'incision'/direction into house (concept) Separate living and working areas and how to arrange them using vertical and horizontal spaces. Tried to use direction of sun and views to maximum advantage. Start with visualising house in 3D form, then plans, then section. Draw perspectives and sketch and concepts along the way.
W-IV								

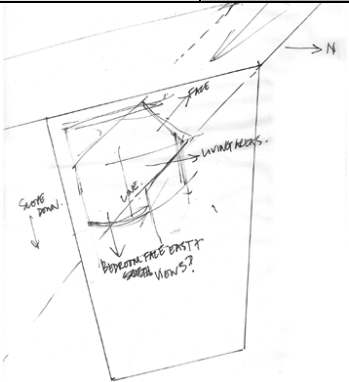
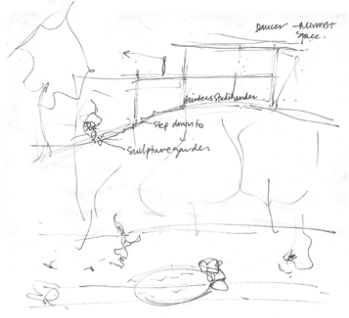
14/V/fem	Yes, I've done similar before	5, Not difficult, I've done similar projects before but here time was the difficulty	4, Not good because I didn't actually arrive at a design	4, Not particularly creative because of the time factor	Didn't get the chance. I always write a lot when designing	Reading and writing concepts, ideas, working out organisation and site strategy, then thinking about the building	- identifying the brief - site floor ratio - height issues - embracing views and slope - separation of living/working with a central outdoor space	- what are the site issues, views, orientation, access... - what spaces are needed (organisational diagram) - writing down ideas on what my strategy would be - attempting a block diagram on site with appropriate sizes
A-V								
15/V/male	Haven't done a single family residence at uni	3, pretty easy – few constraints + nice scale	5, OK ideas but didn't progress far	6, interesting, next step if there was time, that's where the creativity would come in	No, diagrammatic plans, next step would be have to be model	Diagrams, sketch overlays, 3D physical model	- Site, i.e. how my design related to context - Used diagram to start planning, diagram came from site + program - Writing used to organise thoughts, sketching to test ideas	1) Diagram based on site, brief + program 2) Adjusting diagram to section, relationships of spaces 3) Fitting diagram on site
W-IV								
16/IV/fem	Yes	2, I find that housing projects are very familiar to me and require less research	5-6, Medium, I feel my functional relations + consideration of context and climatic factors was okay	5-6, Medium, spatially I feel that the house was not as complex and interesting as I would like, but okay for the amount of time	Not at first but I reached a point where a model would say more than my sketches would Not having a model was only constraint but not a major one	Plans, sections, elevations, sections + models	First consideration was aspect of the site (North point) and access from road. This helped locate spaces I thought needed more access to light and views. Using plans then sections to organise the spatial relationships between various parts of the building. Sense of enclosure, what was more solid, what was more open	1) Diagram showing how services vs living areas related to each other and to North 2) Plans, showing relationships between rooms 3) Sections, showing relationships vertically 4) Axonometric showing 3-dimensional form, how roof work, starts to show external cladding and openings 5) Elevations showing external cladding openings + proportions
AW-I								

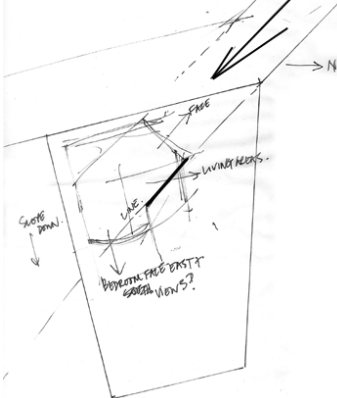
17/IV/fem	Yes, similar to a project in second year	5	4, Not so well , I don't usually work in this environment	8, Good , an eclectic design for an eclectic couple	Yes, definitely! Designing is a 3-Dimensional task for me. I need building blocks	Models	The first idea that entered my mind was how the building sat on the site, its roof plan, which led on to light entering and the overlapping of spaces. Also the usual appearance of the building. The many angles of perspective	1) Draw site plan 2) Arrange house so that it had an ordinary feel outside but extraordinary inside with the use of mezzanines 3) Arrange spaces, looking at sections and perspectives 4) Look at the envelope of the building, integration of light and feeling of space 5) Design of interior and exterior space 6) Elevations, section
A-I								
18/IV/fem	Yes	2, design of dwellings is one of the most basic tasks, we learn about housing in the 1 st year already	8	8	No, but I would have liked some modelling materials	Models	The constraints of the site the brief and also views out of the site	Planning and drawing and modelling. Firstly, I calculate the areas required by the brief and play around with the spaces in plan Then I organise them in section and try to optimise the views out. From there I derive a 3D form of the building. With the constraints and may be additional ideas, the building can be modified to suit as a trial solution
A-V								
19/IV/male	It's ok J	6, no design is easy! Insufficient information on the site and the character make it more difficult. But, ultimately, it's the design methodology that matters more!	7, It's ok	5, Not very creative, because not much inspiration at the moment	Sometimes, still find difficulty expressing ideas, still grasping the methodology of designing, but I think I'm slowly getting there J	Sketch + model making	The site, natural and built environment, the function/program, characters that relate to the program, circulation-connectivity within and without the site	1) Site consideration, natural and built 2) Program 3) Circulation and relation among the program
A-I								

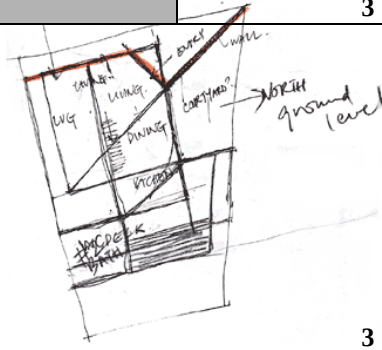
20/V/male	Yes, I have done similar projects	6, it was quite familiar but requires more time to come up with something good	6, I feel my diagrams are useful, and spaces are organised nicely, but it could be more interesting	5, Not very creative because I was concentrating on making it work as a whole, I could achieve that but haven't come up with an interesting visual idea and form, need more time for that	Sketching was easy because I was thinking on paper, it is harder to draw from head -> next stage, interesting shape	Sketching mostly, sometimes computers and sometimes models	The site, the house in the site context, functional areas in the context of the site Relationships between spaces/rooms Relationships between zones	1. Contemplate: site/context, recognise what brief contained 2. Relationships between rooms defined 3. Understanding of the whole house as a number of rooms and also as a whole 4. Opened several spaces up to one and other, and tried to segregate seclusive and active
W-I								

Appendix D1

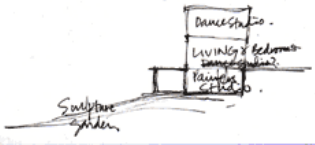
Sample datasets: Protocol session of S13(V)

No	Time	Activity from the video	Retro- and introspective statements by	Sketches
Sheet 1				
1	00.00	<i>Consults the brief and thinks</i>	Here... I'm trying to understand and imagine how it will work...	
2	02.00	<i>Redraws the site in a larger scale</i>	First what I did here is draw the site so that it would be easier for me to arrange the spaces within it...	
3	02.45	<i>Marks the North, marks the slope direction and sun</i>	and I marked the North...standard drawing practice...where's North, where's the boundaries, that sort of thing... I look, I was looking at where the sun goes	
4	02.55	<i>Consults the brief</i>		
5	03.00	<i>Stops to think</i>	and where I should arrange... because its a house, where living areas should go, where master bedroom should go, that sort of thing... ummm...what I'm doing there is trying to visualise in my head in 3D what I'm doing... ummm like what's in my head and what I'm trying to do... ummm...	
6	03.10	<i>Draws invisible & thin lines</i>		1
7	03.30	<i>Draws a simple doodle of the slope and two blocks indicating two levels</i>	so that's when I'm just drawing levels, how I want people to look out of the house, u know... ummm... because I wanted like the working spaces and the living spaces to be separate...	
8	04.00	<i>Draws invisible & thin lines, two thicker lines- corner defined</i>	so that was me just trying to visualise... and like... as how to use the slope... as I wasn't sure what the slope was I assumed it was steep..	1

