The role of gestalt theory in Industrial Design students' hierarchical thinking in the design process

by

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Declaration

The research project described by this dissertation was carried out in the Faculty of Education, University of Pretoria, from January 2013 to August 2015, under the supervision of

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I, **Jan Hendrik Dubery** declare that the dissertation, which I hereby submit for the degree Master of Education in the Department of Science, Mathematics and Technology Education at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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Abstract

This dissertation reports on the role of gestalt in internal mental processes of Industrial Design students during the early phases of their design processes. Design thinking is a contemplative yearning to transform the world, exploiting a combination of aesthetics, ethics and knowledge. However, the thinking behind design is not fully understood, and designers themselves struggle to explain how they make the connections that direct them to the final result and why those judgements are rational. Design thinking in education has not been well addressed especially the education of designers. Research found the problem solving strategies used by novice designers and the theoretical models described in curriculum documents on the design process to be significantly different and suggested that students must be explicitly taught thinking skills to assist them in designing cognitively demanding tasks. However, there is currently insufficient cognitive account on the interwoveness of intentions, the things novice designers think about and the order in which they think about them during the early phases of the design process.

The aim of this research was to examine and describe the ways in which Industrial Design students reacted on their internal and external task environment to establish coherent decision making. It is not clearly understood through the literature on design cognition what the nature of novices' hierarchical thinking is, or what role gestalt guided by global precedence plays in their design thinking. The importance of understanding novice designers' hierarchical way of thinking might assist educators facilitating design students' thinking, to become efficient problem solvers.

The parallel mixed methods approach to this quasi-experimental case study was based on concurrent think-aloud protocol studies (TAPS) to capture designers' moment to moment thought processes together with the production of concurrent sketches. As a result, the mixed methods approach provided me with the opportunity to summarise the way and the order in which designers thought about things in the design task environment.

This research report presents and discusses the salient results of three protocol studies where three groups of Industrial Design students working in pairs to solve an ill-structured design problem. The conceptual framework that was adopted for this study was based on the hierarchical thinking model which was conceptualised as a result of empirical research on expert designers to establish the links between various levels of intentions and physicality.

The results suggest that coherent gestalt was instantiated when extended design cognition actions synergistically integrate internal processes and external sources of information to solve design problems. The gestalt theory of global precedence that are characterised by hierarchical levels was evident as the Industrial Design students' thoughts developed. Their hierarchy of thoughts consisted of four levels, namely aspectual intentions, functional intentions, physical elements and implementation intentions. In each of these hierarchical levels Industrial Design students thought of different things to assist them to understand a given problem and to find a coherent solution in the form of a conceptualised artefact. This confirms the centrality of global precedence in gestalt theory. It furthermore confirms the suitability of the four-level hierarchical model suggested by Haupt (2013) in an expert context, to trace and map the thoughts and cognitive behaviour of Industrial Design students.

The practical contribution of this study, about Industrial Design students' hierarchical thinking in the early phases of the design process, could be seen as an opportunity for design educators to develop design activities where students can consciously practice making links between various levels of intentions, functionality and physicality. This teaching strategy might allow Industrial Design students to structure their problem solving activity and reduce the cognitive pressure, in order to be more efficient and productive with their time. By making design students consciously aware of these hierarchical levels might allow educators to facilitate design students thinking, to mirror expert design behaviour.

Key words: Aspectual intentions; design problem solving space; design task environment; extended design task environment; functional intentions; gestalt; hierarchical thinking; implementation intentions; novice designers; physical elements; problem solving; problem structuring.

Table of Contents

Chapter 3: Research design and methodology

List of Appendices

List of Figures

List of Tables

List of Acronyms

TAPS: Think-aloud-protocol-study

CTM: Computational Theories of Mind

LTM: Long term memory

Chapter One

Introduction orientation

1.1 Overview of the chapter

The purpose of this study is to gain insight into the role of gestalt in novice-designers' hierarchical ways of thinking during the early phases of the design process. This might provide researchers, educators and members of the community of design practitioners with information about novices' ability to align their abstract thoughts and subsequent concretisation; this in turn could lead to a better understanding of how to improve the education of designers.

This chapter introduces the importance of understanding the cognitive skills involved in novice designers' ability to solve design problems appropriately. This includes a discussion of the role played by industrial designers in innovating, creating and implementing new ideas. This is followed by a description of case studies showing how novice designers structure and solve design problems.

The focus then moves to understanding the things expert designers think about, and the order in which they think about them, in order to solve design problems during the early phases of the design process. The problem statement, the rationale for the study and the research questions are then addressed. The research methodology and the key concepts of this study are explained, and the chapter ends with a short description of the theoretical basis of the conceptual framework, and an outline of the organisation of the study.

1.2 Background

Design as an industry has a great responsibility in the economic development of South Africa (Stassen, 2012). Industrial designers' inherent ability to innovate, create and implement new ideas means that design should be viewed as a discipline that can be a leading contributor to incremental economic growth, rather than just a lag supporter of other sector-based growth (Smit, 2010). The current success of design excellence in business internationally, with examples such as Apple, IBM and Sony as forerunners in the electronic market, indicates that business today values a culture of design (Stassen, 2012). Financial restrictions and a lack of awareness and acknowledgement of design as an industry contribute to unsuccessful designs. This was a finding of the International Design Alliance World Design survey (Viljoen, 2010), conducted in 2008 to determine the contribution of design in South Africa.

The survey highlighted the fact that the design industry in South Africa needs an integrated view of skills development, in both secondary and tertiary environments and in the workplace itself. Tertiary institutes offering design courses need to find appropriate and contextually satisfactory data that will inform theoretical and practical courses, so as to enhance and promote excellence in teaching and the attainment of design knowledge and skills (Economou & Joubert, 2009). If tertiary institutions that specialise in industrial design education fail to understand the cognitive skills required by their novice designers, they may fail to develop their problem-solving skills appropriately. This, in turn, may lead to these novice designers producing mediocre and weak design solutions. Current literature on design cognition has been effective in classifying what designers do, but it has been less effective in classifying how they do it (Eastman, 2001).

I therefore decided to locate this study within the general need in industrial design education for design excellence; this design excellence may enhance the quality of people's lives and conceivably also direct the way they live, through the use of the artefacts that designers conceptualise. More specifically, this study aims to gain insight into the hierarchical ways in which novice industrial design students think in the early phases of the design process, guided by the global precedence principle of gestalt thinking. This might provide researchers, educators and members of the design practice community with information about novices' ability to develop abstract thinking into concrete designs by maintaining coherence.

1.3 Rationale and problem statement

I derived my research problem from preliminary reading in the fields of extended design cognition, gestalt theory, and novice design behaviour. The literature on design cognition shows that much more research has been conducted on expert designers than on novice design cognition (Eastman, 2001). Current literature on design cognition in novice designers does not sufficiently explain which abstract aspects they contemplate or the way in which they connect intentions with their physical environment as the driving force behind generating, selecting and developing ideas.

Design thinking is a contemplative yearning to transform the world, exploiting a combination of aesthetics, ethics and knowledge (Nelson & Stolterman, 2003). The thinking behind design is not fully understood, and designers themselves struggle to explain how they make the connections that direct them to the final result and why those judgements are rational (Hegeman, 2008). Furthermore, design thinking in education, particularly the education of designers, has not been well addressed (Eastman, 2001). In support of Eastman, Welch and Lim (2000) found a significant difference between the problem-solving approaches used by novice designers and the theoretical representations described in curriculum documents on the design process. Welch and Lim (2000) argue further that students must be given explicit teaching in thinking skills to assist them in designing cognitively demanding tasks. However, a longitudinal study on the effects of education on design cognition provided evidentiary support that students' design behaviour trends towards expert-like practice (Williams, Lee, Paretti, & Gero, 2011). The study focused on problem definition and scoping activities, not on identifying hierarchical connections for a coherent design solution.

Empirical studies with a computational theory of mind (CTM) approach, carried out on novice design students (Lloyd & Scott, 1994; Popovic, 2003, 2004) when they are given an ill-structured design problem, show that novices tend to base their problem structuring on common-sense knowledge which is domain-independent. This is because novices do not have immediate access to domain-specific knowledge (Popovic, 2003). They typically perform assignments step by step, using knowledge in a 'lengthy' way by recasting the problem several times before solving it. I want to investigate the connections and coherence in this 'lengthy' process between the various intentions and the physical elements that participants consider in order to get to hierarchical thinking.

Many researchers (Adams, 2001; Atman, Chimka, Bursic, & Nachtman, 1999; Christiaans & Dorst, 1992) have made inputs specifically into understanding novice designers' design thinking during the early phases of the design process. Adams (2001) found that both the length of time spent repeating and the kinds of repetitions novices make correlate with the quality of their design solutions. However, the computational approach of Adams (2001) to design cognition does not explain how novices make repetitive connections between hierarchical levels to find a coherent design solution.

The research conducted by Christiaans and Dorst (1992) explored the function of knowledge in industrial design engineering. From protocol studies of industrial design students they learnt that some students are unable to progress beyond information gathering to problem solving during the early phases of the design process. Christiaans and Dorst (1992) also followed a computational approach to design cognition. They do not however, explain or suggest how novices can make connections to move beyond information gathering to a coherent solution. In their studies, Atman et al. (1999) found that a large percentage of the industrial design students demonstrating this type of behaviour produced sub-standard solutions.

In another study, Atman and Bursic (1996) used first-year engineering students to determine whether reading a chapter on the engineering design process would help students learn how to solve ill-structured design problems. With their implied computational approach to cognition, they discovered that even casual interventions (e.g. reading a textbook) can positively influence what things novices think about and the order in which they think about them. Furthermore, in the context of using design methods, Radcliffe and Lee (1989) realised that an intervention aimed at training novice designers to develop a systematic method can help them to design effectively. However, from an implied computational approach to design cognition, they do not explain how connections between hierarchical levels can help novice designers to design in a coherent and effective way. The shortcoming in all these referenced studies is that there is no cognitive account of the interwovenness between intentions, the things novice designers think about, and the order in which they think about them during the early phases.

The question arises: How do expert designers manage to find coherence among all the different things they think about? According to Haupt (2013), it is aspectual intentions that mechanise such coherence through gestalt. The study of gestalt is a branch of psychology involved in higher-order cognitive procedures related to behaviourism (Carlson & Heth, 2010). Coherence refers to the logical and conscious alignment between the various levels of thinking. By understanding the hierarchical order in which novice designers think and the role of gestalt, educators may be able to structure their teaching in ways that would develop novices' complex and dynamic thinking skills.

1.4 Conceptualising the study

Novice designers for this study are third-year undergraduate industrial design students. Novice designers are designers who have acquired some domain-specific knowledge and procedures that they can activate for a particular task. The phenomenon I looked at was novice industrial designers' hierarchical thinking guided by their quest for coherence and fit-for-purpose solutions to design problems during the early phases of the design process. For this purpose, I examined the verbal and visual representations produced by novice industrial designers and focused on the relationship between their various types of intentions, the content of their thoughts represented in their verbal utterances and sketches, and perceived physical elements.

1.5 Research questions

This study is directed by the main research question within a semi-experimental setting, studying the protocols of three pairs of novice industrial designers via research. The following main research problem was formulated:

What is the role of gestalt in Industrial Design students' hierarchical thinking in the design process?

To address the main research question and limit its scope, the following sub-questions guided the inquiry:

1. What aspectual intentions play a role in novice industrial design thinking?
2. How do novice industrial designers link aspectual intentions with functional intentions?
3. How do novice industrial designers link functional intentions with physical elements?
4. How do novice industrial designers link aspectual intentions, functional intentions and physical elements with implementation intentions?
5. What is the distribution of the various types of intentions amongst the problem-structuring and problem-solving phases?

1.6 Significance of the study

The significance of this study lies in investigating the usefulness of applying a new model of hierarchical thinking in a design context with novice designers. Hierarchical thinking stems from hierarchy theory, which is a branch of general systems theory, which focuses on ranks of organisation and distributions of scale (Allen, 1996). Allen (1996, p206) defines the concept *hierarchy* as a "system of persons or things ranked one above the other". Hierarchical thinking can thus be understood as seeing the world through systems of dominance or relative importance. Distinguishing hierarchical structures requires an understanding of the psychological concept of global precedence in gestalt thinking. The assumption of global precedence is that the processing of information proceeds hierarchically from "global structures towards analysis of local properties" (Wagemans, Feldman, Gepshtein, Kimchi, Pomerantz & Van Leewen, 2012, p.1221).

I want to investigate the role played by global precedence in designers' conceptual understanding; that is, the aspectual intentions determined by their intentions as the global (holistic) dominator over all other choices in novice design thinking. Current literature on design cognition in novice designers does not adequately explain what they think about and the ways in which they connect intentions with their physical environment. Understanding novice design students' hierarchical thinking is important because it will allow educators to facilitate such thinking, enabling the students to become effective problem solvers.

1.7 Research methodology

1.7.1 Research design

In order to answer the research questions, quasi-experimental protocol studies were conducted using mixed methodologies from a critical realist perspective. The case study which I have selected allowed me to obtain a deep understanding of the internal mental processes of novice industrial design students in the early phases of their design processes. The purpose of this type of research is to understand students' hierarchical thinking, which can be associated with the interactive perception of an external environment and gestalt. This was to be done using existing theories as building blocks, so as to add to the knowledge of generic design behaviour, giving priority to practical knowing resulting from my non-participatory role of observer. The main aim of using concurrent protocol studies was to objectively describe the hierarchical processes of the novice designers in this study; three separate group protocol studies, consisting of verbal utterances and roughly drawn sketches as well as realism principles, were carried out. This protocol study concept is grounded in Campbell's philosophy of critical realism (Blessing & Chakrabarti, 2009) and is used in social research conditions where it is not feasible to employ true experiments.

I was concerned about conducting true experiments in this study, because they would have required artificial situations, making it impossible to stimulate the naturalistic behaviour of the participants in order to satisfy my research questions. I therefore had to modify the standard experimental research design using a quasi-experimental case study. This allowed me to have control over the selection of participants (third-year industrial design students). I also had control over the design tasks that participants had to solve, but did not have control over when they would choose to interact with their contexts.

I used a mixed-method approach which was best suited to answering my research questions. The qualitative theoretical drive of the study is primarily deductive indicated by QUAL (Creswell, 2003; Morse, 2010), because the research questions focus on explaining instances, exploring relationships and occurrences and sequencing implied questions about mechanisms. The selection of a QUAL + quan mixed method approach provided me with the tools to focus on particular phenomena and cognitive processes, as well as the tools to focus on typical characteristics and shared concepts and themes (QUAL). It also provided me with the opportunity to count incidents, map the distribution of occurrences on a timeline in terms of themes and sub-themes, and determine sequences of events (quan).

1.7.2 Selection of participants

A target group of six third-year industrial design students from the Faculty of Art, Design and Architecture (FADA) at the University of Johannesburg (UJ) were purposefully selected. The criteria used for selecting this purposive sample were based on the students' academic performance. In order for second-year industrial design students at UJ to pass and continue their studies in the third year, they need to have developed sufficient knowledge and skills to allow them to conduct the design process smoothly. The design process necessitates the correct use of both critical (analytical) and creative (lateral) thinking to come to a decision on the diverse requirements of users, manufacturers and the environment (N.A, 2011).

I accordingly asked UJ's industrial design lecturers to identify the top-performing students in Product Design II, based on the final assessment mark awarded to the students at the end of their second year. The six students in third year, based on this final assessment mark, were asked to participate in my protocol study. The reason for selecting third-years was based on the premise that higher-order design cognition in tertiary education was more likely to be found in top performing students than in poorly-performing students (Cross, 2004).

1.7.3 Data collection and instruments

My primary data collection strategy was to conduct quasi-experiments in a design context (Cohen, Manion, & Morisson, 2007). This entailed the provision of an ill-structured design task for the three pairs of novice designers. They were required to think aloud and produce rough sketches at the same time. The verbal and visual data were collected in three phases (as discussed in Section 3.3.4), with each phase entailing a separate concurrent think-aloud protocol study (TAPS) for the three pairs of novice designers. For studying design activity, think-aloud protocol study (TAPS) is the most widely accepted of all observational research methods in recent years (Cross, 2004; Gero & McNeill, 1998). It is believed to provide direct access to the participants' thoughts (Atman & Bursic, 1998). The basic acceptance of TAPS is due to the fact that it enables participants to verbalise their thinking in a manner that does not alter the order of thinking facilitating the completion of a task, and can therefore be admitted as valid data on thinking (Ericsson & Simon, 1993).