9	04.20	<i>Indicated the road and direction towards the house entrance, adds a few thin lines</i>	I'm drawing a shape so here I'm looking at the line of the street, how you approach it by the car....		1
10	04.40	<i>Stops to think</i>			
11	05.10	<i>Adds a few labels</i>			1
12	05.40	<i>Stops to think looking at the plan</i>	How hard to look into the entry, so what happens when you come down this street, how you know... what are you looking at... what's your line of sight... ummm... and that's sort of... trying to dictate... ummm...		
13	06.10	<i>Starts to work on the plan, starts on the first conceptual idea - incision wall</i>	I'm just trying to see if that, I can use that as a way to, you know, go into the building you know... form the shape of the building... what else... yeah... and... I'm thinking about entering the house... which... how do I, you know... I consider the entry into the house quite... and how the house addresses the street...		1
14	06.20	<i>Thinks, consults the brief</i>			
15	06.40	<i>Draws invisible lines, a few thin lines</i>	umm... and that's why I had all these lines... ummm...		1
16	06.55	<i>Adds more labels to the slope and blocks image</i>			2
17	07.10	<i>Consults the brief</i>	Yeah, that's when I'm just looking at the requirements... I think...		
18	07.50	<i>Goes back to drawing 2, adds flaming trees, etc</i>	Im just trying to imagine the view from the balcony upstairs of a sculpture garden below... so that's why I was drawing like that... that's just like balcony rails... so I'm just seeing flaming trees at the end... umm.. that's when I was just trying to visualise in my head... drawing is not fantastic... but...		2
19	08.00	<i>Labels zones of the house (approximate)</i>			2
20	08.10	<i>Consults the brief</i>			
21	08.25	<i>Adds more labels of spaces</i>			2
22	08.30	<i>Consults the brief</i>			
23	08.55	<i>Adds details to drawing 2</i>			2

24	09.45	<i>Back to drawing one, invisible lines, thickens incision wall</i>	Yeah, here I thought I'd keep it...	1
25	10.10	<i>Writes 'view from top balcony of sculpture garden' on drawing 2</i>	That's it...	2
10.25 Moves to sheet 2				
26	10.50	<i>Retraces the lines she decided upon earlier</i>		
27	11.00	<i>Thinks and draws invisible lines</i>	This is me looking at the ground level... and trying basically to arrange the spaces ummm... trying to make it work... ummm... the focus changed a bit from here because I realised that hang on, I cant have the building sort of...	3
28	11.25	<i>Starts to work at the ground level Conceptual idea reinforced, uses marker to show the incision wall</i>	so instead I continue the line with the wall and that's sort of like part of my concept... where it's the wall's incision into the house... like it needs... like it just cuts into the house... and that quite nicely...	 3
29	11.40	<i>Stops to think</i>		
30	11.55	<i>Adds a few thin lines, lots of invisible lines</i>	like has a courtyard area which faces North... and then there's living, dining and kitchen leads up to like a deck at the back which faces East and the second bathroom... and then I thought... hang on... is this going to work as there's a car park coming in...	3
31	12.05	<i>Consults the brief</i>	and I think I checked that... I just kept checking the sizes and stuff like that...	
32	12.25	<i>Adds a note, records unresolved issue</i>		3
33	13.00	<i>Keeps sketching</i>	just trying to make it work and... just trying basically to fit the spaces in... and then to	3
34	13.40	<i>Stops to think</i>	see how that works with my concept... and how I can manipulate and balance between	
35	13.50	<i>Consults the brief</i>	the concept and the spaces and the requirements... And keeping an overview... you	
36	14.00	<i>Stops to think</i>	know, you need to keep an overview, or you will end up with piecy stuff that falls apart	

Okay, how do you know that dimensions or spatial relations are right? I don't see you using a ruler much. I just basically think like 'okay, with thirty meters square, what's that? Is that three by ten, or six by five'... So that in my head I roughly know... you know from drawing so much... you sort of know how these sizes are... And usually I just kind of draw like little sort of squares... sort of but not... they don't have to have walls... like you can see there's not really any definite walls... its just kind of conceptual... more like conceptual I'm thinking... rather than draw the walls, I just write it... so I know that's where the living is...that way I'm not limited by the actual lines that I draw on paper... See, you can see that I'm just drawing over and over... so rather than keep heaps of paper on... because to me those lines don't necessarily represent walls...that's why like the only thing... like what was definite was... the way the shape would address the street... which is why I got the orange pen and went, yeah... that's fixed... and then... then I just manipulate spaces within that, and then I... and occasionally I'll bring the ruler down just to see if my estimates are correct...

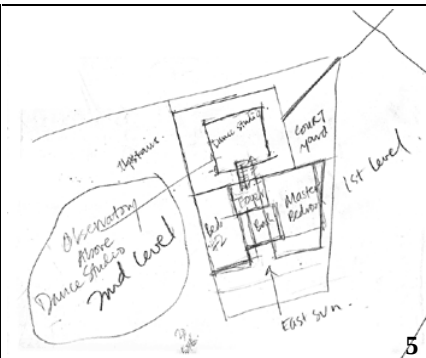
37	14.20	<i>Draws a small doodle cross-section underneath the plan</i>	And down there I was just drawing the... how I wanted the levels to... like a little section to see if that... like it could actually work in sections... rather than just you know, in plan...		4
38	15.10	<i>Labels spaces</i>			4

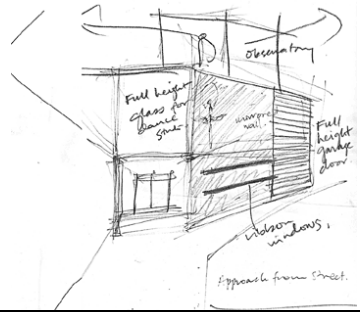
So that's what I do, I usually like... as I go along I will usually like a little section, or a little prospective just to see, just to check back... so I'm not just drawing 2D...

39	15.20	<i>Stops to think</i>			
40	15.30	<i>Works on drawing 3</i>			3
41	15.50	<i>Stops to think</i>			
42	16.00	<i>Draws invisible lines around the entrance</i>	And that's me just checking the lines...		3
43	16.10	<i>Adds a few labels</i>			
44	16.15	<i>Stops to think</i>			
	17.10	<i>Takes another sheet</i>	Yeah, that's me turning it [sheet] over, trying to do the second level...but...and then I realise, hang on, doesn't work... that's why I put it [sheet] back...		
45	17.30	<i>Labels spaces</i>			3
46	17.50	<i>Consults the brief</i>			
47	18.00	<i>Thinks looking at the plan</i>			
48	18.20	<i>Consults the brief</i>			
49	18.25	<i>Draws invisible lines around, accentuates walls, continues with planning</i>	Yeah, I'm giving up... Too many lines hehe...		3
50	19.00	<i>Thinks looking at the plan</i>			
51	19.20	<i>Consults the brief and thinks</i>			

52	19.40	Makes some lines thicker		
53	19.50	Stops to think	That's me realising, hang on, I've like ummm garage to it... but I don't think that was appropriate space to fit it in...	
54	21.25	Adds labels		3
55	21.35	Stops to think		
56	21.55	Continues with planning	That's me just going down doing kitchen, second bathroom...	3
57	22.10	Stops to think	That's me just checking the lines...	
58	22.20	Highlights the main conceptual incision line		3
59	22.50	Labels spaces		3
60	23.10	Thinks and reinforces some lines		3
61	23.40	Folds the sheet and traces over the staircase, gives up		
62	23.50	Consults the brief		

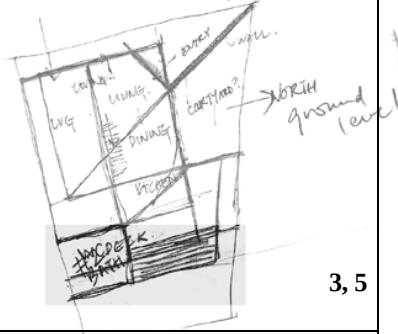
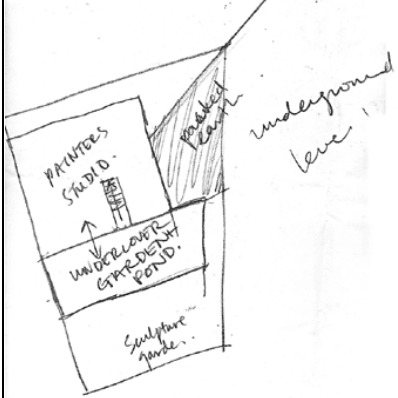
Okay you went back to this one? [ground level plan drawing 3] Yeah, because I do that occasionally... and sometimes I write things, rather than draw them because ummm... There's more flexibility in it or It's faster or else? Yeah, there's more flexibility... Like I know its there but that's just to make sure what I have where... like I can still go and change it... and yeah I remember what I put and where...

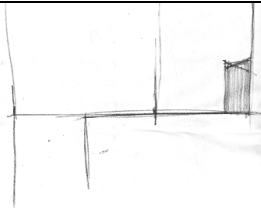
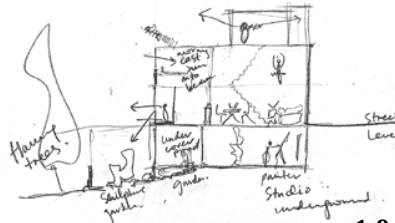
24.00		Moves to sheet 3		
63	24.10	Starts with retracing Adds details from the ground level drawing 3	Okay, I've got another paper on...and I put it over... and basically what im doing the first to the next level... see how the stairs, whether the stairs, whether the placement is right...	
64	24.30	Stops to think	like because of the sizes of the dance studio... because I like the dance studio upstairs so that you can have sort of the North facing wall, you can get all the light coming in... but then you've got always some walls completely blank... that's where you put your mirrors on... and also having the master bedrooms facing East...so you can get the morning sun... and that's like a foyer, basically that's like the pole, stair pole....	

65	24.40	<i>Starts on another sketch</i>	And then I start drawing the prospective, like if I'm coming from the street and over there... you know that's how the building starts to look...that's the observatory on the top...its like little glass box... and that's the entry, that's that wall... the giant wall which kind of goes through into the house...		6
66	26.00	<i>Draws a doodle of a ballerina</i>			6
67	26.05	<i>Stops to think</i>			
68	26.15	<i>Adds labels</i>			6
69	26.20	<i>Stops to think</i>			
70	26.35	<i>Draws a slope</i>			6
71	26.40	<i>Adds labels</i>			6

That's what I do, I usually do a kind of plan, and then I do again another perspective or a section, just to check and see if what I'm drawing in 2D actually translates into 3D... *Do you ever do models during early design stages?* I prefer drawing... I'm too bad at them... its very messy...

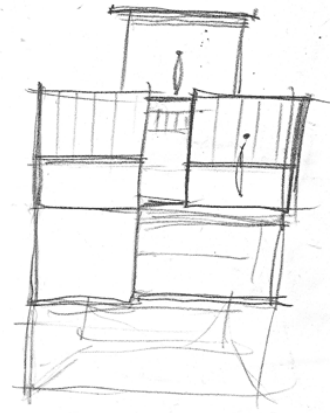
72	26.45	<i>Back to the plan - drawing 5, uses a ruler to measure</i>	That's me just working out the spaces, and working out where the walls and how do I deal with the neighbouring....space... like do I go right up to the edge or do I just like stop one meter away...		5
73	27.10	<i>Stops to think</i>			
74	27.20	<i>Continues working on the plan, thickens several lines</i>	and then I'm just getting the sizes correct right to the edge... and basically I'm just working around the spaces... its just like looking at it...		5
75	29.25	<i>Stops to think</i>			
76	30.00	<i>Finishes planning spaces</i>			5
77	30.30	<i>Matches plan on page 2 against plan on page 3</i>	That's just me checking to see if...		3, 5
78	30.50	<i>Goes back to the prospective sketch, adds top level</i>	and that's me drawing the observatory on the top... you know draw it on top and		6
79	31.10	<i>Goes back to the plan</i>	then I added it [observatory] on to the drawing... you know its like keep going back and fourth...		5
80	31.35	<i>Consults the brief</i>	<i>And then you checked with the requirements again? Yeah...</i>		
81	31.45	<i>Continues planning</i>			5
82	32.00	<i>Adds labels</i>			5

83	32.10	Places sheet 2 on top of the current sheet (3), introduces changes in accordance with the latest plan (adds bath)	Okay, what are you doing here? You went back to the second drawing? Yeah, because what I was doing was... what happened was, originally I had that just up to there... and then I realised, hang on... second floor is overhanging quite a bit, so I decided to extend the spaces, because I hadn't actually thought of the bath at that point of time, I just thought this is a square box... that's it... and now I'm extending it, making that curve round so that will enclose the courtyard...and have a little deck... umm that's what I was doing there, because what happens was the first level was very big and ground level really small...	
84	32.50	Adds labels		3
85	33.00	Continues sketching and thinking	this is where I was trying to balance it out... like in terms of doing... construction-wise... thinking in my head, okay, how is this going to work? How far... what kind of overhang can I work with? Probably the max would be like three meters or something...	3
86	34.35	Stops to think		
	34.45	Moves to sheet 4		
87	34.50	Retracing staircase from drawing 3	So that's just lining up the drawings to see if they work...	7
88	35.15	Consults the brief		
89	35.20	Thinks, says 'okay I'm here'	... there's an underground level with packed earth... its almost like you go in and rock up the world... that whole concept of like look inwards... and so that can be, like kind of... I think that's how painters work, I have no idea he he...I'm not a painter...	
90	35.30	Starts detailed underground level planning	That's just me working at the underground level, because for me its like... to me the painters don't need... they'd rather not have light, rather than... I mean... they'd rather have artificial light rather than natural light because that doesn't destroy your paint... and so like I had	
91	35.50	Labels spaces		7
92	36.00	Stops to think, invisible lines		7

93	36.35	Finishes planning with 'yes, that's it!'	And that's me basically trying to work the shapes and sizes...umm...	7
94	36.45	Stops to think		
95	37.10	Adds sculpture garden	Yeah, and then... that's sort of like, you've got these spaces where.. umm... its like a studio and then you've got like under-cover like garden [sculpture] slash work like you can have only... because its under cover you can have like your works in progress... and then before like finished and graduate student sculpture garden kind of thing... so its kind of like a process, like represents the process of the painter and the work...so its like this is where it starts and this is where it comes up...	7
96	37.30	Starts with another sketch on page 4, draws a street line, transfers measurements from the previous drawings onto the new one	And that's just me drawing the street line so that I know exactly...	 8
97	38.40	Consults previous drawings on page 2,3,4	Trying to work the shapes and sizes here.... and this basis....	3, 5, 7, 8
98	39.10	Adds a few more lines	...and how far I need it to go out to support the level up...on top...ummm...	7
39.15		Moves back to sheet 2		
99	39.20	Starts drawing a cross-section using a ruler, consults all drawings, mainly plans	And that's me starting to do a section but... I finally realise that I couldn't... so that's why I stuffed up... Because I need to have like... correlate it with the plan...So that's me trying to draw the section there then kind of giving up...	 1-9
100	43.50	Stops to think		
101	43.55	Adds labels		9
102	44.15	Stops to think		

This is... basically I usually do a big whole section once I've done like the plans so that I can see again – this works, this doesn't work...

44.50		Moves from one sheet to another		
103	45.00	Fixing details here and there,	Yeah... basically filling it with little pictures to show what was to do what and little changes... and where the street level is... and the views...	1-9
104	45.20	Labelling and making notes		1-9
	45.30	Stops to think		

105	45.40	Adds notes to plans on sheets 3 & 4	And when you look from the out... where the sun is coming in... that sort of stuff...	6, 8
106	45.45	Stops to think and make notes		5, 6, 8
107	46.00	Works on drawing 6, adds details	I want ribbon windows and then you've got the garage door... how do I use that in context... so I get the building not looking so piecy... and the whole thing looks like an object... and that's just me adding something to that....	6
108	46.55	Adds labels and doodles		6, 9
109	48.10	Goes through all pages checking		
	48.45	Moves to sheet 5		
110	49.10		Okay this is the view... I was trying to do a view from... the elevation from the back... so that would be like... inside... the transitional space, and the painters, and that's like the kitchen and the bathroom... that's the bedrooms and that's the observatory... so I was just trying to do an elevation... to see how it looks from the back...	
	51.50		And that's where I stopped...	

How do you get your ideas? I'm not the sort of person who can look at pictures and think 'Oh, that looks nice, let me try that' I sort of think, start with the lines, you know... then okay... that's okay, that will be set... that's how it addresses the street and then... and how do I work within that, how do I work with spaces within that, and then usually right in the beginning I had already a vision in my head... like this house is going to be partially underground... because I want a painter to do this... the dance studio is like light, so that's going to be up.... And then there's going to be all these levels, and the bottom is going to be separate from the living and... so it's all in my head already... and that's when I just start to visualise it when I draw the plan or a section... like I said I just go back and fourth... like I draw a plan, then I draw a little section or prospective and then I come back again... rather than just do all the plans and then all the sections... because I want them to fit well together... and to have like one concept... That's me... see that elevation drawing? So originally it would just be a box and then I develop it up... I add the observatory at the top... and then I thought, hang on, how do I address the street? I want ribbon windows and then you've got the garage door... how do I use that in context... so I get the building not looking so piecy... and the whole thing looks like an object... and that's just me adding something to that.... And I think that's it...