Protocol studies are conventionally conducted in a true experimental setup, which is involves isolating participants in laboratory conditions in order to free them from the need to communicate (Guba & Lincoln, 2008; Simon, 1996). However, I chose to base my protocol study on the critical realist approach of the research methodology used by Haupt (2013), because it creates a natural task environment. Haupt (2013) adjusted conventional experimental protocol studies in order to enhance the naturalistic behaviour of participants as they would normally manifest it in their design studio on campus. Haupt (2013) found that, when participants' natural behaviour was elicited, relatively normal and undisturbed structures of thought about sequences of action could be achieved.

The TAPS protocols consist of five steps, capturing both verbal and visual data simultaneously (Goel, 1995; Haupt, 2013). The following steps are based on Haupt's (2013) adapted method for conducting TAPS protocols. The first step required preparing an ill-structured design brief that had to be stimulating, realistic, suitable for the participants, not too large, achievable in the time available (± 2 hours), and within my expertise as researcher (Dorst & Cross, 2001). The second step involved preparing a setting to effectively elicit novice design behaviour, where the participants could receive instructions to think aloud and make sketches. The third step consisted of a period in which the participants physically interacted with their environment. The fourth step commenced after the physical interaction, when the participants started to work at solving the design problem in pairs as the natural dialogue between them enhanced the flow of their thoughts. I treated these dialogues as data regarding the process as a whole, by not analysing the utterances of individual participants (Van Someren, Barnard, & Sandberg, 1994). The fifth step involved the process of transcribing the verbal protocols captured on video and making copies of the concurrent sketches made by the participants as preparation for data analysis. Each protocol was recorded on video camera where voice data, general movements and gestures, sketching and writing of participants were captured. The video camera technician focused on recording the sequential verbal utterances, writing and sketching in order to capture all representations.

1.7.4 Analysis and interpretation

Data analysis and interpretation in this study involved organising and explaining the recorded audio and video information in terms of the theory embedded in my conceptual framework. I derived my interpretation from the content of the participants' thoughts as represented in their verbal and visual data. In order to organise data so that emerging patterns or connections could be identified (Goel & Pirolli, 1992; Haupt, 2013) and to reduce the data to manageable amounts without loss of complexity (Haupt, 2013; Tashakkori & Teddlie, 2009), it was necessary to carry out data structuring. This involved, firstly, editing, segmenting and summarising and, secondly, coding notations (remarking, codes, categories and themes), and developing connections amongst a priori categories.

Data interpretation was driven by the theory of global precedence in gestalt. The assumption is that conceptual insights are characterised by a hierarchical system with nested relationships. In applying this insight to the interpretation of the data, I had to identify the more global concepts which involved the aspectual intentions at the top of the hierarchy.

The aspectual intentions had to form the essence of the participants' drive to find a solution. Thus, aspectual intentions had to precede the local properties, which consisted of functional intentions, physical elements and implementation intentions. After interpreting a coherent and fit-for-purpose solution through hierarchical thinking it was necessary to determine whether abstract thinking developed more closely to concrete thinking.

1.7.5 Quality assurance strategies

To ensure that the data in research is legitimate, quality assurance has to be carried out. This involves the verification of measures (Onwuegbuzie & Teddlie, 2003). To ensure that the use of a mixed-methods approach did not reduce the study's qualitative measure of transferability, I aimed to achieve a logical and appropriate integration of rigorous and systematic qualitative and quantitative research strategies (Onwuegbuzie & Teddlie, 2003). I endeavoured to present sufficiently thick, rich descriptions to enable the readers of this study to determine whether transferability had been achieved (Cohen et al., 2007). I also tried to use temporal identification of participants' verbal utterances with snapshots taken from the video recordings on the sketches made by the participants in order to enhance triangulation.

1.8 Clarification of key concepts

Important terminology underlying the theory and assumptions of the dissertation is explained here, in order to facilitate an appreciation of the purpose, focus and potential contribution of this study.

Aspectual intentions**:** Design considerations, which Haupt (2013) labelled 'aspectual intentions', are based on Dooyeweerds' aspects of reality. Aspectual design intentions refer to qualitative abstractions that are ways of seeing things that are important to aim for in a solution (Basden, 2000).

Design problem-solving space**:** The design problem-solving space is the mental space where designers access information by memory recall as well as from their perception of the physical environment as they structure the problem and generate preliminary solutions (Kirsh, 2009).

Design task environment: A design task environment according to Kirsh (2009) is an abstract structure that corresponds to a design problem. 'Environment' refers to people attempting to improve their task performance by adapting their behaviour to environmental constraints. This means that what designers know or do not know, and the information they can or cannot access and use, form part of their design task environment.

Extended design task environment: This is an abstract structure that corresponds to the interactivity between the internal processes of the designers and the environment of a design problem. This interactivity means that there is a systematic flow between environmental stimulation and existing socio-technological knowledge from field-specific environments stored in the long-term memories of the designers (Haupt, 2013).

Functional intentions: The functional intention defines the purpose or function of artefacts: they are objects meant for doing things in relation to the designers' intentionality (Kroes & Meijers, 2002). Thus, the functional intention is an answer to the question 'What is it for?' (Kroes, 2006). Prototypical examples would be: to sit on, to store vegetables in, and to sleep on.

Gestalt: Gestalt is a branch of psychology which originated in Germany in the 1920's. The aspects of gestalt theory that interest designers are those that are linked to gestalt studies of visual perception. These are mainly the relationship between the parts and the whole of visual experience. The visual world is so multi-dimensional that the human brain has developed strategies to deal with confusion. The human brain adopts the simplest solution to a problem, and one of the ways it does this is to group items that have certain qualities in common. Gestalt is concerned with how these groups develop and what influence they have on perception (Carlson & Heth, 2010). The stronger the grouping, the stronger the gestalt or coherence that creates unity in the mind. For instance, a piece of music has a gestalt, because it has qualities of tune and melody which none of the individual notes have.

Hierarchical thinking: The notion of hierarchical thinking stems from hierarchy theory, which is a branch of general systems theory, which focuses ranks of organisation and distributions of scale (Allen, 1996). Allen (1996) defines the concept of hierarchy as "a system of persons or things ranked one above the other". Hierarchical thinking can thus be understood as seeing the world through systems of dominance or relative importance.

Ill-structured problems: An ill-structured design problem means that the problem is not provided with sufficient information in the design brief (Cross, 2007). Designers will typically rely on their own interpretation of a design brief to ascertain which social, technical and environmental aspects may constrain, limit and challenge them while directly perceiving the physical environment in which the problem is embodied (Haupt, 2013).

***Implementation intentions*:** Implementation intentions are intentions that people declare in activities that they think may support them in achieving other goals (Gollwitzer & Schaal, 1998). Physical elements and aspectual and functional intentions are linked and ordered in ways that help expert designers to realise their implementation intentions, and this enables them to make and affirm their commitment (Haupt, 2013).

Novice designers: Novice designers for this study are third-year undergraduate industrial design students. Novice designers are designers who have acquired some domain-specific knowledge and learnt some domain-specific procedures which they can activate for a particular task. However, they do not have task experience and expertise and consequently perform assignments step by step and apply their knowledge in a 'lengthy' way by recasting the problem several times before solving it (Popovic, 2004).

Physical elements**:** Physical elements fit into the physical or material understanding of the world which aims to describe things as they are. The attributes of a physical element are an answer to the question 'What is it?' (Kroes, 2006). A physical element has, for example, a specific weight, shape, size and number of components, is made from specific materials and has mechanical properties (Kroes & Meijers, 2002).

Problem solving: Problem solving refers to the phase in which information and details relating to the problem are taken into consideration. The size and complexity of the design problem requires the problem-solving phase to be subcategorised into three different phases, namely preliminary design, refinement and detail design (Goel & Pirolli, 1992; Zeiler, Savanovic, & Quanjel, 2007).

Problem structuring: The problem-structuring phase involves searching for information that has not been fully provided in the design brief, and which is needed in the design problem space for a full understanding of the problem (Goel & Pirolli, 1992).

1.9 Theoretical framework

The theoretical basis of my conceptual framework is the psychological concept of global precedence in gestalt thinking in an extended cognition context. Carlson and Heth (2010) explain that the features of gestalt theory that interest designers are its studies of visual perception, primarily the relationship between the parts and the whole of visual experience. The visual world is so multi-dimensional that the human brain has developed strategies to deal with confusion, such as adopting the simplest solution to a problem. One of the ways it does this is to group items that have certain qualities in common. Gestalt is concerned with how these groups are formed and what influence they have on perception (Carlson & Heth, 2010).

The role of gestalt theory in this study is to provide a descriptive framework that will allow precise operational definitions and experiments. Wagemans et al. (2012) proposed the concept of part-wholes being attached on an orthogonal hierarchical tree, in which a gestalt represents the highest level and its sub-structures the levels of a branching tree. Distinguishing hierarchical structures requires an understanding of the gestalt principle of global precedence. Global precedence is a simplicity-based hypothesis which asserts that the processing of information proceeds from "global structures towards analysis of local properties" (Wagemans et al., 2012, p1221). Conceptual insights imply a hierarchical system with nested relationships. The globality of conceptual content relates to the level it dominates within the hierarchy: properties at the highest of the hierarchy are 'more global' than those at the lowest, which are in turn 'more local'.

In a design context, designers are often given ill-structured design problems, which means they are not provided with sufficient information in their design briefs (Cross, 2007). Designers hence frequently rely on their own interpretation of the client's instructions and intentions. By satisfying these intentions, designers gain confidence in the functional suitability of the imagined artefact (Newell & Simon, 1972). Such confidence in their own decision-making is based on global precedence. This guides the coherent application of what they perceive to be the physical elements that are most likely to realise the abstract intentions that overarch the design intentions (Haupt, unpublished). Haupt (2013) used this conceptualisation of gestalt as the basis for a framework for classifying the levels at which expert designers' thoughts develop in an extended cognition context.

The theoretical assumptions of extended design cognition have been developed through the integration of computational and embodiment theories and a focus on the interactivity between internal processes and external sources (Haupt, 2013; Kirsh, 2009; Shani, 2012). This notion of interactivity allows designers to move between environmental stimuli and existing knowledge from domain specific environments stored in their long-term memory (Haupt, 2013). The implication of such interactivity is that it supports the designer's need for perception (externally-driven sources) as well as the kind of internal and linear strategies that are needed in order to structure a coherent solution. The two main aspects of this theory on which my conceptual framework is based are the notion of the design task environment and that of the problem space.

1.10 The extended problem-solving space

The design problem space is the space where designers access information by using memory recall and by perceiving the physical environment as they structure the problem and generate preliminary solutions (Kirsh, 2009). A problem-solving space can accordingly be seen as a modelling space that is influenced by the psychological limitations of the information-processing system and the task environment (Goel, 1995). Designers' design strategies, including the use of external resources such as verbal utterances, gestures and sketches, usually emerge from this space. Goel and Pirolli (1992) identified twelve invariants commonly found in the construction of the design problem spaces; abstraction hierarchies is one of these.

For the purpose of this study, I only focused on the abstraction hierarchies of novice designers, in order to explain how they thought about the artefacts they were designing as a structure for the design problem space, which Haupt (2013) further elaborates on. This extended theory of Haupt's (2013) hierarchical thinking entails expert designers' linking of internally-driven cognitive processes with the externally-driven cognitive processes that the design task environment provides. I adapted Haupt's (2013) extended cognition theory about hierarchical thinking into a conceptual framework, because I wished to find information about the following: themes and patterns of global precedence in gestalt thinking; aspectual intentions meeting functional intentions; functional intentions meeting physical elements; and finally aspectual and functional intentions and physical elements meeting implementation intentions. My goal was to gain insight into the ways in which novice industrial designers internally integrate their intentions (aspectual, functional and implementation intentions) with their external environment when encountering perceivable physical elements.

1.11 Outline of the remainder of the dissertation

This thesis consists of five chapters dealing with the following:

Chapter Two. In Chapter Two I discuss the theoretical concepts in design cognition literature that form the basis of the conceptual framework of this study. I also review what has been written about the hierarchical ways in which novice designers think in the early phases of the design process and discuss the conceptual framework for the study.

Chapter Three. In Chapter Three I describe, explain and justify the research design of the study, the data-gathering methods, the paradigmatic perspective, sampling, instruments, validity issues, and the ways in which data collection and data analysis were conceptualised and conducted.

Chapter Four. Chapter Four presents the findings, explains how the data was interpreted and provides the theoretical underpinning of the inferences that were made in order to answer the research questions.

Chapter Five. In Chapter Five I discuss the findings in relation to the formulation of the research questions, the literature and the conceptual framework. I also provide recommendations for developing educational strategies for industrial design programmes.

Chapter Two

Literature review

2.1 Overview of the chapter

The purpose of this chapter is to gain insight into the hierarchical ways in which design students versus industrial design students think in the early phases of the design process. This might inform researchers, educators and members of the design practice community about novices' ability to think abstractly and then concretise these abstract thoughts; this information could, in turn, lead to a better understanding of how to improve the education of designers. The literature on design cognition shows that a great deal of research has been conducted on expert designers relative to the small amount carried out into novice design cognition (Eastman, 2001). Furthermore, current literature on design cognition has been effective in classifying what designers do, but it has been less effective in classifying how they do it (Eastman, 2001).

In order to understand the observed behaviour through the filter of my interests, I also discuss three theories in design cognition in this chapter: these are computation, embodiment and extended cognition against its historical background. I also discuss design as a special kind of problem solving (Goel & Pirolli, 1992), one that requires significant problem structuring because of the lack of information involved. This notion concerning the design process originated in computation theory and consists of two distinct cognitive phases, which I explain further on in more detail.

I then review the history of gestalt theory, the controversy around gestalt, contemporary gestalt approaches and how the insights of gestalt enable researchers to distinguish hierarchical structures in the thinking of designers. After that, I discuss the conceptual framework for this study, which is based on Haupt's (2013) hierarchical model of design thinking. Haupt (2013) synthesised theoretical ideas related to gestalt psychology within an extended design cognition context, which I explain. My object in using this conceptual framework is to establish whether Haupt's (2013) model of hierarchical thinking in a design context can be useful to novices.

2.2 Design cognition

Designing as a cognitive activity can be seen as a problem-solving activity in which the design problem and its solutions co-evolve during the design process (Zeiler, Savanovic, & Quanjel, 2007). In other words, the design process iteratively scans the problem and the solutions, using both as the foundation for a coherent fit when evaluating different options (Maher & Tang, 2003). Wagemans et al. (2012) found the moment of understanding to be the moment when the problem solution is coherently structured and some degree of global precedence occurs, which in turn drives the gestalt thinking in a design process.

There are several ways of modelling the design process. Dorst (1997) proposed that design is a process that typically starts with an investigation into and a breakdown of the problem, followed by an intentional linking of the interconnections between the various components of the problem. Designers then solve sub-problems in isolation before combining partial solutions coherently into an overall problem solution (Goel & Pirolli, 1992). Design success in general results from a reasonably structured thought process that is solution-focused rather than problem-focused. This solution-focused thought process comes with education and experience in design (Cross, 2001a). My approach to the study of design is to ask how external elements can be captured and represented internally in such a way that they become meaningful to the designer and those involved in problem-solving situations (Haupt, 2013).

Meta-theoretical underpinnings to design cognition developed amongst the design research community as a result of industrialisation and the integration of scientific knowledge into the design of new products such as steam engines, the products of the automotive industry and electric globes (Visser, 2004). Researchers in the 1960s (Cross, 1982, 2001b; Cross, Naughton, & Walker, 1981) started to reflect on the fundamental concepts of design cognition in an attempt to improve their understanding of the nature of designing.

Researchers found that design thinking has distinct characteristics that set it apart from other cognitive activities (Cross et al., 1981). Furthermore, instances of design thinking in different design situations share commonalities but also display differences. What is more, the commonalities among all the kinds of design thinking are sufficiently generic, and sufficiently distinct from the qualities of other mental activities, to allow design to be viewed as a specific, generic mental activity (Visser, 2009). I will now discuss three different theoretical approaches to design cognition, namely information processing, embodiment and extended cognition against its historical background.