Note: Outside of the table are introspective claims from an open interview

	Thinking
	Consulting the brief
	Sketching

Appendix D2

Sample datasets: Questionnaire of S13(V)

Present occupation *Student*

What is the typical design assignment you would do at the University?

Usually one conceptual project and two 'real' projects a year à public/commercial buildings

Was the design assignment we gave you familiar to you? *No*

How would you rate the difficulty of this assignment? (use a 1 to 10 scale) Why?

4

How would you rate your performance in this design task

8

How would you rate the creativity of your design ideas, solutions

6 or 7

Did you have any problems expressing your ideas by freehand sketching?

Sometimes spatial sketching perspectives are difficult to put on paper (Mind à paper)

What kind of tools/techniques do you generally use to support the expression of your ideas

Concept sketches & perspectives

Please briefly describe the issues that you considered relevant to the design task (*i.e. light, space, etc.*) and the strategies you used in designing (**for example:** *what part of the design task you considered first and why, what made you use writing or sketching etc.*)

- 1) Line à line of street and context - draw*
- 2) Where sun is – NSEW & what rooms need, what light*
- 3) Slope – how to use to advantage*
- 4) Views to surroundings*
- 5) Living areas and outdoor areas & type/size of spaces needed*

Please briefly step by step summarize the process you followed to complete the design task. If you have come up with several design solutions repeating the same process, please describe either one. If not, please provide more details

First looked at requirements of brief, then how the house should address the street (looking at site lines and how to approach entry). Use wall as 'incision'/direction into house. (Concept). Separate living and working areas and how to arrange them using vertical and horizontal spaces. Tried to use direction of sun and views to maximum advantage. Start with visualising house in 3D form, then plans, then section. Draw perspectives and sketch and concepts along the way.

How did you feel about designing? Any problems, constraints?

Need more info on site slope & neighbouring context.

How did you feel about the process of retrospection?

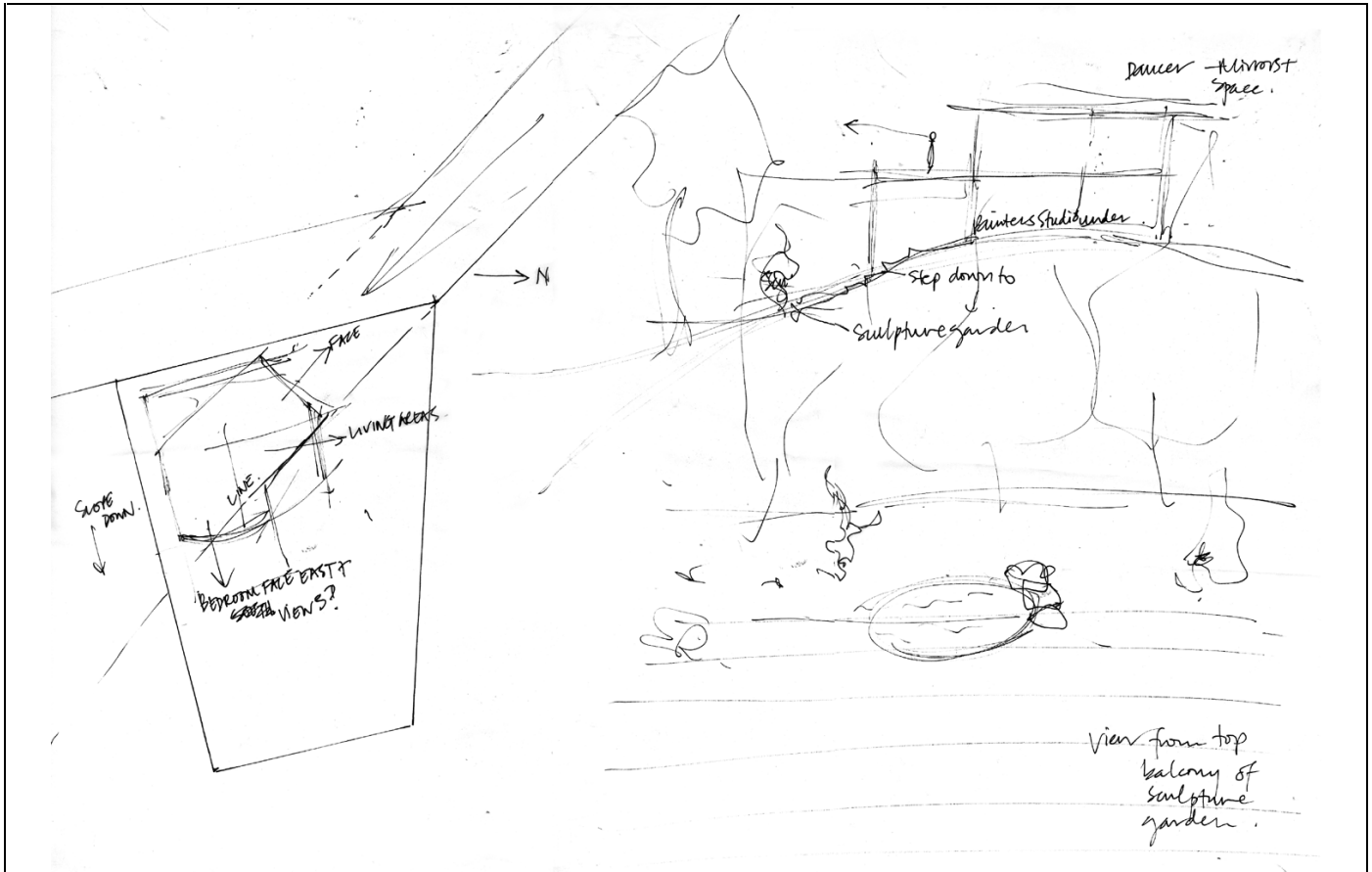
Do you have any comments regarding the whole experiment?

Would be interested in knowing the results

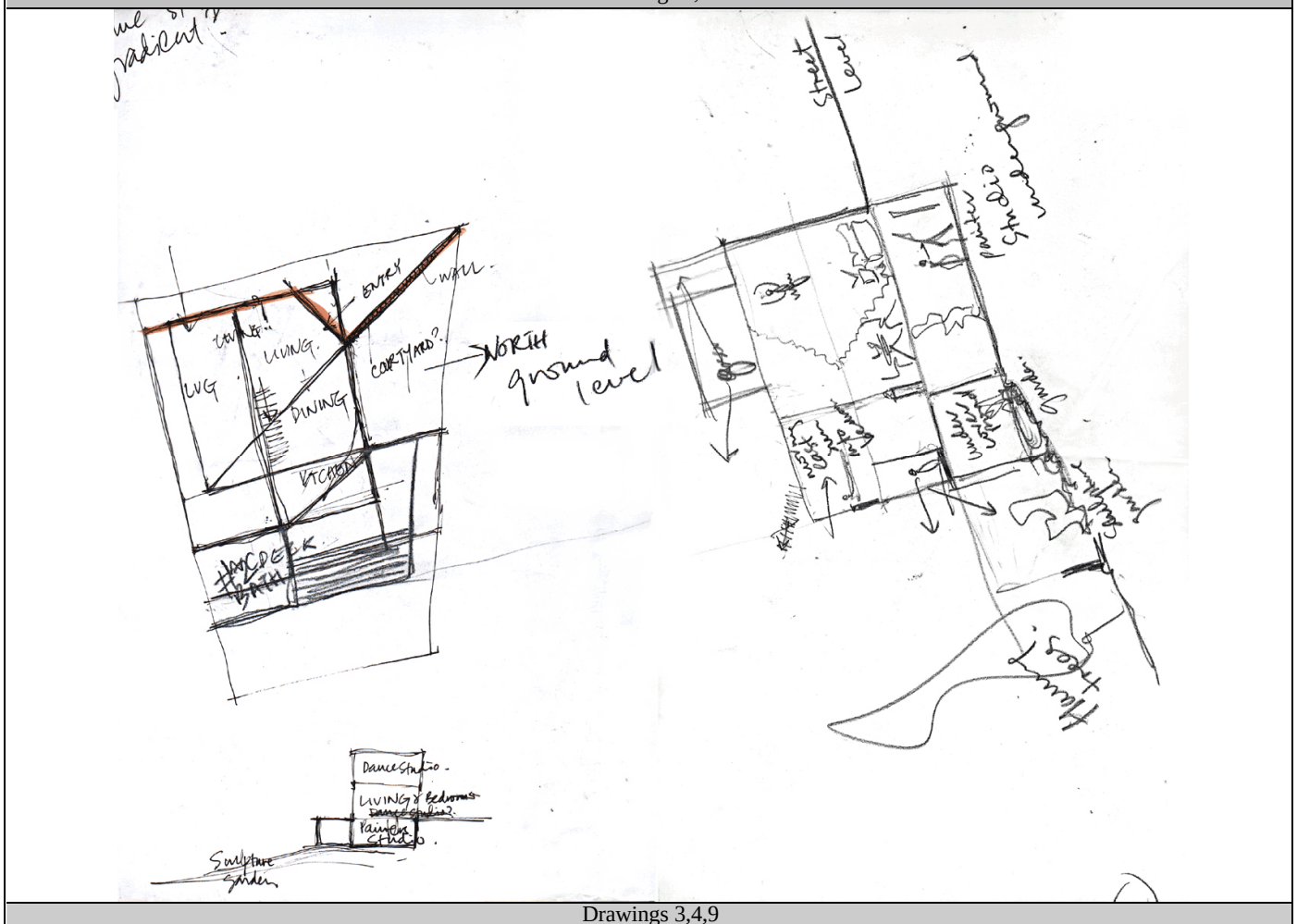
Do you have any other comments?

Appendix D3

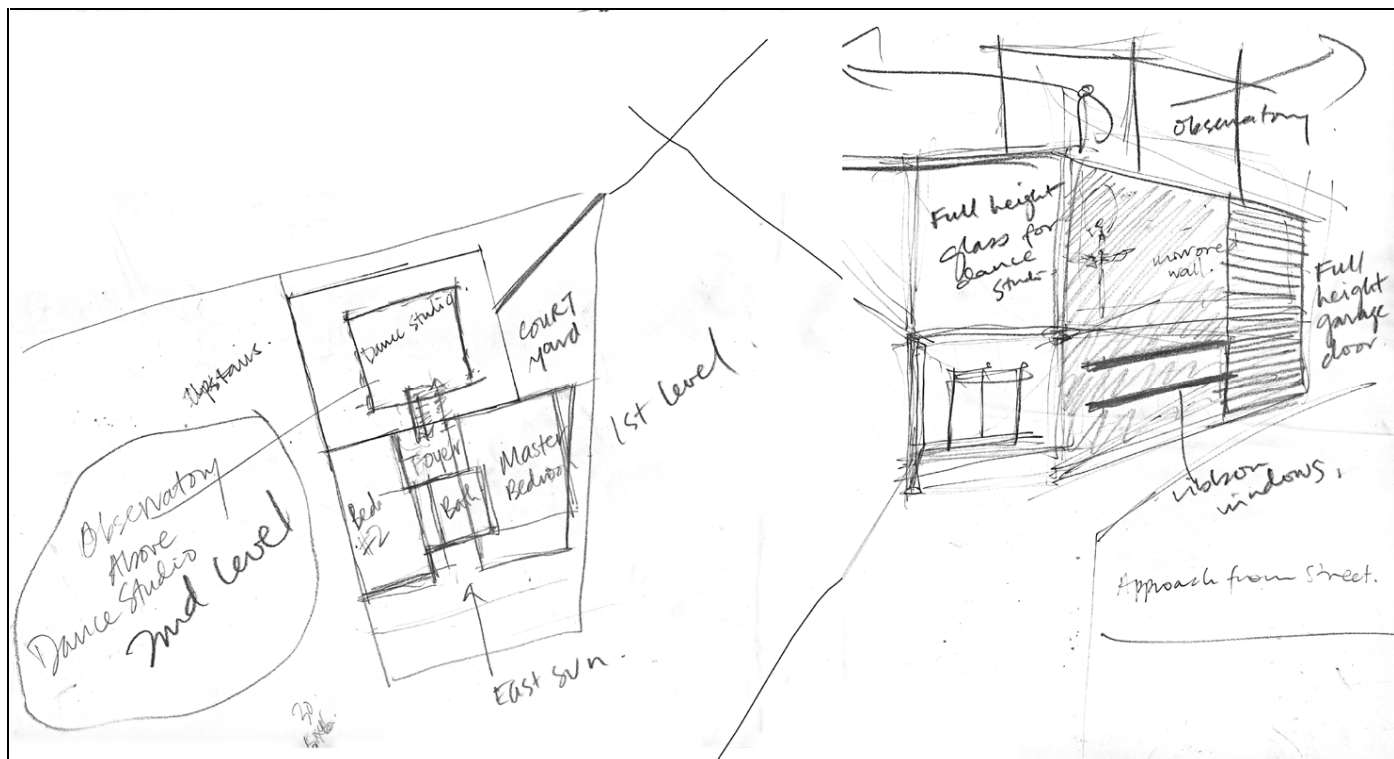
Sample datasets: Design drawings of S13(V)