2.2.1 Information processing

The classical Computational Theory of Mind (CTM), also known as information processing, developed as the first approach to design cognition. Information processing focuses on establishing the superiority of scientific knowledge by using the experimental approach, which restricts the view of representation to a purely linear, prescriptive and predictable activity (Ericsson & Simon, 1993). Researchers (Newell & Simon, 1972; Simon, 1996) viewed scientific knowledge as an integral part of designing products and argued that, in order to construct new artefacts, designers needed to approach the design process objectively and according to a repeatable process, which would lead to better quality products.

Information processing theory improved our understanding of problem solving as a fundamental cognitive activity from the early 1960s onwards (Goel, 1995). Designing was regarded as a type of problem solving (Newell, 1969), taking place in an information-processing system. This implies a search in an abstract mental space in which possible solutions are considered, an approach similar to the understanding of well-structured chess games and puzzle solving (Eastman, 1970). Problem solving and, hence, designing have been, and still seem to be, regarded as designers' ability to recognise unsatisfactory states of affairs (needs or problems) and to change them into satisfactory state solutions (Goel & Pirolli, 1989). It is assumed that, in order to change these states, designers must adjust their responses to the requirements and intentions of the task environment, which is the external environment (fully encompassing the problem) in which information processing functions (Goel & Pirolli, 1992).

The meta-theoretical principles of CTM stem from psychologists' use of the computer as a metaphor to explain how human cognitive behaviour takes place during different cognitive stages of information processing (Reed, 2007). The meta-theoretical principles of CTM require that the language of thought be a language with rigorous properties, also known as computational properties. These symbol-system properties are required to be rigid, specific, clear and determinate, which calls for a centralised representational medium in which information can be represented and computations carried out (Bickhard, 2008). For designers, representations are the things they use to express their understanding of the world with a view to solving design problems (Goel, 1995). The importance to this study of representations that use the classical computational approach lies in asking how external elements can be captured and represented internally in such a way that they become meaningful to the designer and those involved in problem-solving situations (Haupt, 2013). The computational view of representation assumes that designers have some rational and logical way of representing the goal of solving problems (or the intention to do so), or of attaining a particular state (Haupt, 2013). Accordingly, representation plays a valuable role in information processing in structuring ill-structured design problems and in problem solving during the early phases of the design process (Goel, 1995). On this basis, I trust that the representations of novice designers in this study will allow me to gain access to their thoughts, accounting for moment-to-moment information processing.

The symbol-systems theory attempts to identify what happens in the minds of designers during the separate stages of information processing, which include acquisition, storage, retrieval and use of information (Newell & Simon, 1972). The structure of a symbol system consists of (1) an information-processing system, (2) the task environment and the (3) the problem space as illustrated in Figure 2.1, as suggested by Goel and Pirolli (1989) and adapted by Haupt (2013). Designers use information-processing symbols to represent current states of affairs and goals to assist them to purposefully transform states, as they adapt themselves and their thinking in order to solve problems (Goel, 1995). However, the information-processing system is ruled by its meta-theoretical limitations, which are structure sensitivity and combinatorial syntax and semantics, as well as by psychological limitations, which are sequential processing and short-term memory limitations (Goel, 1995). For this study, I am to investigate and explain the manner in which novice industrial designers use strict symbol-system properties to represent their understanding of the world in order to solve design problems.

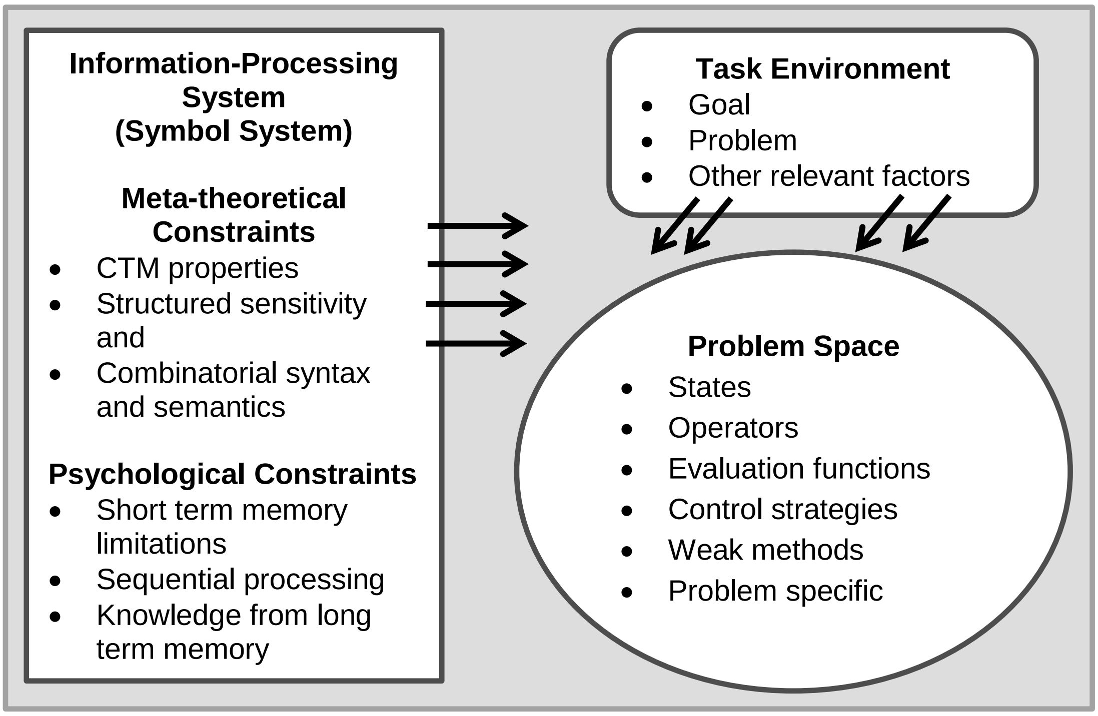


Figure 2.1: *Components of a symbol system characteristic of computational properties (Haupt, 2013, p.43)*

The notion of task environment that forms part of the structure of the symbol system was introduced by Newell and Simon (1972) to designate an abstract environment that corresponds to a problem (Goel & Pirolli, 1992). The terms ‘problem’ and ‘task’ are hence interchangeable (Kirsh, 2009). ‘Environment’ signifies people attempting to increase their task performance by adapting their behaviour to environmental constraints. Therefore, what designers know and do not know and what information they have access to and what not, are a part of their task environments. The task environment typically consists of a goal, a problem, and other relevant factors (Goel, 1995).

Regarding the other relevant factors, I find Goel's (1995) explanation vague. Understanding the design task environment requires an appreciation of designers' ability to access information that is not evident in the design brief but can be found in the external environment in which the design problem is situated (Haupt, 2013). For this study, I consider other relevant factors to include the embodiment elements of affordance, perception-action, intention-attention and specification of information as a guide to obtaining insights into the interaction between existing knowledge and situational knowledge (Haupt, 2013). The four embodiment elements are discussed further on.

Goel and Pirolli (1992) explain that the different states of mind of designers match the three components of design problems which (Haupt, 2013) adapted as illustrated in Figure 2.2. These mental states consist of a start state that often has very little information concerning the problem (Cross, 2001b, Simon, 1996, Vincenti, 1990), the goal state with even less information concerning the solution (goal), and the transformation state mediating between the start and goal state with absolutely no information concerning the transformation function. Because of this lack of information in the various states, designers experience uncertainty during most of the design process. As a result, they need to draw continuously on knowledge to make up for missing information and use it to structure the problem space (Simon, 1973).

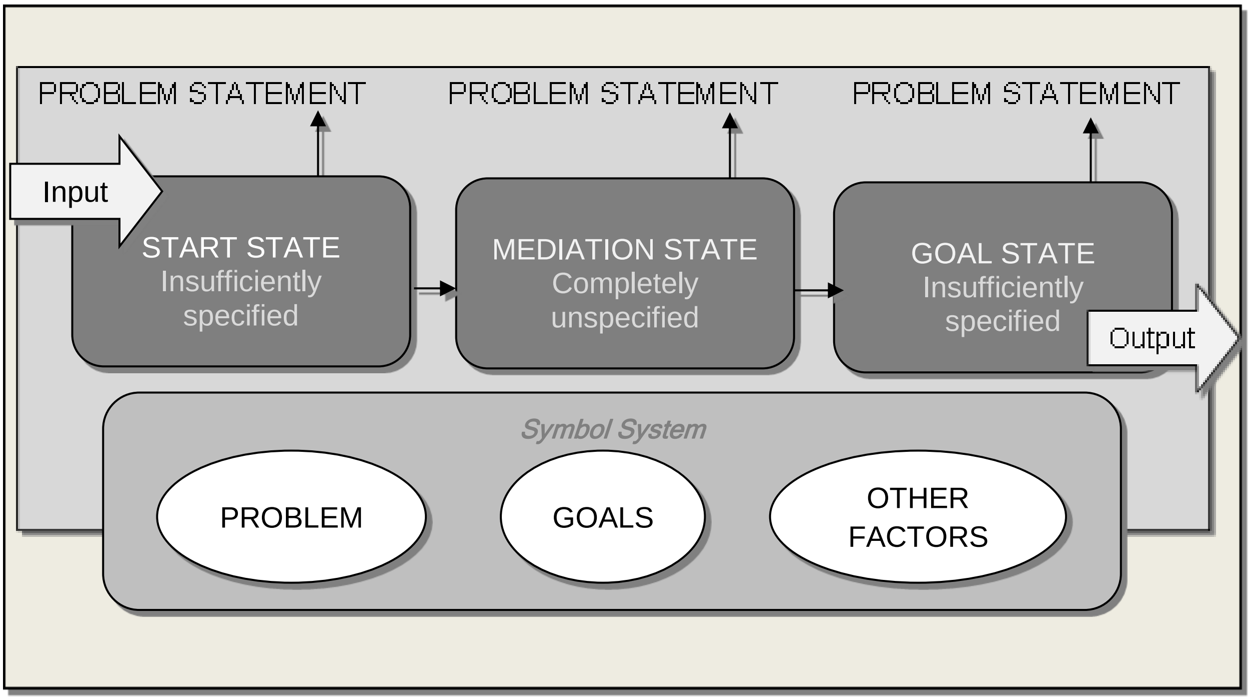


Figure 2.2: *States in design task environment operating in a symbol system (Haupt, 2013, p.74)*

The problem space, which is the third component of the symbol system structure, is assumed to be a representation that is mentally constructed when a task is understood correctly (Kirsh, 2009). As such, a problem solving space can be regarded as a modelling space that is influenced by the psychological limitations of the information-processing system and the task environment (Goel, 1995). As Goel and Pirolli (1992) explain, structuring the design problem space calls for a rational process consisting of a sequence of steps that are consciously followed in a linear way.

For the purposes of this chapter, I used Goel and Pirolli's (1992) design problem-solving theory to structure my investigation into the nature of the design problem space and the role of representation in the early phases of the design process. However, I regarded design cognition not as predictable, sequential computation, but as a complex set of interrelationships between multiple variables. These variables were the ill-structured nature of design task environments, and the symbol system properties that contributed to the use of knowledge, the interpretation of the problem, commitment to ideas and the transforming of these ideas into intentions.

The limitation of this problem-solving theory lies in the fact that it views designing as an internally-driven process that isolates natural human behaviour from the environment in which it occurs. Designers use a complex design process that is not sequential and has many iterations (Kruger & Cross, 2001). Information processing, on the other hand, seems to be capable of explaining only rational and linear cognitive processes. It does not account for the way in which designers' thought processes connect with external elements, such as sketches and other perceptually visible objects in the environment (Haupt, 2013; Kirsh, 2009). It may therefore be concluded that information processing fails to exhaustively explain the unique nature of design problem solving.

Exclusion of the physical environment from the information processing system resulted in theories embedded in an embodiment approach to cognition (Bickhard, 2008). It seems that embodiment theories meet the need to focus on the problem solver as 'agent'. This approach seems to provide some reasoning apparatus for considering the significance of perception-action cycles in design processes (Richardson, Shockley, Fajen, Riley, & Turvey, 2008). These perception-action cycles may help to explain some of the cognitive activities not explained by information processing (Kirsh, 2009).

2.2.2 Embodiment theories

The externally-driven embodiment concept, also known as ecological or situated cognition, is found in a constructivist approach to cognition (Kirsh, 2009). The theories of embodiment came from the domain of ecological psychology, which was originally conceived by Gibson as explained in Bickhard (2008). Gibson's ecological approach opposed the division between organism (human cognitive system) and environment, which stems from everyday observation that a cognitive agent has a body, occupies an environment and exists by the limitations of both (Bickhard, 2008). By focusing on problem solving, embodiment theorists (Anderson, 2003; Suwa & Tversky, 2003) argue that in an externally-driven cognitive process, perception and action seem to appear through the body's being in the world, resulting in synergy between perception and action when solving problems. The way in which the world and human cognition systems are integrated is seen as the primary assumption of embodiment.

A number of embodiment principles underlie the assumption that designers use the environment as a source of information(Anderson, 2003); these are affordance, perception-action, intention-attention, and specification of information. In empirical research on expert designers, Haupt (2013) showed the relevance of these principles in explaining the connections between some external and internal aspects of design cognition, that is, to construct new knowledge in the design task environment. I used these four embodiment principles specifically because they allowed me to identify how the participants, guided by their intentions and associative connections between existing pieces of information, regarded the situation. Furthermore, the processes involved in considering the environment have also been described as important to the cognitive processes of perception and conception (Gero, 1999).

Affordance refers to real discoverable properties of the environment and objects in the environment (Gibbs, 2005). Some examples of affordance as a discoverable property are being graspable or 'pullable', being a structure that can be sat on, walked on, picked up, thrown or climbed, and so on. Designers' intentions due to typically ill-structured design problems require them to access and use external information afforded (presented) by primary physical objects and elements that they perceive and act on as they pay attention to selected or emerging elements (Anderson, 2003; Haupt, 2013). In this study, I aimed to explain how participants intentionally searched for such information through perception in order to establish gestalt.

The notion of *perception-action* arises from the understanding in embodiment theory that humans do not see the world statically, but explore the environment actively (Gibbs, 2005). Perceiving information from objects in the environment (including perceiving sketches made previously) plays a significant role during the early phases of the design process (Gibbs, 2005). The visual function of perception-action as explained by Gibbs (2005) is to become aware of the environment and to direct action, and not to create inner experiences and representations (Gibbs, 2005). According to Anderson (2003), the perception-action embodiment theory is part of the same continuous and cyclical process, which assumes that designers intentionally perceive and act all the time. The implication of perception-action for my study is that I looked for instances when participants came to appreciate the nature and scope of their design problem through epistemic knowing and knowledge as perceived, rather than conceived (Richardson et al., 2008).

Intention-attention is the notion of what makes designers act on their perception (Anderson, 2003). Intention-attention provides new observable targets which involve acts of labelling to create a new range of observable objects (Haupt, 2013). A study conducted by Suwa and Tversky (1997) explains how expert architects know when to use their drawings to assist them by reminding them of prior intentions which were interrupted by other thoughts or information. For this study, the notion of intention-attention was important in distinguishing between higher-order and medium-order intentions and lower-order external elements (Haupt, 2013). The higher-order goal intentions were referred to as the abstract aspectual intentions for the physical and/or functional properties of an intended artefact. Medium-order implementation goals involved participants articulating how they intended to concretise their conceptual ideas. When participants persistently paid attention to lower-order embodiment information that conformed to their higher-order goal intentions, this indicated to me that their thought structure was hierarchical in nature.

Specification of information means that the physical world typically presents specific information about itself, for example shape, size, colour or texture. Richardson et al. (2008) explain that this embodied principle is used to explain how designers retrieve information – in the form of patterns – that uniquely specifies properties of the world and is not as vague as the information in design briefs is. The implication of this notion of specification of information for my study is that I attempted to look for instances where perceiving the physical specificity of objects could be associated with deliberation about their functionality.

In summary, embodiment theories assert that human behaviour can only be studied naturally as it occurs (Clark, 2006). Although embodiment theories recognise that the environment provides organisation for cognitive activity, they do not explain how internal cognitive processes interact with the design problem space, in which the design task has to be integrated so as to transform intelligent activity (Kirsh, 2009). As a result, an extended design cognition theory developed which recognised the dynamics involved in problem solvers' minds as they "constantly translate moves in their abstract problem space and then act in the world" (Kirsh, 2009, p.269).