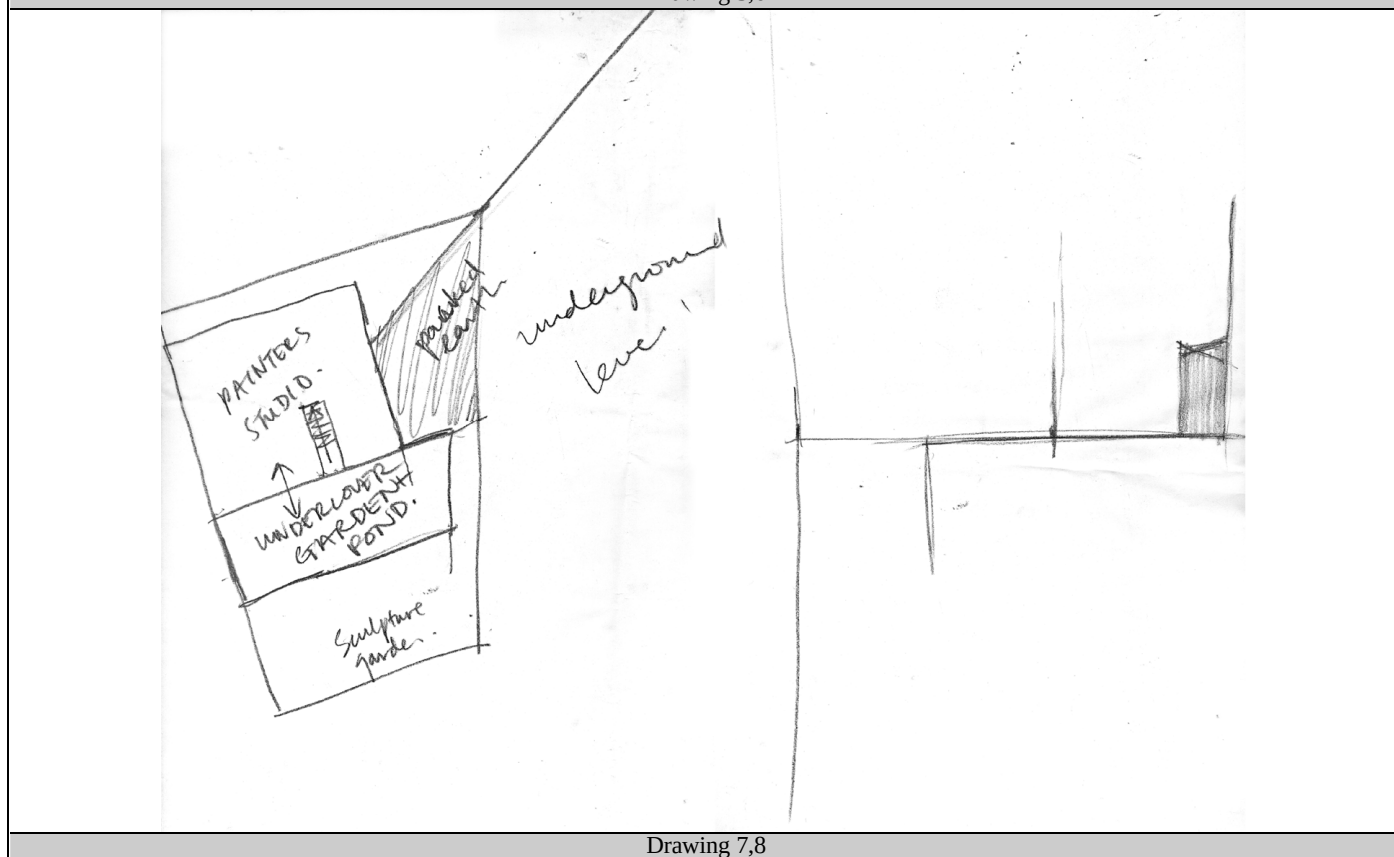
Drawings 1,2



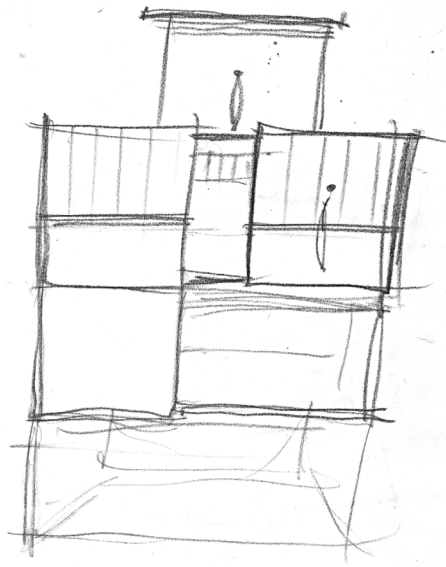
Drawings 3,4,9



Drawing 5,6



Drawing 7,8



Drawing 10

Appendix E

Cognitive Abilities Assessment

Test Materials

Selected Visual-Spatial Abilities (*Gv*) from the CHC Theory of Intelligence

Visualization (*Vz*): The ability to apprehend a spatial form, object, or scene and match it with another spatial object, form, or scene with the requirement to rotate it (one or more times) in two or three dimensions. Requires the ability to mentally imagine, manipulate or transform objects or visual patterns (without regard to speed of responding) and to predict how they would appear under altered conditions (e.g., parts moved or rearranged). In Carroll's (1993) analysis, more than 800 variables have salient loading on this factor. It differs from *Spatial Relations* primarily by a de-emphasis on fluency.

Spatial Relations (*SR*): Ability to rapidly perceive and manipulate (mental rotation, transformations, reflection, etc.) visual patterns or to maintain orientation with respect to objects in space. *SR* may require the identification of an object when viewed from different angles or positions.

Visual Memory (*MV*): Ability to form and store a mental representation or image of a visual shape or configuration during a brief study period, over at least a few seconds, and then recognize or recall it later, during the test phase.

Spatial Scanning (*SS*): Ability to quickly and accurately visually explore a wide or complicated spatial field or pattern and identify a particular configuration (path) through the visual field. Usually requires visually following the indicated route or path through the visual field.

Imagery (*IM*): Ability to mentally depict (encode) and/or manipulate an object, idea, event or impression (that is not present) in the form of an abstract spatial form to solve spatial problems. Separate *IM* level and rate (fluency) factors have been suggested.

Selected Idea Production Abilities (*Gl*) from the CHC Theory of Intelligence

Ideational Fluency (*FI*): Ability to rapidly produce a series of ideas, words, or phrases related to a specific condition or object. Quantity, not quality or response originality is emphasized.

Associational Fluency (*FA*): A highly specific ability to rapidly produce a series of words or phrases associated in meaning (semantically) when given a word or concept with a restricted area of meaning. In contrast to *FI*, quality rather than quantity of production is emphasized.

Expressional Fluency (*FE*): Ability to rapidly think of and organize words or phrases into meaningful complex ideas under general or more specific cued conditions. Requires the production of connected discourse, not words (unlike *FA* *FW*) or rephrasing given ideas, not generating new ones (unlike *FI*).

Figural Fluency (*FF*): Ability to rapidly draw or sketch as many things (or elaborations) as possible when presented with a non-meaningful visual stimulus (e.g., set of unique visual elements). Quantity is emphasized over quality or uniqueness.

Figural Flexibility (*FX*): Ability to rapidly change set and try-out a variety of approaches to solutions for figural problems that have several stated criteria. Fluency in successfully dealing with figural tasks that require a variety of approaches to a given problem.

Index of cognitive factors and tests as assessed by the *Kit*

The *Kit of Factor-Referenced Cognitive Tests* contains two or more tests for each of the 23 cognitive factors. The factors and tests are listed below. Each test has two parallel parts. Detailed information about the factors and the tests, as well as scoring keys, is contained in the *Manual* (1976).

CF—Closure, Flexibility of 1. Hidden Figures Test 2. Hidden Patterns Test 3. Copying Test CS—Closure, Speed of 1. Gestalt Completion Test 2. Concealed Words Test 3. Snowy Pictures CV—Closure, Verbal 1. Scrambled Words 2. Hidden Words 3. Incomplete Words FA—Fluency, Associational 1. Controlled Associations Test 2. Opposites Test 3. Figures of Speech FE—Fluency, Expressional 1. Making Sentences 2. Arranging Words 3. Rewriting FF—Fluency, Figural 1. Ornamentation Test 2. Elaboration Test 3. Symbols Test FI—Fluency, Ideational 1. Topics Test 2. Theme Test 3. Thing Categories Test FW—Fluency, Word 1. Word Endings Test 2. Word Beginnings Test 3. Word Beginnings & Endings Test	I—Induction 1. Letter Sets Test 2. Locations Test 3. Figure Classification IP—Integrative Processes 1. Calendar Test 2. Following Directions MA—Memory, Associative 1. Picture-Number Test 2. Object-Number Test 3. First & Last Name Test MS—Memory Span 1. Auditory Number Span Test 2. Visual Number Span Test 3. Auditory Letter Span Test MV—Memory, Visual 1. Shape Memory Test 2. Building Memory 3. Map Memory N—Number 1. Addition Test 2. Division Test 3. Subtraction & Multiplication 4. Addition & Subtraction P—Perceptual Speed 1. Finding A's Test 2. Number Comparison Test 3. Identical Pictures Test RG—Reasoning, General 1. Arithmetic Aptitude Test 2. Mathematics Aptitude Test 3. Necessary Arithmetic Operations Test	RL—Reasoning, Logical 1. Nonsense Syllogisms Test 2. Diagramming Relationships 3. Inference Test 4. Deciphering Languages S—Spatial Orientation 1. Card Rotations Test 2. Cube Comparisons Test SS—Spatial Scanning 1. Maze Tracing Speed Test 2. Choosing A Path 3. Map Planning Test V—Verbal Comprehension 1. Vocabulary Test I 2. Vocabulary Test II 3. Extended Range Vocabulary 4. Advanced Vocabulary Test 5. Advanced Vocabulary Test II Vz—Visualization 1. Form Board Test 2. Paper Folding Test 3. Surface Development Test XF—Flexibility, Figural 1. Toothpicks Test 2. Planning Patterns 3. Storage Test XU—Flexibility of Use 1. Combining Objects 2. Substitute Uses 3. Making Groups 4. Different Uses
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Learning Styles Assessment

Test Materials

PROCEDURE & QUESTIONS © 2001 Creative Learning Systems

1. Respond to all statements according to your preferences when you are concentrating, solving a problem, learning something new and/or difficult, or working on a project or assignment that is difficult for you.
2. Mark each statement with T (True) F (False) or U (Undecided). Write the letters in front of each statement
3. Add up the number of your T (True) responses for each section and write the result (0-4) into the TOTAL T-Scores Box
4. Transfer your results (0-4) into the provided spaces on the LSA Response Sheet (1A-15B). Enter your results into the LSA-Adult Software programme on your computer
5. REMEMBER: This is not a test, there are no trick questions, no 'right' or 'wrong' answers

Code	Sample Questions*	
Q8(C-1)	Once I have developed a routine I like to stick with it.	
Q8(C-2)	I don't like changes to my work or study pattern.	
Q8(C-3)	I need daily routines to get my study or work done.	
Q8(C-4)	When I work on something difficult, I follow the same procedure each time.	
Q5(B-1)	School is very boring for me.	
Q9(E-2)	I don't like people in authority telling me what to do.	
Q5(B-4)	It's hard to find anything interesting I could study or learn.	
Q8(A-1)	I like to be told exactly how to do something.	
Q8(A-2)	My schoolwork is much better when I can follow instructions.	
Q8(A-3)	I prefer to receive clear directions before I start something.	
Q8(A-4)	For difficult tasks I need clear guidelines, then I know what to do.	
Q8(B-1)	I don't like to be told how to do things.	
Q8(B-2)	Unless I'm stuck, I'd rather try different solutions than ask for help.	
Q8(B-3)	I prefer to figure out how to get things done without following instructions.	
Q8(B-4)	I like to work things out for myself.	
Q8(B-1)	I don't like to be told how to do things.	
Q8(D-1)	I always like to find new ways of doing things.	
Q8(D-2)	I get bored when I have to follow the same routines.	
Q8(D-3)	I enjoy change and variety in my daily schoolwork.	
Q8(D-4)	When I have to do the same tasks, I try to do them differently each time.	
Q10(A-1)	I really like lectures and usually remember the content well.	
Q10(A-2)	I learn best when I hear the teacher explain something.	
Q10(A-3)	I like to listen to audio tapes, the radio or when someone reads to me.	
Q9(B-4)	I learn more and remember better if I can discuss it with a friend.	
Q10(A-4)	I can remember best by listening and discussing.	
Q10(C-1)	I usually say the words in my head when I am reading.	