2.2.3 Extended design cognition

The limitations of both information-processing and embodiment theories led to a further development in theories of cognitive behaviour, namely extended design cognition (Haupt, 2013; Kirsh, 2009). This study is embedded in the theoretical assumptions of this extended design cognition theory. Figure 2.3 illustrates how the extended cognition theory developed by integrating computational and embodiment theories and focusing on the interactivity between internal processes and external sources (Haupt, 2013; Shani, 2012).

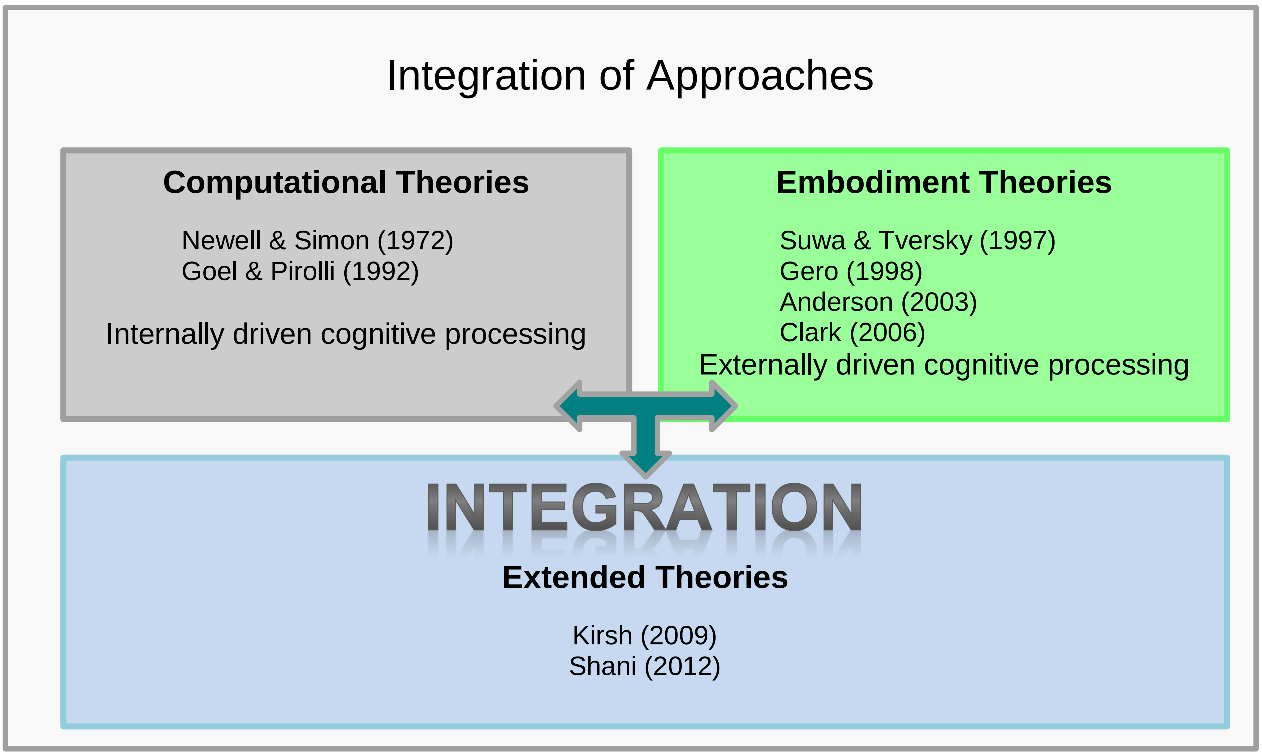


Figure 2.3: Interaction between computational and embodiment theories leading to Extended theories (Haupt, 2013)

Cross (1995) explains that designers have the ability to create original or unforeseen conceptual solutions and accept uncertainty by working with incomplete information. Cross (1995) furthermore describes designers' ability to apply powers of invention and consideration to practical problems by using external elements such as drawings and other media for solving design problems.

Extended theories are based on the components of the symbol-systems theory of information processing, which emphasises the methodological importance of designers' need for perception and their natural environment. In other words, extended theories consider the basic sequence of events, namely seeing-acting-seeing as illustrated in Figure 2.4 (Haupt, 2013). This notion allows designers to move between environmental stimuli and existing knowledge, stored in their long-term memory, from domain-specific environments (Haupt, 2013). The implication of such integration for my study is that it supports the designer's need for perception (externally-driven source) as well as internal and linear strategies in order to structure a coherent solution.

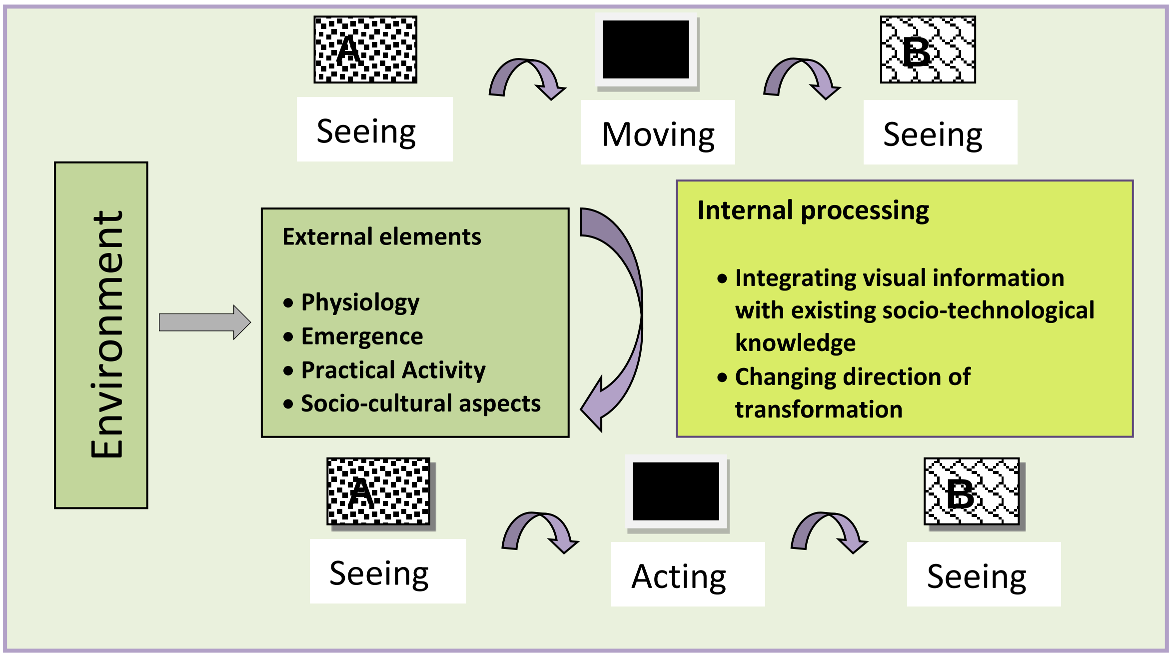


Figure 2.4 Components of an extended problem-solving space (Haupt, 2013, p.63)

This notion of integration is supported by a study on engineering students conducted by Cardella, Atman, and Adams (2006). Cardella et al. (2006) found that it was helpful to students when they concretised, through external representations (sketching), that which had been conceived of in the imagination. These external representations helped students to quickly test and reflect on different design ideas by recalling the tangible make-up and physical environments and objects.

In the computational paradigm, conventional protocol studies relied on scientific conditions for validity (Cross, 1999; Simon, 1996). However, with extended cognition theory, designers interact directly with the natural environment (Haupt, 2013). Integration means that there is a systematic flow between environmental stimulation and existing socio-technological knowledge from field-specific environments stored in the long-term memories of the designers (Haupt, 2013).

To augment the theory of extended cognition, Haupt (2013) developed a model of hierarchical thinking to improve our understanding of how expert designers successfully find suitable solutions that align coherently with their intentions. She found a hierarchical pattern in which expert designers' thinking ranges from abstract aspectual intentions to functional intentions, physical elements and implementation intentions. Haupt (2013) concluded inter alia that coherence is brought about by gestalt thinking, in which expert designers create self-regulating perception-action feedback loops in their thinking by constantly establishing interrelationships between their intentions on all four hierarchical levels (see Section 2.6.1).

This study focuses on novices' gestalt and hierarchical thinking in an extended cognition context, which will be discussed in more detail in the conceptual framework further on.

2.3 Early phases of the design process

The focus in this study is on the early phases of the design process, as these early phases are generally regarded as a critical stage in the problem-solving space for finding coherence amongst an array of unknown and known information (Cross, 2001b; Goel & Pirolli, 1992; Liikanen, 2009). This early phase iteratively connects with the development of conceptualisation and the refinement of ideas for solving a design problem (Cross, 1995). In order to achieve coherence, most designers apply critical and creative skills (Dorst & Cross, 2001; Liikanen, 2009) by constantly seeking appropriate information and applying domain-specific and domain-independent knowledge recalled from memory. For designers to shape their ideas, they need to interpret the design brief so as to determine the intention(s) of the task and understand the context. Designers typically consider what social, technical and environmental knowledge may constrain, limit and challenge them, while directly perceiving the physical environment in which the problem is placed (Goel & Pirolli, 1992; Liikanen, 2009). An in-depth understanding of the way in which novice designers achieve coherent thinking is therefore needed.

One of the reasons why it is challenging for designers to achieve such coherence during the early phases of the design process is the ill-structured nature of the design process. Designing is typically considered to be a non-routine, irregular and ill-structured problem-solving activity, which makes it unique (Goel & Pirolli, 1992). This means that designing is not a negligible activity (Visser, 2004); it is not the same as solving mathematics problems, construction problems, or visualisation problems, and it requires its own unique kinds of cognitive processes (Blessing & Chakrabarti, 2009).

The nature of problem solving in design requires designers to move backwards and forwards constantly between identifying unknown information, finding such information, restructuring the problem and finding suitable solutions (Goel & Pirolli, 1992) that align coherently with their intentions (Haupt, 2013). To obtain more information about the ill-structured design problem, designers employ strategies to expand their knowledge base, by means of questioning and direct perception, so as to fill in the gaps in the information they received from the design briefs (Haupt, 2013). In order to achieve their intentions, therefore, designers generate and develop thoughts from the information they have gathered that are consistent with one another and with their intention of establishing coherence (Kieran, 2011).

Being typically ill-structured, design problems require significant problem structuring because of the lack of information in the three states (start, mediation and goal) (Goel &

Pirolli, 1992) involved in the structure of the symbol system of the problem (see Figure 2.2). The scope and essence of the structure of a given problem are typically not well specified in advance. This means that the constraints are non-logical, allowing designers to negotiate, enlarge or simply change problem parameters (Goel & Pirolli, 1992). The implication for coherence is that designers will find it difficult to establish a guide for making connections that will provide meaning for subsequent problem-solving activities. This notion in the design process – which originated in information processing – consists of two distinct cognitive phases in the early stages of the design process, namely problem structuring and problem solving.

2.3.1 Problem-structuring phase

Problem structuring is the first distinct cognitive phase. Problem structuring in itself is not believed to be a problem-solving activity. However, the extent to which problem structuring is successful determines the number of sub-problems designers engage in (Mitcham & Holbrook, 2006). During the problem-structuring phase, designers try to understand what the problem is and what they need to solve, what its scope is, and what its constraints, requirements and specifications are (Goel & Pirolli, 1992).

Designers typically draw upon prior experience, domain-specific knowledge, or information they have obtained during the design process by using their sketches to align their thoughts with the design brief in their attempt to understand the problem (Schön & Wiggins, 1992). Designers also interact with external sources of information to make up for information that has not been provided, by employing limited control structures to consider multiple contexts and possible ideas without fixating on one idea early in their process (Goel & Pirolli, 1992; Simon 1973). During this phase, designers consider information at a higher level of abstraction, which involves a series of repeated activities (Goel & Pirolli, 1992).

One of these activities involves statements about people, the function of the artefact, and resources, which indicates that problem structuring is associated with how the artefact may be used and what is available to shape it. In the second activity, designers repeatedly refer to the client and design brief as primary sources of knowledge in order to bring new information into the problem space. A third activity during problem structuring is when designers repeatedly make verbal comments about particular design decisions without necessarily committing to any of them, as they are still in the process of gathering information about various solutions. A fourth and last activity during problem structuring is when designers repeatedly add statements about how the problem can be defined and propose ways of specifying evaluation criteria so as to give structure to the problem space. For example, they typically use abstract conceptual knowledge, including knowledge about aesthetics, ergonomics, economics and properties of material, and knowledge about structures, machines, systems, and manufacturing methods (De Vries, 2005). Moreover, the extent to which problem structuring is fruitful determines how designers proceed with problem-solving activities to find suitable solutions that align coherently with the intentions of their design task (Haupt, 2014).

In order to structure a design problem, therefore, designers redefine the ill-structured design task by setting its boundaries and selecting particular elements which involve people, objects and contexts and their coherent interrelations (Love, 2002). In this way, designers gain insight into the nature and scope of the problem and tend to establish coherence in the problem space that guides subsequent problem-solving activities (Bickhard, 2008).

2.3.2 Problem-solving phase

Problem solving is the cognitive phase in which designers generate and explore alternative solutions that emerged in the problem-structuring phase. The problem-solving phase consists of three sub-phases distinguished by Goel and Pirolli (1992), namely preliminary design, refinement and detail design. According to these authors, the three sub-phases are related to the extent and complexity of design problems, and the functional information that mediates between the input and the output information. The input consists of information from the client, the design brief and perception of the physical environment. The output consists of the functional specification of the artefact.

Given the scope and complexity of design problems, and the restricted short-term memory of designers, one would expect that problems would be broken up into many modules (Goel & Pirolli, 1992). However, as connections between modules are mostly provisional, designers usually attend to some connections and ignore others. Furthermore, concepts develop incrementally until they are suitably coherent for the task.

Goel and Pirolli (1992) found descriptive accounts generated by expert designers of a design solution in the preliminary sub-phase of problem solving. In the refinement sub-phase, designers were found typically to elaborate on an established design solution, whereas in the detail sub-phase the same design solution became more transparent and specific as designers started committing themselves to a particular concept.

Refining a particular design solution hence requires that designers increase detail coherently and incrementally. This typically involves physical elements that designers envisage using in their designs in order to achieve their functional goal intentions (Haupt, 2013). During problem solving, information about the aspects of the design is considered (i.e., people, purposes, behaviour, function and structure), as it is during problem structuring, as the information required determines the coherence of intentions to solve the design problem (Goel & Pirolli, 1992).

2.3.3 Overlapping

As problems do not pre-exist prior to solutions, but build up and elaborate simultaneously, problem structuring and problem solving constantly intermingle and overlap and are hence labelled 'leaky modules' by Goel and Pirolli (1992). Cross (2001a) describes the overlapping as an oscillating motion, as the designer's attention moves between the problem-structuring and problem-solving activities and as the design clarifies the various intentions at hand. Cross (2001a) explains further that overlapping in designing appears to be an 'appositional' exploration for a corresponding problem-solution pair, rather than a propositional line of reasoning from problem to solution as an attempt to make sense of the ill-structured nature of the design task environment.

Research further highlights the relationship between the ill-structured characteristics of the design task environments and designers' awareness of new criteria during the actual process of designing, called 'problem solving triggers' (Visser, 2004). This might include knowledge accessed by perceiving the physical or external triggers and connecting it to internalised knowledge (Shani, 2012).

This notion of making appropriate connections in the problem space between external triggers and internalised knowledge as a whole connects with the gestalt theory of coherence (Kieran, 2011). Such coherence can only be instantiated when various intentions are held together by the designer's ability to synergistically align their ideas with their intentions (Haupt, 2013). In the context of this study, gestalt thinking can be described as the coherent way in which a designer organises a challenging design situation, by contemplating different options before the details of a solution can be specified (Haupt, 2014). In the next section, I review the literature on expert and novice design thinking.

2.4 Expert versus novice design thinking

Various empirical studies (Björklund, 2013; Petrina, Feng, & Kim, 2008; Visser, 2009) on design cognition indicate that expert and novice designers think similarly in some ways but differently in others. There is substantial confirmation of this; however, I could find only a limited amount of recent research that approached it from a gestalt perspective and dealt with the differences between expert and novice designers in respect of the representation of knowledge, its management, and the ways in which knowledge is applied. Different levels of design expertise have been studied in many different domains, and various theoretical approaches have been proposed to investigate designer performance (Ericsson & Lehmann, 1996, 1991; Feltovich, Ford & Homan, 1997); these approaches include information processing, embodiment and extended cognition. Eastman (2001) found that researchers into design cognition have been motivated to move beyond what designers do to understanding what effective processes and skills expert designers use, in order to help improve the quality of design education.

Many researchers (Kavakli & Gero, 2003; Petrina, 2010; Petrina et al., 2008) have contributed to the understanding of reasoning and efficiency in the design process. Petrina (2010) found that both novices and experts can cope with all the cognitive activities, but that novices are short on strategies to structure their problem-solving activity. The productivity of experts is almost three times as high as that of novices (Kavakli & Gero, 2003). This is because experts have learned to structure the activity and reduce the cognitive pressure in order to be more efficient and productive with their time (Petrina et al., 2008). However, neither the computational approach of Kavakli and Gero (2003) nor the situated approach of Petrina (2010) explains the connections designers make to organise their thoughts between hierarchical levels so as to find a coherent design solution.

The research conducted by Björklund (2013) explored how the early conceptual representations and suggestions of experts differ from those of novices when they are developing artefacts. Björklund (2013) investigated representational differences in structured interviews and found that experts proactively perceive supplementary information and information resources related to the problem during the early phases of the design process. Novices, on the other hand, were found to lack a proactive sense of awareness and insight to make interconnections (Björklund, 2013).

In another empirical study with a computational approach, clear differences were found between novice and expert designers when dealing with design tasks (Ahmed, Wallace, & Blessing, 2003). Novices employ a specific model of trial and error when approaching a design task, whereas experts use particular design strategies that they have individualised for approaching a design task. However, this particular study does not investigate the role of the gestalt theory of coherence when approaching the design task.

The design task requires designers to make concept drawings related to specific knowledge connections (Popovic, 2004). Popovic (2004) found that, when using an extended cognition theory approach, both novices and experts generate concept drawings to solve problems during the early phases of the design process. What is of greater interest is the finding that novices use common-sense knowledge to conceptualise their concept drawings; they perform tasks step by step; they apply domain-specific knowledge in a laborious manner by reforming the problem several times before solving it; and, as mentioned earlier, they apply trial-and-error procedures because they do not know which procedure might provide the best solution (Popovic, 2004). However, Popovic (2004) noticed that intermediate designers with more domain-specific knowledge apply knowledge in more efficient ways.

Dixon (2011) conducted a case study using a computational approach to gain a better understanding of how novice and expert engineers solve specific engineering problems, and found differences in core thinking skills. Expert engineers spend more time in the solution space where they recognise the system requirement and focus their efforts on designing what is seen to be the most important element in the system (Dixon, 2011). This approach described by Dixon is also known as the breadth-first approach in cognition literature (Liikanen, 2009; Visser, 2009). Novices on the other hand explore sub-solutions in detail, also known as depth-first approach (Dixon, 2011). This does make novices solution-oriented as well, but they constantly evaluate and discard their ideas simply because they lack the cognitive strategies to cope with the ill-structured nature of the design problem (Liikanen, 2009). Dixon (2011) suggests that more research is needed to help novices develop coherent gestalt thinking strategies, which would enable them to move rapidly from being novice problem-solvers to being advanced and finally expert design thinkers.

Haupt (2013) found that expert designers' hierarchical thinking is constructed through individual multi-directional thinking processes. The hierarchy of thoughts consists of four levels, namely aspectual intentions, functional intentions, physical elements and implementation intentions. Haupt (2013) explains that, at each of these hierarchical levels, expert designers think coherently of different things to help them identify the problem and come up with a suitable solution in the form of a conceptual artifact. However, I could not find literature on novice designers' hierarchical thinking.

The question arises: How do expert designers manage to find coherence between the four levels and all the different things they think about? Haupt (2013) asserts that it is aspectual intentions that bring about such coherence. Coherent gestalt thinking takes place when a logical and conscious alignment is formed between the things designers think about and the intention of the task. Understanding the role of coherent gestalt thinking in novice designers will allow educators to structure their teaching and learning activities so that they can develop the complex and dynamic thinking skills of novices to mirror those of expert designers.

2.5 Gestalt

The German word gestalt apparently does not have an exact English equivalent but is generally rendered as 'configuration', 'figure', 'completeness', 'form', 'totality' or 'wholeness'. It denotes the ability of the human mind to form a global whole with self-organizing tendencies (Carlson & Heth, 2010). The gestalt principle maintains that our minds consider an object as a single entity in the present moment, or in parallel with the perception of its different parts. For example, a musical piece has a gestalt, because the tune and melodies as wholes display characteristics that none of the individual notes have on their own. Similarly, a sentence has gestalt: the individual words contribute to the meaning of the whole, but they do not themselves have that same complete meaning. These characteristics of the whole are called emergent properties (Carlson & Heth, 2010).

2.5.1 History of gestalt theory

Gestalt is a branch of psychology that emerged as a reaction to Wilhelm Wundt's structuralist theory. Wilhelm Wundt focused on splitting mental events and experiences into the smallest elements (Behrens, 1998). Max Wertheimer, in Behrens (1998) noticed while travelling by train on vacation that quick successions of perceptual events, for example rows of flashing lights, create the false impression of motion even when there is none. This phenomenon is described by Wertheimer as the phi-phenomenon (Behrens, 1998). Along with Wolfgang Köhler and Kurt Koffka, Max Wertheimer was one of the main advocates of gestalt theory, which emphasised higher-order mental processes relative to behaviourism in the early twentieth century. The core of gestalt theory was the notion of 'grouping'; for example, we mentally group the various qualities of stimuli, which leads us to construct a scientific or mathematical problem, say, in a particular way (Hergenhahn, 1997). The gestalt principles that control grouping or unified perceptual wholes were:

1. proximity – elements that are close to one another in space, time or relationship are grouped together
2. similarity – objects that are similar or equal lend themselves to being grouped together
3. closure – items are grouped together if they seem to make a whole
4. simplicity – items will be organised into the simplest form possible that allows symmetry, regularity or smoothness.

The above-mentioned principles were termed the laws of perceptual configuration and were clarified in the context of perception and problem solving (Hergenhahn, 1997). However, the limitation of perceptual gestalt is that it focuses on perceptual information in getting a whole consistent picture. In order to structure and solve a problem coherently, on the other hand, conceptual gestalt is needed. The gestalt interpretation of problem solving was provided by Wertheimer after his analysis of examples of problem-solving by famous scientists (e.g. Galileo, Einstein) and also after presenting children with mathematical problems (Hergenhahn, 1997). This interpretation maintains that problem solving is successful when you have the ability to understand the complete make-up of the problem.

The relevance of gestalt to this study is the understanding that external sources of information through perceptual stimulation are needed to structure a design problem in a way that reflects a holistic understanding of all the components and their interrelations with the context of the given design task. Conceptual gestalt provides the insight to combine a set of immediately given facts so as to make sense of a problem (Hergenhahn, 1997).

2.5.2 Gestalt controversy

Despite the initial positive reception of gestalt, it has been criticised in the psychology research agenda and disappeared for a number of years from mainstream research. Gestalt struggled with several foundational problems arising from the vague and non-discriminatory nature of its initial theories, failing at both the descriptive and explanatory levels of theorizing (Wagemans et al., 2012). Gestalt theorists maintained that perceptual occurrences are inherently holistic and organised, and discarded any cumulative explanation in which to the sum of sensory parts of an entity is tallied to produce unity. According to gestalt theorists, what humans perceive immediately is integrated structured wholes; and not the properties which did not result from its individual parts of their tallied sum. The principal parts were considered to be in dynamic interrelations (Wagemans et al., 2012). The implication is that the individual functions, as well as properties of the parts, can only be distinct in relation to the whole. Gestalt parts refer to parts in a human's perception and not to stimulus parts in the environment (Wagemans et al., 2012).

This theory was criticised for not being able to explain the functional correlations between parts and wholes and how they will possibly change continuously through their dynamic interrelationships (Wagemans et al., 2012). Gestalt theorists were also criticised for being too vague when they insisted that people could construct new solutions based on their ability to understand in a holistic manner and to restructure unsuitable relational structures into more relevant ones. Critics rejected the idea that perceptions are structured from conceptually unconnected local sensations, which meant that traditional gestalt failed on both the internal processes and external stimuli levels (Wagemans et al., 2012). These failures of conventional gestalt theory led to alternative, contemporary explanations of holism within an information-processing system approach.

2.5.3 Contemporary approaches to gestalt

In contrast to the traditional gestalt view, contemporary gestalt theorists integrate gestalt into an information-processing system approach, basing it on a variety of modern perspectives so as to allow for operational definitions and a refined understanding of its psychological implications. These perspectives include the following: Garner's dimensional integrality; emergent features and configural superiority; global precedence in hierarchical patterns; and the primacy of holistic properties (Wagemans et al., 2012).

Contemporary gestalt theorists including Navon, Pomerantz, Sager, Stoewer and Palmer, proposed that integrated part-wholes or gestalts emerge naturally from selforganizational processes in the human brain (Wagemans et al., 2012). Gestaltists borrowed their explanatory principles from the theory of global electrostatic field forces. This theory asserts that systems living in equilibria of minimum energy expenditure are at a specific moment also the simplest possible organization given the available stimulation (Wagemans et al., 2012). The modern gestalt concept has fragmented into four quite divergent approaches (economy, self-organization, the simplest possible, and given the available stimulation) to further specify the gestalt perspective (Wagemans et al., 2012).

For the purposes of this study I have adopted an interpretation of the theories of simplicity and self-organization proposed by Wagemans et al. (2012), in order to accommodate designers' synergistic movement during problem solving between higher- and lower-order mental processes while structuring and solving design problems.

The first gestalt principle, simplicity, suggests that perceptions are arranged into the simplest organizations conceivable. Simplicity is also connected to global precedence, where the globality of perceptual properties corresponds to a simple structure with levels progressing in detail and specification within a hierarchy.

This idea connects closely with the second gestalt principle of self-organization, which is automatically hierarchically structured when a mental grouping of multiple sub-concepts is separated into smaller parts (Haupt, 2013). The conceptual framework of this study builds on the contemporary approach to gestalt, namely global precedence of self-organization and its connection with hierarchical thinking. In the next section, I explain the importance of gestalt in understanding how designers maintain coherence.

2.5.4 The role of gestalt in design thinking

Gestalt theory provided me with an explanatory theoretical framework that allows precise operational definitions and experiments. Wagemans et al. (2012) proposed the concept of part-wholes being attached on a notional orthogonal hierarchical tree, where a gestalt forms the top level and its sub-structures are levels of a branching tree. The relevance to this study of the idea of an orthogonal hierarchical tree is to explain how novice designers' thoughts develop in order to structure and solve a problem coherently. Distinguishing hierarchical structures requires an understanding of the gestalt principle of global precedence.

Global precedence is a simplicity-based hypothesis which states that the processing of information follows the self-organizing principle. This principle holds that global structures progress in detail and specification towards the analysis of local properties (Wagemans et al., 2012). The assumption is that conceptual insights and perceptual stimuli are characterised by a hierarchical system with nested relationships. A nested relationship consists in the constant interaction between the top and lower levels of conceptual insights and perceptual stimuli, where all the decisions on lower levels contain elements of the higher levels. The globality of conceptual content accordingly matches the level it occupies within the hierarchy. This implies that properties at the top of the hierarchy are 'more global' than those at the bottom, which are in turn 'more local' (Wagemans et al., 2012, p.1221). I used this conceptualization of global precedence by adapting Haupt's (2013) model of hierarchical thinking to classify the levels on which novice designers' thoughts developed, as discussed in the following section.

2.6 Conceptual framework

The conceptual framework for this study is embedded in the theoretical assumptions of the extended design cognition theory, focusing on coherent gestalt thinking of novice designers during the early phases of the design process. I selected this conceptual framework because it allowed me to explain the design problem-solving space in an innovative way, which may contribute to existing theory on research methodology in design contexts to clarify how novice designers transform and represent knowledge.

For the conceptual framework, I used the lens of extended design theory to examine the way novices solve ill-structured design problems in order to find instances where the following intersect: the gestalt principles of simplicity and self-organization guided by global precedence; conceptual understanding through internal processing; and perceptual stimulation through external processing.

Extended design cognition theory essentially entails the integration of information processing and embodiment theories; this focuses on the assumption of 'synergistical interactivity' (Shani, 2012, p.6) between the internal processes and the external sources of perceptual information. The notion of 'synergistical interactivity' allows researchers to explain designers' need for perceptual stimuli as well as their internal meaning-making of information in a coherent manner in order to structure and solve problems (Haupt, 2013). Such meaning-making is directly dependent on coherent interactivity, which implies a systematic flow between existing socio-technological knowledge from discipline-specific environments stored in the long-term memories of the designers and external perceptual stimulation (Haupt, 2013). The role of gestalt thinking in extended design cognition (Figure 2.5) naturally and logically links very closely with external and internal processes and sources of information.

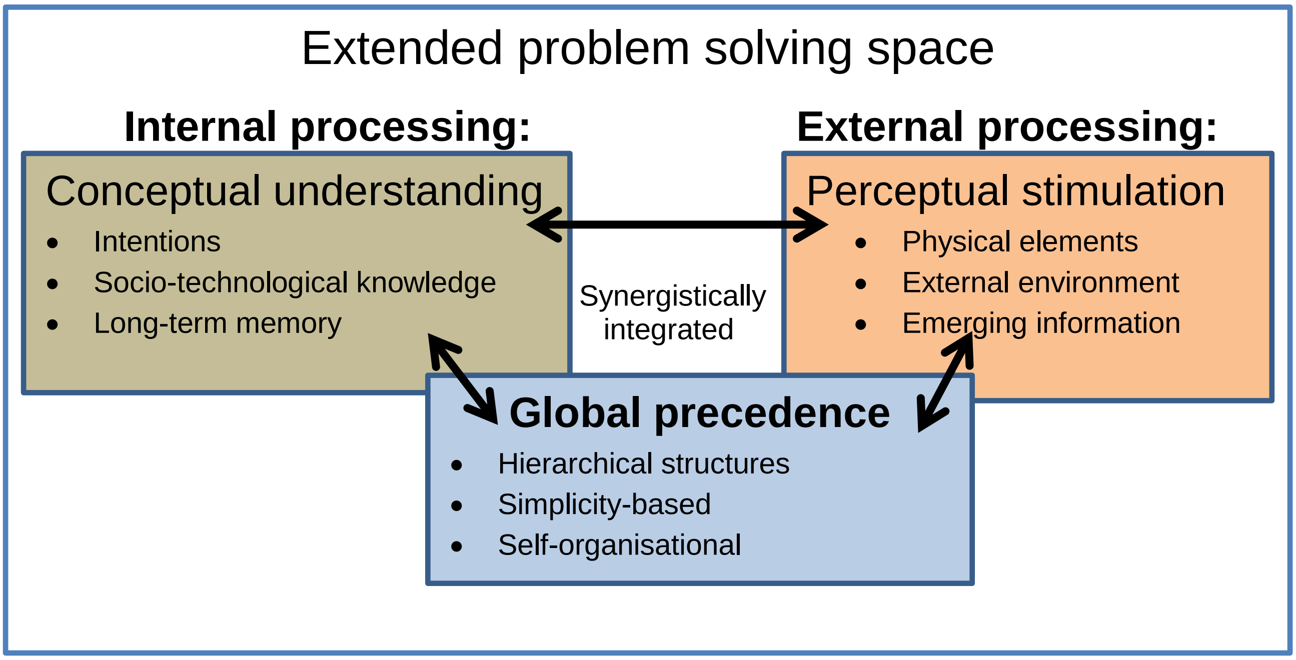


Figure 2.5: The role of gestalt thinking in extended design cognition (Asch, 2015; Wagemans et al., 2012)

The conceptual understanding in Figure 2.5 represents the internal processes and sources that synergistically integrate with external processes and sources of perceptual stimuli. Furthermore, the hierarchical structures of global precedence as shown in Figure 2.5 synergistically integrate and process designers' conceptual understanding and perceptual stimuli in an attempt to describe how they maintain coherent gestalt.