Q10(C-2)	I understand difficult topics better when I can talk them over in my head.
Q10(C-3)	By talking to myself I often find solutions to my problems.
Q10(C-4)	When I worry I always have a lot of self-talk going on in my head.
Q10(D-1)	I like computer programmes with lots of printed text.
Q10(D-2)	I remember best when I can read about something.
Q10(D-3)	I enjoy solving crossword puzzles and/or word games.
Q10(D-4)	I like reading & prefer books & assignments with clear, written instructions.
Q10(E-1)	I really enjoy computer programmes with pictures, colours and graphics.
Q10(E-2)	Doodling helps me to remember what the teacher says.
Q10(E-3)	When I take notes I like to underline, highlight, use colours and my own symbols.
Q10(E-4)	I remember well what I see on TV, in a movie or video.
Q10(F-1)	I often daydream in class.
Q10(F-2)	I can quite easily picture the outcome when I have to solve a problem.
Q10(F-3)	Visualising helps me to remember or understand what I have seen, heard or read.
Q10(F-4)	When I worry I create images in my mind.
Q14(A-1)	Quite often I start a book, magazine or newspaper in the middle or at the end first.
Q14(A-2)	I prefer teachers who have a sense of humour and tend to go off on 'tangents'.
Q14(A-3)	I always like to know the outcome/ending or where I am going before I start.
Q14(A-4)	I remember best when I hear a story or see pictures about what I am learning.
Q14(B-1)	I hardly ever start reading a book at the end first or dip into the middle.
Q14(B-2)	I prefer teachers who stay on the topic and don't tell irrelevant jokes or stories.
Q14(B-3)	I like assignments that move step by step to an answer or a conclusion.
Q14(B-4)	Lots of details help me to understand difficult learning content.
Q15(B-1)	To really understand what I'm learning I need to reflect and ponder on it.
Q15(B-2)	When teachers ask me questions I have to think before I can give an answer.
Q15(B-3)	I hardly ever make snap decisions and don't interrupt in conversations.
Q15(B-4)	I always think about the consequences before I do something.
Q15(A-1)	I get bored if I have to think about something for too long.
Q15(A-2)	Most of the time I don't think before I speak or do something.
Q10(B-1)	I love debating and enjoy participating in discussion groups.
Q10(B-2)	For better understanding I need to talk about things I have learned.
Q10(B-3)	Talking out loud helps me to organise my thoughts.
Q10(B-4)	I remember best when I can explain to others what I have seen, heard or read.

* Provided on a selective basis i.e. only a number of questions from W-A and V-V dimensions are included, the original order is not preserved.

SAMPLE RESULTING REPORT FOR S05/V © 2001 Creative Learning Systems

This profile allows you to define your strengths in 24 basic areas you have responded to in a series of statements about yourself. You will recognise and be able to control the elements which can make or break your attempts to concentrate, to learn and study effectively and solve problems.

The following key indicates the conditions under which you perform best: *

	= strong preference (always needed)
	= preference (needed most of the time)
-----	= non-preference (avoid if possible/not applicable)
	= flexibility (adjustable to situations - comes natural)
	= strong adaptability (comes with effort - influenced by situation/context)
????????????	= result invalid (contradictory responses)

BIOLOGICALLY BASED ELEMENTS

Analytic ("Left")

Wholistic ("Right")

BRAIN DOMINANCE BRAIN PROCESSING

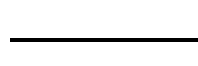
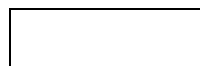
Sequential



Simultaneous

THINKING STYLE

Reflective



Impulsive

CONDITIONED / LEARNED ELEMENTS

CONFORMITY

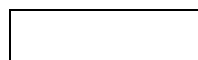
Conforming



Non-conforming

RESPONSIBILITY

Other-directed



Self-directed

VARIETY

Routine



Change-oriented

SENSORY MODALITIES

Verbal (External)



Words/Reading & Writing

Verbal (Internal)



Self-talk / Inner dialogue

Visual (External)



Seeing / Watching

Visual (Internal)



Visualising / Imagination

* The data is provided on a selective basis, i.e. the information concerning the W-A and V-V dimensions only is included.

PERSONAL REPORT AND PROFESSIONAL DEVELOPMENT GUIDELINES**
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If you act on the recommendations in your personal LSA report, you will not only enhance your learning abilities and problem solving skills, but also improve your academic achievement.

BRAIN PROCESSING:

You are a more simultaneous, right-brain processor who tends to engage the creative right hemisphere in problem solving more often. You need the big picture first and then the reasons for a study assignment before you are ready to start. You prefer studying with people who have a sense of humour, and your overall comprehension improves when you have concrete examples or hands-on techniques during the learning process. You are probably a multi-task learner who likes to do things simultaneously, and most of the time you can't be bothered with details. You probably thrive on 'creative chaos' and might be quite random in your thought processing. Usually you seem somewhat disorganised in your studies and it is most likely that you also have a time management problem. To improve your performance, plan study tasks, set priorities, practise time management, or follow certain routines, but make sure you feel good about them and enjoy the process.

THINKING STYLE:

Your way of thinking often depends on what you are supposed to do or learn, with whom you study, and mainly on the overall circumstances. You are hardly ever really impulsive in your thinking style and you generally prefer to reflect on things, analysing and contemplating all aspects of a learning assignment. This kind of flexibility enables you to adjust to adverse learning situations but you tend to use reflective thinking more often than not.

SENSORY MODALITY FLEXIBILITIES - AUDITORY (hearing), VERBAL* (external/talking, discussing), VERBAL**** (words), TACTILE (touching):**

You have quite considerable flexibility in your sensory modalities. This means you must use multi-sensory techniques when you are learning something new and difficult. For better understanding and longer recall you should always combine listening, talking, watching, reading, writing, actively participating, personally experiencing and feeling good about what you are learning and doing. When you are interested in an assignment or a learning task you find it much easier to concentrate and remember. This also helps you to feel good and stay motivated for difficult information intake. However, you need to be aware of one aspect of sensory flexibility: when you lose interest in a topic or a learning task, you switch off and the information just bypasses you.

VERBAL (internal - talking):

You often like to talk to yourself, particularly when you have to deal with tricky study situations or when you have to learn new and difficult material. Your memory improves and your understanding increases when you can have an inner dialogue about it. You probably don't need to talk to other people so much, you rather prefer to have a conversation with yourself - either in your head or out loud. You can be slowed down in your reading because you might be saying the words in your head when you read. Make sure that you avoid negative self talk and that you allow time for discussions with yourself when you study.

VISUAL (external - watching):

You have a strong preference for seeing/watching/observing and you probably love movies. Looking at things, watching what's going on and absorbing what you see is very important for your learning success. Your understanding of a text increases when pictures, diagrams and drawings are included. Rather than reading text passages you often like just to look at the pictures. To enhance your learning, use colours, pictures, magazines, films, mind maps and written materials with pictures and graphs. You remember well what you see, and observation might be another good way for you to take in new and difficult information.

VISUAL (internal - visualising):

You often use your imagination for problem solving, and visualising helps you to remember. Your understanding increases when you visualise what you have seen, written, heard or read. You have the ability to 'see' the solution for difficult situations in your mind. To improve your memory, enhance your study skills and reduce stress, allow yourself to practise your imagination, maybe even daydream (but not in class or during study time!). Use visualisation techniques, particularly when you have to learn something new and difficult. If you tend to worry through negative pictures in your mind, practise positive ones instead.

CONFORMITY:

You are a real non-conformist who always questions the status-quo. You like to do things 'your way'; you need study projects or assignments based on your interests, with frequent rewards, and little feedback from your teachers. As you don't like to 'fit in' and resent authority figures, make sure that you are not too closely supervised and controlled. Let the people in charge know that you learn best with a lot of freedom and prove that you are trustworthy. You learn and study more effectively when you have choices and understand why a task or assignment is important. Only when you respect a teacher/lecturer, when you are treated as a colleague and not spoken "down to", are you willing to follow rules and regulations imposed by your superiors or the institution. Being a non-conformist you deliberately don't 'fit in' and this can get you into difficulties with your teachers/authority figures. Please be aware of the fact that as a student you are expected to follow rules and regulations of the institutions you study at.

STRUCTURE/GUIDANCE:

Your need for guidance and direction while studying, solving problems or handling difficult learning tasks is dependent on what you do, with whom and why. Sometimes you are influenced by the overall structure of your learning tasks, sometimes by the guidelines set by others and sometimes by your own directions. Although you prefer to learn or study by following directions in a well structured set-up, your flexibility allows you to learn also in a self-directed way when required.