Conceptual understanding can be defined in gestalt thinking as experiencing the awareness of a required relation between instantaneously given details in order to develop new structures or organizations (Asch, 2015). The development of new structures for conceptual understanding requires the internal processing of designers' intentions, long-term memory and knowledge. This in turn links to the theoretical assumption of extended design cognition's internal and linear strategies (Haupt, 2013).

Perceptual stimuli, on the other hand, can be defined in gestalt thinking as the occurrence of processes of discovery (Asch, 2015), directed by physical elements and the external environment in which the design problem is situated (Haupt, 2013). The initial process of discovery through perception provides a preliminary vision of a coherent but incomplete solution (Asch, 2015). Repetitively and iteratively revisiting the external environment and perceiving physical elements produces the change to a new vision with greater coherence (Asch, 2015).

Furthermore, perceptual stimuli in gestalt thinking can be linked to the theory of extended design cognition (refer to Section 2.2.3), as extended theories acknowledge the importance of designers' need for perception in order to structure a coherent solution (Cross, 1995). However, extended theories are based on designers' need for perception as well as internal linear strategies to structure a coherent solution (Haupt, 2013).

The interactivity between the occurrence of conceptual understanding of the design problem and the occurrence of processes of discovery by integrating perceptual information hence allows me to explain how novice designers' gestalt thinking develops. The way in which I combined the role of gestalt thinking in extended design cognition is summarised in Figure 2.5.

2.6.1 Conceptual framework: Hierarchical thinking through gestalt in an extended cognition context

For the purposes of this study, I built on Haupt's (2013) extended design cognition theory of hierarchical thinking as a conceptual framework to accommodate and empirically learn about the role of gestalt, guided by global precedence of novice aspectual intentions. The extended design cognition theory in this conceptual framework firstly emphasises the methodological importance of perceptual stimuli of designers and their natural environment in design work (as discussed in Section 2.2.3). Secondly, extended design cognition theory allows for the difficulty of explaining designers' need for external stimuli but also internal cognitive processes that will help them to solve design problems (Haupt, 2013) including gestalt processing.

The conceptual framework hence emphasises the way in which external stimuli and internal cognitive processes interact by connecting functional intentions, physical elements and implementation intentions to aspectual intentions. The gestalt principle of 'global precedence' is a key aspect of the conceptual framework of this study: it assumes that aspectual intentions are the overarching intentions of designers that guide their embodiment actions so that they pay attention to their intentions in a top-down fashion.

The premise from which the hierarchy works is that intentionality is recognised as an all-inclusive property of the mind or 'gestalt' that originates from a system of causally related states (Haupt, 2013). This implies a system of coherent beliefs, desires or intentions (Mitcham, 1994).

Popovic (2003) explains that experts have the intention to achieve 'gestalt' when designing, and they employ domain-specific knowledge. Extended design cognition theory represents the integration that occurs between conceptual thinking through internal sources and processes and perceptual thinking through external sources and processes to act together in a gestalt-oriented hierarchy.

From this perspective, the hierarchy consists of four levels, namely aspectual intentions (level 1); aspectual meeting functional intentions (level 2); functional intentions meeting physical elements (level 3); implementation intentions (level 4). The basis of the conceptual framework is 'gestalt' and how it influences designers' aspectual intentional thinking, with a distinct starting point that begins at aspectual intentions (level 1).

The hierarchy of thoughts consists of four levels, namely aspectual intentions, functional intentions, physical elements and implementation intentions. At each of these hierarchical levels, expert designers think of different things to help them understand a given problem and find a coherent solution in the form of a conceptualised artefact. However, novice designers find it difficult to make links between various levels of intentions, functionality and physicality that are appropriate and fit for purpose (Popovic, 2004).

Developing a tool to guide novice designers' hierarchical thinking will allow educators to facilitate this thinking so as to enable them to become effective problem solvers. The conceptual framework enabled me to trace and explain both the content and hierarchical order in which novice designers connect various levels of intentions and physicality. The hierarchy of thinking of expert designers to examine novice designers' thinking is presented in Figure 2.6, which is a visualisation of my conceptual framework. I regard the framework as a tool to systematically investigate whether there is a pattern of hierarchical thinking by novice designers in the early phases of the design process.

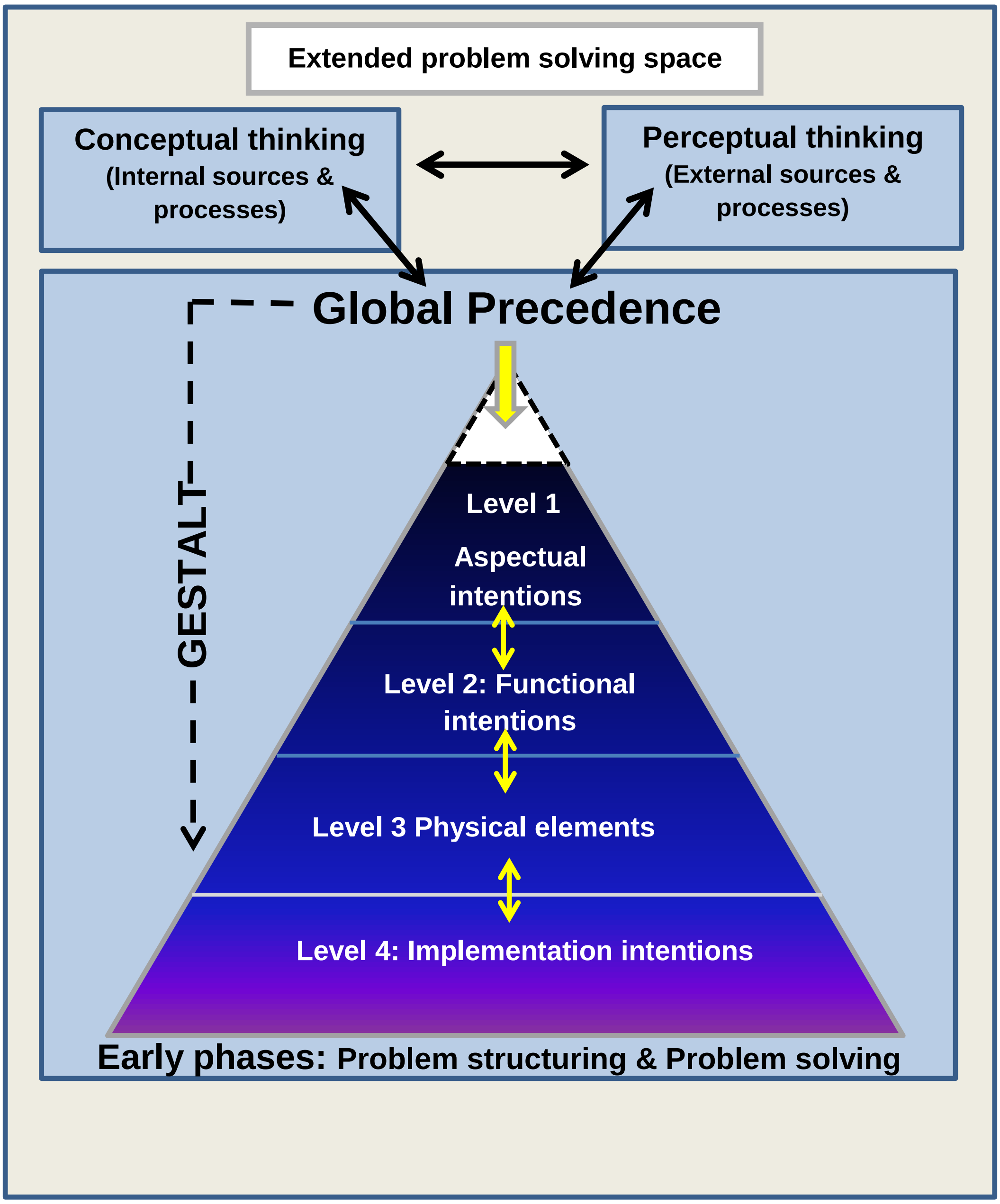


Figure 2.6: Conceptual framework: Hierarchical thinking in extended cognition (adapted from Haupt, 2013)

Aspectual intentions (level 1) are qualitative abstractions (Basden, 2000) that are considered to be distinct design aspects that give meaning and direction to the way designers select and develop ideas, commit to some and reject others (Haupt, 2013). Aspectual intentions serve as the overarching design aspect that mechanises the global precedence principle, which subsequently forms the filter through which selections are made on all the subsequent levels of designers hierarchical thinking (Haupt, unpublished). Thus, aspectual intentions precede and are more global than local properties, which consist of functional intentions, physical elements and implementation intentions.

The local properties found on the bottom level of the hierarchy represent the concrete structural elements that designers envisage an artefact as consisting of. From attention to aspectual intentions (level 1), the mindfulness of functional intentions (level 2) follows. Intertwined with these internal engagements, conceptually related ideas can be explored.

Level 3 is where functional intentions provide criteria for satisfaction to pay attention to physical elements that can meet the functional criteria. Levels 2 and 3 can originate multi-directional as the internal processes and sources of thoughts or the external environment that embodies information. Hence, the arrows between the levels indicate the iterative and interdependent action which, as Haupt (2013) suggests, occurs during the problem-solving phase of expert designers.

The hierarchy represents abstract levels of thinking, which gradually develops into concrete thinking using an extended cognition theory of gestalt thinking. Designers achieve this development by connecting their conceptual understanding of the problem to perceptual stimuli in order to concretise their ideas (Haupt, 2013). The effect of global precedence is therefore the conceptual understanding of aspectual intentions that include the designers' intentions and attention to perceptual stimuli determined by physical elements. Since novices employ general knowledge (Popovic, 2003) and their internal representation is unstable, I am curious to know the role of intention as a driving force in what novice designers pay attention to, what information they access, their process of making commitments and transforming their ideas in the early phases of the design process to establish 'gestalt'.

Designers' ability to design entails both the mental competence to formulate intentional states about a desired reality and the mental competence to formulate intentional objects that resolve conflicts between intentional states (Zamenopoulos, 2011). Different kinds of design considerations or aspects in the context of design cognition have been identified by various authors (Goel & Pirolli, 1989; Searle, 1983; Tversky, 2005). Design aspects that Haupt (2013) labelled 'aspectual intentions' are based on Dooyeweerd's theory of aspectual modalities of reality. Design aspects are qualitative abstractions that are regarded as ways of seeing things that are important to attempt in a solution (Basden, 2000). As such, they qualify as the content of intentional states. Dooyeweerd identified fifteen possible aspects for identifying such abstractions (Basden, 2000). A summary of Dooyeweerd's aspects of reality, including a brief explanation of the core meaning and an example of each aspect, is provided (refer to Appendix F).

To identify the different aspectual intentions that the participants contemplate that provide meaning in the way they select and develop their ideas, Dooyeweerd's aspects of reality (Basden, 2000) are used. For example, in identifying the aspects of an air traffic control room, the kinematic aspect of movement and the formative aspect of control are most important. However, for the air traffic control room to be effective, the lingual aspect of communication and symbols on screen is critical, as are the physical aspect of instrumental monitoring, the social aspect of relationship in a team under pressure, and the pistic aspect of having a well-defined mental picture of what is being done. The implication of this example is that an inter-aspect analogy can exist between various aspects (Basden, 2000).

Dooyeweerd's notion of aspects of reality also suggests that when the participants refer to a particular aspect, their knowledge of the aspect is implied and not necessarily made explicit (Basden, 2000).

On the second (functional intentions) level of the conceptual framework, designers typically define the functional nature of the artefact's purpose or function: they are objects meant for doing things in relation to the designer's intentionality. The functional intentions of the participants are used to identify the way and the order in which design aspects meet end functional goal intentions. Functionality has a close connection with concrete objects and facilitates the need for designers' thoughts to simplify and concretise the abstract nature of their aspectual intentions (Haupt, 2013). To understand the interactions contributing to the development of abstract thinking into concrete thinking, I will trace the utterances of the participants in which aspects and functional intention statements occur at the same time. For example, the participant wants to move a sculpture from its original position. The participant identifies the lingual aspect governing the interpretation of what the functional intention of the sculpture in its new location should be, namely to announce the theatre space.

Level three of the conceptual framework focuses on examining how the initially vague aspects of level 1, in which the participants link the functional intentions of their envisaged artefacts, meet with physical elements. The dual nature of artefacts consists of a physical structure that describes the artefact and a functional intention of what the designer wants the artefact to do. To get a good design, there must be an optimal fit between the physical elements and functional intention; this is achieved by means of a careful selection of physical elements to realise the functional intention of the design (Kroes & Meijers, 2002). The physical structure, for example, has a certain weight, shape, size and a number of parts, is made from certain materials, and has particular mechanical properties (Kroes & Meijers, 2002).

Adding physical elements to the abstract nature of aspectual intentions at the third level of the model leads to further transformation of abstract thinking into concrete thinking (Haupt, 2013).Thus, the focus is not just on the physical elements, but includes the previous two levels of the framework that are intertwined with processes of selection, combination and adaptation of the things the designers think about (Haupt, 2013). Knowing how they make the links, the types of knowledge they use and their ability to concretise abstract intentions will allow me to detect when and how novices establish a fit between physical elements and functional intentions, but also to align selected physical elements with aspectual intentions

(Haupt, 2013). For example, a participant is asked to design a device to count and organise large quantities of Lego™ blocks. The functional-physical connection is when the participant connects the physical elements of a box with slots in it with its functional intention of pushing things through it.

Finally, the bottom level (level 4) of the conceptual framework consists of implementation intentions. Gollwitzer and Schaal (1998) refer to implementation intentions as those intentions in which people declare activities that they think may support them in achieving other goals. For example, you 'transport' things here, you 'put' your stuff in the container and 'take' the container back. As Haupt (2013) explains, the nature and order of physical elements, aspectual and functional intentions are linked so as to meet expert designers' implementation intentions and give them the ability to make and propagate their commitment to their ideas. An example of implementation intention is a parking area on a campus close to a theatre site. The participant connects his\her spatial design aspect to reuse the existing parking space. The implementation intention is to move the parking space, which is a long thing (physical element), to allow for maximum visibility (functional intention) of a sculpture in the theatre space as a position where an activity catalyst (implementation intention).

However, the limitation of using this conceptual framework is that it can only be seen as a tool to systematically investigate whether there is a general pattern of hierarchical thinking that mechanises interactivity between the conceptual and perceptual thinking of the participants. This framework does not explain the personal stopping rules and the predominance of long-term memory in the hierarchy of thought. Personal stopping rules involve decisions when designers see fit to pursue their intentions or when to ignore these intentions based on their own personal knowledge and bias (Cross, 2007). The focus of this conceptual framework is therefore not to regulate feedback loops such as personal stopping rules, but rather to explain the way in which various intentions interact and establish coherent gestalt thinking guided by global precedence.

2.7 Conclusion

Against the meta-theoretical assumptions discussed in this chapter, I summarised the notions and clarifying concepts of information processing, embodiment theories and the theory of extended design cognition as different approaches to design cognition. From the integration of information processing and embodiment theories, extended design cognition developed and focused on the interactivity between internal processes and external sources. The conceptual framework for this study is embedded in the theoretical assumptions of the extended design cognition theory. I discussed the augmented theory of extended design cognition, which led to the building of a model of hierarchical thinking to improve our understanding of how expert designers successfully operate during the early phases of the design process. The early phases of the design process iteratively connect with the conceptualization, development and refinement of ideas for finding coherence amongst an array of unknown and known information to solve a design problem. Furthermore, I found various empirical studies on design cognition indicating differences between expert and novice designers when it comes to the representation of knowledge, its management and the way in which knowledge is applied.

It was established that expert designer's hierarchical thinking is constructed through multi-directional thinking processes. The hierarchy of thoughts consists of four levels, namely aspectual intentions, functional intentions, physical elements and implementation intentions. Furthermore, I discussed how coherence is brought about by gestalt when expert designers create self-regulating perception-action feedback loops in their thinking by constantly drawing interrelations between their intentions and instructions on all four hierarchical levels. However, it is not clearly understood from the literature what the nature of novices' hierarchical thinking is, or what role gestalt guided by global precedence plays in their design thinking. A successful investigation into the connections and coherence in this lengthy process between various intentions and physical elements that novices consider during the early phases of the design process is needed. This study might result in educators' being able to structure their teaching and learning activities so as to develop complex and dynamic thinking skills. In the following chapter, I describe the empirical study that I undertook.

Chapter Three

Research design and methodology

3.1 Overview of the chapter

The purpose of this chapter is to discuss the methodology that was used to carry out this case study in order to answer the research questions. I first explain my selected paradigm and describe the research design that I implemented. I then explain the data collection process and present the analysis and interpretation. I conclude the chapter with a discussion of quality assurance strategies, the challenges that I experienced as a result of my methodological choices and the ethical considerations I observed.

3.2 Paradigmatic approach

The philosophical position that underlies this study is informed by critical realism (Danermark, Ekstrom, Jakobsen, & Karlsson, 2002). Taking a critical realist stance enabled me to describe novice designers' need for perceptual stimuli as well as their internal processes of making meaning from information in a coherent manner in order to structure and solve problems. Critical realism unites a realist ontology, which accepts that there is a real world that exists independently of our knowledge about it, with a constructivist epistemology, which is concerned with how things really are and how things really work. I therefore had to ask myself the question, what do I look for in order to understand the phenomenon?

Research frameworks are expected to be embedded in a particular worldview that functions as the lens through which meaning is made of what the researcher perceives and understands as the truth (Creswell, 2003; Denzin & Lincoln, 2008). This study is based on the following research paradigms supported by Danermark et al. (2002).

- **Ontological paradigm –** This describes how things really are and how things really work.
- **Epistemological paradigm –** This explains how knowledge is possible when selecting a research methodology.
- **Methodological paradigm –** This describes the aims and methods of data collection techniques.

These paradigms will now be dealt with in turn.

3.2.1 Ontological paradigm

The ontology of this study involves the reality of the nature of the design problem space. The design problem space is the space where designers access information by memory recall, as well as from the perception of the physical environment, as they structure the problem and generate preliminary solutions (Kirsh, 2009). The study comprised three pairs of novice Industrial Design students working to solve a design problem in the Heads of Departments' Boardroom on UJ's campus. To form my ontological perspective in this study as recommended by Haupt (2013), I focused on the abstraction hierarchies of novice designers to explain how they thought about the artefacts they were designing as a structure in the design problem space.

3.2.2 Epistemological paradigm

The world I looked at is that of novice industrial designers' ways of thinking about the world in the early phases of the design process. I examined the verbal and visual representations produced by novice industrial designers and focused on the relation between their intentions and their thoughts about physical elements. I applied a-priori theoretical constructs when engaging with the data produced in the study. As such, intentions represent designers' inner world, which consists of aspectual, functional and implementation intentions (Haupt, 2013). Designers' outer world includes physical elements which are found in their design task environment (Kirsh, 2009).

The extended cognition and gestalt theory, on which my conceptual framework is built, is used in a problem-solving environment. I therefore hoped to find the following: information informing me about themes and patterns of global precedence in gestalt thinking; aspectual intentions meeting with functional intentions; functional intentions meeting with physical elements; and finally aspectual and functional intentions and physical elements meeting implementation intentions. My goal was to gain insight into novice industrial designers' integrating their intentions (aspectual, functional and implementation intentions) with their external environment when encountering perceivable physical elements.

3.2.3 Methodological paradigm

The methodological paradigm is the plan of action that underlies the choice and use of particular methods (Scotland, 2012). In other words, methodology refers to how I as a researcher could go about finding out knowledge and carrying out research.

The assumption of a critical realist point of view is that diversity is a real and significant phenomenon. Thus, by selecting a critical realist paradigm I was able to integrate a QUAL+quan mixed methods approach with the aim of increasing the usefulness of the qualitative and quantitative approaches. Time measurement and counts as parts of a quantitative approach provided me with the tools to focus on particular phenomena and cognitive processes, whereas the qualitative approach provided me with the tools to focus on typical characteristics and shared concepts and themes. As a result, the mixed methods approach provided me with the opportunity to summarise the way and the order in which participants thought about things in the design task environment.

3.3 Research design and methodology

In the context of this study, concurrent qualitative and quantitative strategies were used (Tashakkori & Teddlie, 2009). To establish the role of gestalt theory in novice designers' hierarchical thinking in the early phases of the design process, concurrent think-aloud protocol studies (TAPS) were conducted on a small group of novice designers in a semi-controlled environment. This research design produced resonance with my critical realist stance and mixed methods approach, which is discussed in the following sub-sections.

3.3.1 Research design

A research design is a plan that outlines the methodology of data collection that the researcher will use to investigate the research question (Maree & Van der Westhuizen, 2009). The design therefore includes detailing precisely what the researcher wishes to find out about the phenomenon in question. The study engaged mixed methods research. In mixed methods research, Johnson and Turner (2003) recommend that methods be mixed in such a way that the study has the strengths of both and the weaknesses of neither. Triangulation of methods, which refers to the interpretation of findings by mixing qualitative and quantitative data, was best suited to answering my research questions.

The qualitative theoretical drive of the study was primarily deductive, indicated by QUAL (Creswell, 2003; Morse, 2010), because the research questions focused on explanations of instances, exploring relationships, occurrences and sequencing implied questions about mechanisms. The selection of a predominantly QUAL+quan mixed method design for this study provided me with the tools to focus on particular phenomena and cognitive processes as well as tools to focus on typical characteristics and shared concepts and themes (QUAL). It also provided me with the opportunity to count incidents, map the distribution of occurrences on a timeline in terms of themes and sub-themes, and determine sequences of events (quan). The challenge in terms of procedures and practice of a mixed methods design for maintaining control, rigour and complexity was overcome by adopting the theoretical stance of Morse (2010), given the clarity of her explanations and its relevance to this study.

Another challenge I faced was in terms of the credibility of this study, in terms of the concept of internal validity (Lincoln & Guba, 1985). The quality of my research was dependent on my ability to make interpretations of data that would be compatible with the constructed realities of the participants, making me (the researcher) the centre of the quality requirement (Patton, 2008). To overcome this challenge of determining the credibility of my interpretations, triangulation was used, which is described in detail in Section 3.3.6 (Cohen, Manion, & Morisson, 2007). The research process is summarised in Table 3.1.

Table 3.1: Phases of the research process

	Strategy	**Approach**	**Purpose**	**Rigour**
	Pilot study Reflective diary Literature survey	QUAL+quan	Conceptualise study Establish relevance and fit of design task Cross referencing Counting occurrences Measuring units of time	Multiple instruments Ensuring fit Credibility Validity Reflexivity
	Phase 2: Sampling			
	Strategy	**Approach**	**Purpose**	**Rigour**
	Purposeful sampling	Use of selection criteria	Identify top-performing third-year students to apply knowledge and skills in the design process	Consent: benefits, risks Transferability through descriptive adequacy Representativeness of novice students Credibility
	Phase 3: Concurrent Data Gathering and Capturing			
	Strategy	**Approach**	**Purpose**	**Rigour**
	Concurrent TAPS Data: Verbal protocols Visual: Sketches	QUAL+quan used in parallel	Cross referencing Counting occurrences Measuring units of time	Validity Multiple appropriate instruments Trustworthiness Triangulation to enhance credibility Controlled observations

	Phase 4: Structuring Data			
	Strategy	**Approach**	**Purpose**	**Rigour**
	Constructs: Problem structuring and problem solving Criteria: • Commenting • Qualifying • Elaborating • Justifying • Evaluating • Proposing • Repeating	QUAL+quan	Establish correlation between semantics of symbol systems and relevant constructs. Render concepts embedded in theoretical schemes which can be observed and manipulated.	Limit research bias Maximise objectivity Triangulation to enhance credibility from three pairs of participants Theoretical validity: • Explains phenomena sufficiently • Construct validity ensures external validity
	Phase 5: Data Analysis			
	Strategy	**Approach**	**Purpose**	**Rigour**
	Constructs A priori criteria Categories (Hierarchical model) Time measurement and numbers Reflective	QUAL+quan	Establish correlation between semantics of symbol systems and relevant constructs. Render concepts embedded in theoretical schemes which can be observed and manipulated.	Limit research bias Maximise objectivity Triangulation to enhance credibility from three pairs of participants Dependability by means of inter-rater reliability Theoretical validity: • Explains phenomena sufficiently (through thick, rich descriptions) • Construct validity ensures external validity
	Phase 6: Reporting and Dissemination			
	Strategy	**Approach**	**Purpose**	**Rigour**
	Integrate parallel methods	QUAL+quan Narrative Tables and diagrams	Integrate Qual+quan findings Correlations and cross-referencing Classifying, grouping and pattern recognition Patterns	Triangulating truths on reality Dependability and conformability through member checking Interpretive validity External validity

3.3.2 Research strategy

As a research strategy, I selected a case study, which allowed me to obtain a deep understanding of the internal mental processes of novice industrial design students during the early phases of their design processes. My aim was to grasp their hierarchical thinking, which can be associated with the integration of the perception of an external environment and the internal processing of information in terms of the gestalt principle of global precedence. By using existing theories of extended cognition and gestalt thinking as building blocks, I was able to add to the knowledge of the generic design behaviour of novice designers, with the primacy of practical knowing resulting from my non-participatory role of observer. To describe objectively the hierarchical thinking processes of the novice designers in this study, I used a concurrent TAPS protocol study consisting of verbal utterances and sketches, as well as realism principles.

TAPS is a well-documented rigorous empirical approach to understanding what designers think while solving a problem. It has been applied in various protocol studies in different design disciplines, the essential ones being mechanical engineering (Stauffer & Ullman, 1991), software design (Guindin, 1990), electrical design (McNeill, Gero, & Warren, 1998), industrial design (Cross, Christiaans, & Dorst, 1996) and architecture (Akin, 1993). Of all the empirical research methods for the analysis of design activity, TAPS is the data-collecting procedure that has received the most attention in recent years (Cross, 2004; Gero & McNeill, 1998). It is believed to provide direct access to the participants' thoughts (Cross, 2004). The central assumption of TAPS is that it is possible to instruct participants to verbalise their thinking in a way that does not alter the sequence of thinking that mediates the completion of a task, and can therefore be accepted as valid data on thinking (Ericsson & Simon, 1993). Ericsson and Simon (1993) further claim, based on their theoretical analysis, that the closest connection between thinking and verbal utterances is found when participants verbalise thoughts generated during task completion, called concurrent protocols. However, I acknowledge that it is not possible to access all the participants' thoughts during a design activity (Cross, 2004).

In an attempt to capture the participants' thoughts more comprehensively, I also considered the sketches that they produced simultaneously with their verbal protocols. Goel (1995) provided evidence in his book *Sketches of Thought* that sketches, in addition to verbal utterances, are equally trustworthy as scientific data in informing the investigator about the participants' structure of thoughts when produced simultaneously with the TAPS.

Protocol studies are conventionally conducted in a true experimental setup, which is characterised by isolating participants in laboratory conditions in order to free them from the necessity to communicate (Guba & Lincoln, 2008; Simon, 1996). However, I regard this isolation as artificial and not reflecting the naturalistic way in which contemporary design work takes place (Van Someren et al., 1994). Therefore, I have chosen to base my protocol study on the critical realist approach of the research methodology used by Haupt (2013), as it creates a natural task environment. Haupt (2013) adjusted the conventional experimental protocol studies in order to enhance the naturalistic behaviour of participants as they would normally experience it in their design studio on campus. Haupt (2013) found that, by enhancing participants' natural behaviour, relatively normal and undisturbed structures of thought on sequences of action could be obtained.

Similarly, the participants in my study worked in pairs in a familiar environment and engaged directly with an ill-structured design problem. Working in pairs ensured a natural dialogue between the members of the pair, which enhanced the flow of their thoughts to ensure a natural task environment. However, differently from Haupt's (2013) protocol study, my role as researcher in ensuring a natural task environment was to act as a non-participatory observer, by only providing information on request and not interfering with the participants' pace of thinking or generating of ideas. Therefore, my use of an adjusted quasi-experimental protocol to enhance the naturalistic behaviour of participants means that my objective role is in line with my critical realist stance towards this study (Cohen et al., 2007).

This TAPS protocol study concept is grounded in Campbell's philosophy of critical realism, which is used in social research situations where it is not possible to employ true experiments (Blessing & Chakrabarti, 2009). Conducting true experiments in this study would have been challenging, because it would have required artificial situations, making it impossible to stimulate the naturalistic behaviour of the participants to answer my research questions. I therefore had to modify the standard experimental research design using a quasi-experimental case study. This allowed me to have control over the selection of participants. I also had control over the design tasks that participants had to solve, but I did not have control over how participants chose to interact with their contexts.

3.3.3 Selection of participants

Purposeful sampling is a non-random method of sampling where the researcher selects "rich information" cases for study in depth (Patton, 2008). Purposeful sampling takes place when the researcher selects a sample from which the greatest amount can be learned (Merriam, 1998). It is a common sampling strategy in QUAL+ quan mixed methods research design and seeks cases rich in information that can be examined in great depth about issues of central importance to the purpose of the research. The advantage of purposeful sampling is that, as Patton (2008, p.235) states, "Any common patterns that emerge from great variation are of particular interest and value in capturing the core experience and central, shared dimensions of a setting or phenomenon".

I purposefully selected six top-performing third year Industrial Design students from the Faculty of Art, Design and Architecture (FADA) at the University of Johannesburg (UJ) to work in pairs (The reason for selecting top-performing students is based on the premise that higher-order design cognition in tertiary education is more likely to be found in top-performing students than in poorly-performing students). This viewpoint is supported by comparative studies that report on the limited value of studying first-year design behaviour for domain-specific disciplines compared to studying third-year design students (Cross, 2004; Popovic, 2004). I limited my sample selection to six participants due to the large amount of information that is generally generated in cognitive studies, which makes reporting impractical. For practical reasons and to ensure the credibility of the study Industrial Design students from the Faculty of Art, Design and Architecture (FADA) at the University of Johannesburg (UJ) were selected, instead of Industrial Design students at the University I am currently employed. The decision to select third-year Industrial Design students completing a three-year national diploma is based on a case study by Popovic (2004, p.532) on expertise development in product (industrial) design. She found that third-year students have more domain-specific knowledge (knowledge in a particular field of expertise) than first year students do to structure the problem “building a structured representation of requirements and constraints”. She also found third-year students’ immediate access to relevant knowledge to be more efficient than that of first-years. And finally, first-year students typically apply trial-and-error processes, because they do not know which procedure will bring them to the solution of the problem, whereas third year students’ design process through task experience is better embedded. This implies that third-year students’ development in their representations is more stable, which in turn means that less of a trial-and-error process is used.

For selecting a purposive sample of six top third-year industrial design students, the input of the lecturer responsible for the subject Product Design II was needed. The responsible lecturer’s input was required in helping me identify which students I could select for this study based on the following criteria:

Consistently being one of six top performers in all of the design projects given to the students in the subject Product Design II.

- The student’s ability to apply knowledge and skills smoothly to the design process in the subject Product Design II.
- The student’s ability to use both critical (analytical) and creative (lateral) thinking to resolve the diverse requirements of users, manufacturers and the environment for the subject Product Design II.

3.3.4 Data collection and instruments

My instrument was a design task (which I discussed in detail in Section b, p.50). All the participants received the same task. The protocols captured on digital video provide quantitative data in terms of temporal information as well as qualitative visual information in order to map the participants' hierarchical thinking during the early stages of the design process. The simultaneous production of verbal data and sketches also provided quantitative data regarding the distribution and frequency of the four levels of hierarchical thinking. In addition, the protocols also provided qualitative data based on the semantics of the verbal and visual data that I collected. Furthermore, I also kept a research diary and recorded my observations and reflections during all three protocol studies.

(a) Overview of the data collection process

My primary data-collection strategy was to conduct quasi-experiments in a design context. This entailed the provision of ill-structured design tasks to the participants. They were required to think aloud and produce rough sketches concurrently. The verbal and visual data were collected in three phases, with each phase entailing a separate concurrent TAPS protocol study for the three pairs of novice designers. I experienced the data-collection process during my pilot study as mentally taxing mind while recording my observations. I therefore decided to collect each of the three phases on separate dates in sessions of ± 2 hours.

(b) Steps in conducting TAPS

The TAPS consisted of five steps, capturing both verbal and visual data simultaneously (Goel, 1995; Haupt, 2013). The following steps are based on Haupt's (2013) adapted method for conducting TAPS.