VARIETY:

You like change and probably get easily bored with the same routine. You need variety, and may rarely do things in the same way twice in a row. Consider this preference for variety when you are exploring a course of study or when planning a career. You need to learn and study in many different ways, with or without people, with multimedia, computers and under changing conditions. This will keep your learning motivation high.

- * * Provided on a selective basis i.e. the information concerning the W-A and V-V dimensions only (and a number of other qualities other studies associate with W-A personalities) is included.
- * * * In the Instrument referred to as Auditory, though all characteristics correspond to the Verbal Style
- * * * * In the Instrument referred to as Visual, though describes verbal information processing, i.e. reading and writing

Protocol Session

Distributed Materials

In this experiment we are interested in what you think about when designing. The experiment consists of two parts. In the first part we will ask you to solve one design problem. In the second part I will ask you to give a retrospective report about your design activities. If you do not understand please tell the experimenter now.

1. Design Task:

Client: your task is to design a house for a couple, whose ages are 29 and 34. The female is a dancer, and the male is a painter. They are sensitive to colors and beauty, enjoying contact with the natural environment. In order to make their dream house come true, they have a budget of about \$350,000.

Site: the site is located on the corner of the fully serviced home sites surrounded by a large central open space recreation reserve in Matraville, one of Sydney's south eastern newly desirable locations.

It is a trapezium in shape and slopes down to the edge of the recreation reserve. The site has a view of the flame trees in the recreation reserve and the whole reserve. The site area is 700m². The floor space ratio for this site is 0.65:1, so the maximum floor plan can be 455m².

House: the house is expected to be caressed by gentle sea breezes and screened by a stately grove of magnificent flame trees along the edge of the estate. A sculpture garden is required for the display of their art collections. According to the Randwick development control plan No4 the height of a dwelling house should not exceed a maximum of 9.5m. Your task is to give forms to and arrange the following spaces on the site with the approximate sizes:

Living/dining area:	40 m ²	Painter studio :	50m ²
Kitchen :	15m ²	Dancers studio:	50m ²
Bath :	10m ²	Observatory :	20m ²
Master bedroom :	30m ²	WC-shower :	9 m ²
Bedroom :	20m ²	Parking space :	36m ²

To start the design process you will be given the site plan. In addition, you will be given sheets of tracing paper. Your design task should proceed with drawing a series of sketches. You can go onto a new sheet whenever you need to. In this way you can try out different ideas, changing and developing the arrangement of spaces. By sketches we mean all kinds of drawings including just trifling traces of your pencil and small doodles besides main drawings. You are highly encouraged to draw anything.

Begin by freely copying the outline of the site onto the first sheet of tracing paper and numbering that page 1. Please number each sheet of tracing paper every time you go on to a new sheet. Try to remember why you drew things in each sketch and why you changed things in each subsequent sketch. Please save all your sketches (don't damage or erase) as we will ask you to describe them in the second part of the study. You can use as many sheets as you need to work out your design, and you may overlay a new sheet on a previous sketch if you want to preserve some features of a previous sketch.

2. Reporting Task

The objective of the second part is to obtain information on what you were thinking. We are going to ask you to recall and report on what you were thinking; from the moment you saw a design assignment to the time you finished it. We are interested in what you can actually REMEMBER about your thought process rather than guess on what you might have thought. We know remembering the whole process is very hard, so the videotape will be used to help you recall it step by step. Please report it verbally by pointing to your drawings on the TV screen, which will be showing a record of your sketching activity.

We hope you can give us an exact sequence of your thinking process. That means describing what you thought step by step. So please try to report on every stroke of your pencil and as much as you can, keeping in mind the following questions:

- 1) what you were drawing (or tried to depict)
- 2) which thoughts made you draw that
- 3) what you were thinking about while drawing it
- 4) what did you find in your sketches having drawn them and looking at them, and how these findings made you move to the next step, i.e. what in these sketches made you think and continue in a particular direction

You can pause the video when your speech lags behind it. Please tell me when you are uncertain about any of your memories. I don't want you to work on solving the problem again, just report all you can remember, including any little thought. Mention everything, even if you think it is irrelevant to your design. The more DETAIL you can remember, the BETTER.

It is not a conversation between you and me, so please try to remember and report as if I'm not here. I'm not here to judge what you have said or done, but to make sure the experiment is conducted in a correct way.

Do not rationalize your sketching activities at the time of reporting. Instead, just verbalize what you remember from the design session.

If you have any questions about the process, please ask me now.

OK. Now tell me all that you can remember about your thoughts from the beginning as you watch the videotape or designing. Please report loudly to the microphone.

3. The Questionnaire

Good! That was the experiment, and now we will have a little break. Feel free to take some time before you continue with the questionnaire. After it you are done. The questions follow:

Thank you for participating in this research again. We would appreciate if you gave us some information about yourself.

Present occupation _____

What is the typical design assignment you would do at the University? _____

Was the design assignment we gave you familiar to you? _____

How would you rate the difficulty of this assignment? (use a 1 to 10 scale) _____

Why? _____

How would you rate your performance in this design task _____

How would you rate the creativity of your design ideas, solutions _____

Did you have any problems expressing your ideas by freehand sketching? _____

What kind of tools/techniques do you generally use to support the expression of your ideas

Please briefly describe the issues that you considered relevant to the design task (*i.e. light, space, etc.*) and the strategies you used in designing (**for example:** *what part of the design task you considered first and why, what made you use writing or sketching etc.*)

Please briefly step by step summarize the process you followed to complete the design task. If you have come up with several design solutions repeating the same process, please describe either one. If not, please provide more details _____

How did you feel about designing? Any problems, constraints? _____

How did you feel about the process of retrospection? _____

Do you have any comments regarding the whole experiment? _____

Do you have any other comments? _____

That's all we need. Thank you very much and looking forward to working with you in future!

Assessment of Design Solutions

Distributed Materials

1. Assessment Guidelines

All dimensions are included on each rating sheet; there are twenty sheets to rate.

Please complete the ratings proceeding at your own pace.

1. Before beginning the rating process, please accustom yourself with the design brief
2. Browse through the range of student drawings to familiarize yourself with the projects and establish your own impression of the overall range of project merit represented
3. It is important that you rate the projects relative to one another (for each of the two student groups separately) and then with respect to the design brief and your domain expertise, and not according to some absolute standard for excellence
4. Rate all projects according to the dimensions described on each sheet before moving to the next rating sheet
5. The projects may be selected for rating in any random order and the order may be different for each sheet as you go through the rating process
6. When you have finished the ratings, please make sure that all project numbers and ratings are complete, and return the forms
7. Any additional comments or observations arising during the rating process are welcome and will be noted down by the researcher

Please remember that the difficulty of a design task varies with the background and repertoire of the designer. A pre-architect may not perform well on architectural design briefs as the performance is affected by their prior learning experience. Please make your judgements in terms of the measurement of achievement (or how well the relevant skills and knowledge have been learned) or/and considering the individual's natural potential.

2. Rating Sheet

Name of the Judge _____ Student's Name _____ Code _____

Assessment Dimensions (constraints)	Score			Assessment Dimensions	Score		
Client: (1) dancer; (1) painter				Constraints met* (adjusted)			
Site analysis: (1) orientation (north, sun, noise, etc); (1) slope				Creativity/Originality			
House: (10) incorporation of 10 functional spaces; (1) views/placements; (1) dimensions (vertical & horizontal)				Complexity/Elaboration			
				Flexibility and Fluency			
				Functionality and Knowledge			
				Technical Merit			

Please use a 4-grade scale for the following dimensions (1 is the lowest score)

Creativity and Originality. Please rate design drawings in terms of unusual, uncommon and novel ideas, suggestions or solutions, new relationships among ideas, combining remote ideas, etc

Complexity and Elaboration. Ability of participants to articulate ideas in terms of related & composite parts; developing the basic idea/object into details and looking into the implications of ideas

Flexibility and Fluency. Refers to producing a variety of ideas, solutions, possibilities, interpretations, by shifting perspectives, methods, designs, approaches in the direction of thinking and valuing multiple viewpoints and possibilities

Functionality and General Knowledge of Design Process. The degree to which the designed space is functional. Refers to displaying the design process knowledge and skills, including skill in task clarification, concept generation, evaluation and refinement, and overall skill displayed in execution of design process

Technical Merit of Design Drawings. Measure evaluating the degree to which the project, overall, was good technically.

* this is the final average score for all constraints met, completed by the researcher