Step 1: Preparing the design brief

This step required preparing an ill-structured design brief that had to be challenging, realistic, appropriate for the participants, not too large, feasible in the time available (± 2 hours), and within my knowledge as researcher (Dorst & Cross, 2001). The design brief required the participants to *Design a multi-purpose seating surface for people living in low-income housing* (refer to Appendix A). I regarded the design brief as ill-structured because it did not imply or specify a solution. The participants were confronted with a lack of information in all three states in the design problem spaces, namely the start (input) state, the transformation state and the goal state. The participants had to access input information from various sources at their disposal, including the design brief (which was underspecified), relying on stored generic experiential and domain-specific knowledge and information embodied in the environment. The participants' goal was to represent a satisfactory solution by transforming the accessed information through verbal utterances and concurrent sketches to fully understand the requirements and scope of the problem. To ensure credibility through triangulation the same design brief were given to all three groups. Industrial design students are normally put under a great deal of pressure during the academic year. I therefore had to negotiate with the selected participants to conduct the protocols during their recess, when they had the time to focus on the task which I wanted them to complete. I believe that this may have helped the participants not to be concerned about missing classes or falling behind with their assignments.

Step 2: Preparing the setting

The second step involved preparing a setting to improve the effective elicitation of novice design behaviour where the participants could receive instructions to think aloud and make sketches. I arranged for the participants to work in the Heads of Departments' Boardroom. I provided the students with a laptop connected to the internet, as well as magazines and books related to the design problem. This gave them the opportunity to really understand the problem they had to solve. As it was a quasi-design experiment, I did not provide the opportunity for a site visit, as the participants do not normally go on site visits when given a design problem to solve. I introduced the participants to the camera technician, the procedures were explained and they were given the opportunity to practise the TAPS protocols to get used to the idea of verbalising their thoughts. The video recording started the moment the participants began to study the design brief.

Step 3: Standard introduction to the protocol instruction

As standard procedure for introducing the participants to the procedure, I gave the following instructions:

"I will hand out the design brief in a moment. You are requested to read the brief and perform this task in the way you normally would do in class. Please say aloud everything that you think or do when designing. The video camera will focus on capturing your words as well as any sketches you make."

Step 4: Conducting the concurrent protocols

The fourth step commenced after the physical interaction when the participants started and completed the remainder of the problem-solving process. My role as researcher was to provide information on request, but not to interfere with the pace of thinking or generating of ideas (Haupt, 2013; Lloyd, Lawson, & Scott, 1995). The participants solved the design problem in pairs, as the natural dialogue between them enhanced the flow of their thoughts. I treated these dialogues as data about the process as a whole by not analysing dialogues of individual participants (Van Someren et al., 1994). I sometimes had to remind the participants to think aloud when they became so immersed in their thinking while sketching, or during pauses, that they forgot to speak aloud (Haupt, 2013; Van Someren et al., 1994).

(c) Capturing the data

Each protocol was recorded on video. The voice data, general movements, gestures, sketching and writing of participants were captured. The video technician focused on recording the sequential verbal utterances, writing and sketching in order to capture all representations. Although the video technician was able to clear most of the background noise during editing, the audibility of the recordings was affected at some stages in the protocols. However, I was able to track initial missing spoken words from sketches, writing and visual information through multiple viewings. A further limitation was having only one camera, which limited the viewpoints from which participants' activities were recorded. Having more than one video camera at the same time might have provided me with more angles and a focus on more than one object at a time. Although I considered conducting TAPS in a recording studio, which would have ensured better quality recordings, the financial implications of such a decision would have been too great. Furthermore, I would also have taken the participants out of their natural working environment. I was able to track initial missing visual information from the spoken words or sketches through multiple viewings.

3.3.5 Analysis and interpretation

Data analysis and interpretation in this study involved organizing and explaining the recorded audio and video information in terms of the theory embedded in my conceptual framework (Figure 2.6). I derived this from the content of the participants' thoughts as represented in their verbal and visual data.

(a) Data analysis

Once each of the three groups had completed their design task, the video and audio recordings of their concurrent protocols were transcribed. I analysed the verbal and visual data that had been collected during the concurrent protocols. The transcribed protocols were then segmented into think-aloud utterances, divided into sentences and coded according to a priori themes which were regarded as modules when structuring data (Atman et al., 1999). The syntactics of the sketches was not analysed. Since the objective of the study was to examine what novices thought about while solving the design task, I only considered the semantics (content) of their sketches.

The analysis and interpretation processes began after the transcriptions had been completed. Because the principles of the selected critical realism stance (Maxwell & Mittapalli, 2010) were applied, both processes relied on the extended cognition theory that underpinned the conceptual framework of this study. I used a concurrent mixed methods analysis to generate and validate interpretations, formulate inferences and draw conclusions (Tashakkori & Teddlie, 2009). The QUAL+quan data were analysed in parallel (Creswell, 2003). For qualitative data, verbal transcriptions of the three concurrent TAPS protocols and the sketches produced by the participants were used to analyse their thoughts. This also enabled me to test whether the four levels of hierarchical thinking (aspects, functions, physical elements and implementation) could be identified among the participants. Quantitative data was drawn from the video recordings linked to the textual transcriptions of the protocols and provided temporal measurement of instances of occurrences of particular cognitive activities. This allowed me to count, objectify and support the qualitative data by identifying the exact point in time (quan) to which a particular text (QUAL) related.

Both inductive and deductive reasoning were employed (Cohen et al., 2007) for the analysis. For identifying what novice designers thought about, the theoretical categories of the conceptual framework assisted me in the use of an inductive approach. A deductive approach was used to structure the protocols in terms of cognitive phases.

(b) Structuring data for analysis

In order to analyse the data, I had to carry out extensive data structuring of the verbal data set. To organise the data in such a way that emerging patterns or connections could be identified (Goel & Pirolli, 1992; Haupt, 2013) and to reduce the data to manageable amounts without loss of complexity (Haupt, 2013; Tashakkori & Teddlie, 2009), data structuring was needed. The process of data structuring was, however, not separate from the analysis, but essentially part of it. It firstly involved editing, segmenting and summarizing, and secondly coding notations (remarking, codes, categories and themes), and developing connections amongst a priori categories, which I discussed in Chapter 2. The research questions and theory implied in this study provided the focus for the data structuring process.

My aim was to examine empirically and describe the way in which novice designers transformed and represented their various intentions in the early phases of the design process. Each of the three data sets was accordingly structured and analysed individually according to a stringent and consistent strategy. The first step in structuring the data entailed the identification of the three primary categories summarised in Figure 3.1.

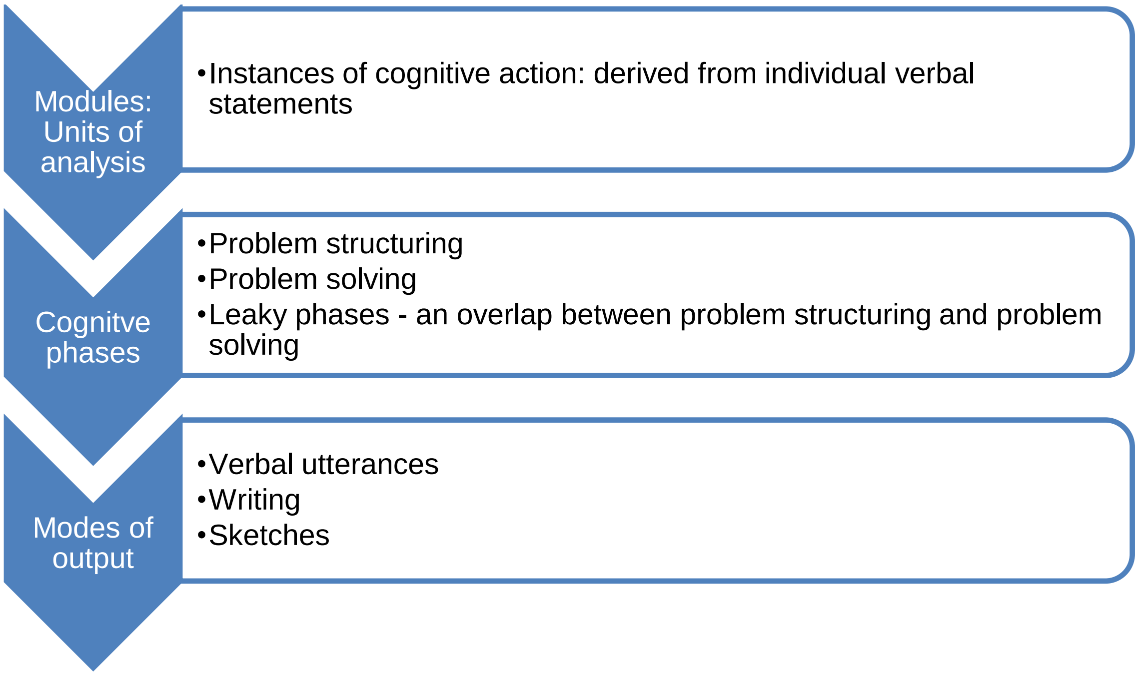


Figure 3.1: Primary coding steps in the qualitative data structuring process for verbal and visual data

This process of structuring the data sets entailed working with the qualitative data within the structure provided by the temporal identification of participants' verbal utterances. The data was structured in terms of a priori theoretical categories according to my conceptual framework, as discussed in Chapter 2. These sections assisted me in examining the content and context of the verbal data. The 'modules' and 'modes of output' identification process had no connection with the theories underlying this study but were only used to break the data into more manageable chunks, as described in the following steps.

Step 1: Identifying cognitive phases

The process of identifying the cognitive phases was the first step in applying Goel and Pirolli's (1992) procedure for analysis of design problem phases. I used particular operators as suggested by Goel and Pirolli (1992) to construct when and how participants' cognitive processes moved between problem structuring, problem solving and leaky phases, as discussed in Section 2.3. I labelled all the statements (verbal utterances) according to the function they served in the problem space and assigned an operator to it (Goel & Grafman, 2000). I found the following seven operators, as identified by Goel and Grafman (2000), adequate for my purposes: *commenting, qualifying, elaborating, justifying, evaluating, proposing and repeating* to indicate when and how the participants' cognitive processes moved between problem structuring, problem solving and leaky phases.

Step 2: Segmenting the content of protocols in themes and sub-themes

The step after problem structuring and problem solving was to segment the protocol content into themes and sub-themes. The purpose of segmenting was to determine the attention and knowledge the participants used. Designers normally require and use multi-disciplinary knowledge about the technical aspects of artefacts, social aspects of people, and the complex interaction between artefacts, people, and the contexts in which artefacts are used (Love, 2000). Such knowledge can facilitate an understanding of understated design problems and requirements of solutions, hence proposing solutions (as discussed in Section 2.3).

Step 3: Structuring data for hierarchical thinking

After segmenting the content into themes, I went on to structure data for hierarchical thinking which consisted of four independent steps, namely aspectual intentions, functional intentions, physical elements and implementation intentions. Data on aspectual intentions was structured in terms of things that the participants thought were important to aim for in a solution. Out of a possible 15 different aspectual intentions (as discussed in Section 2.6.1), I had to identify which ones the participants contemplated that supplied meaning in the way they selected and developed their ideas. Data on functional intentions was structured by asking the question: What is it for? as suggested by Kroes (2006). Data on physical objects and elements was structured on geometrical descriptions and the physical make-up of the artefact (Kroes, 2006). Lastly, data for implementation intentions was identified through verbal utterances and sketching to apply physical elements to functional and aspectual intentions (Haupt, 2013). The structure of verbal data in the levels illustrated in Figure 3.2 served the methodological purpose of systemizing my investigation and enabling me to quantise occurrences and co-occurrences of the various categories and sub-categories.

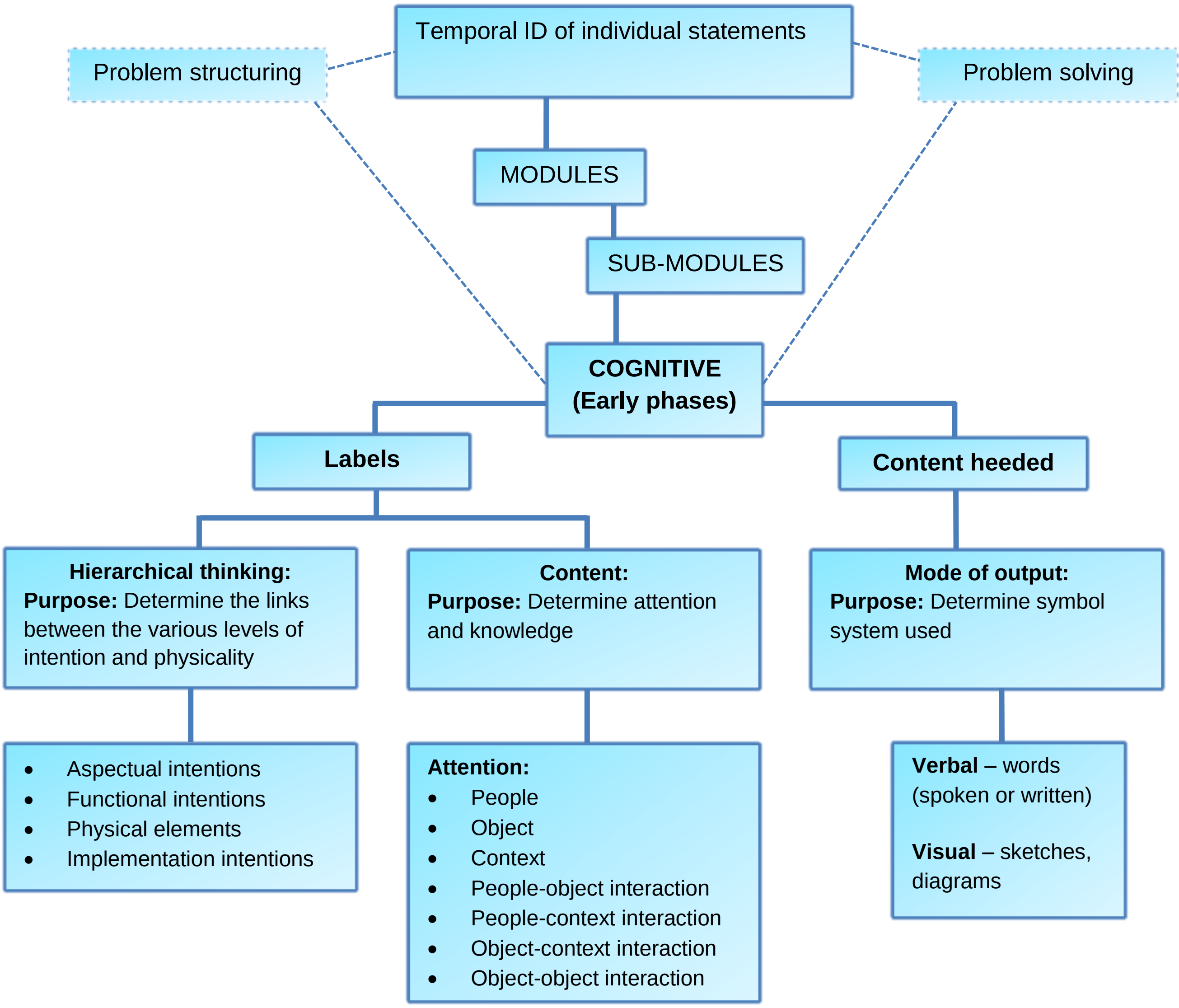


Figure 3.2: Coding tree for structuring analysis of verbal data

(c) Data analysis procedure

I will now provide a plan of the QUAL+quan analysis procedure that was followed:

- Transcribe the verbal data recorded on video of the three concurrent TAPS protocols.
- Analyse verbal data by individuating episodes and segments on the core data set.
- Individuate verbal data of aspectual intentions on supporting data set.
- Individuate verbal data of functional intentions on supporting data set.
- Individuate verbal data of physical elements on supporting data set.
- Individuate verbal data of implementation intentions on supporting data set.
- Individuate and categorise cognitive phases (problem structuring, problem solving and leaky phases) of the design process.

- Quantise qualitative data of temporal measurement and counts of occurrences.
- Relate sketches to verbal data on core data sheet.
- Consolidate integration by drawing relationships between verbal data, categories of supporting data sets and visual data on the core data sheet.
- Conclude integration by interpreting and drawing conclusions of fully integrated QUAL+quan (verbal + visual) material leading to meaning making.

I decided to analyse the data manually, as the mapping and distribution of the four levels of hierarchical thinking underlying the vocal utterances and sketches are complex. I decided to use EXCEL to capture and analyse qualitative and quantitative data based on the following aspects:

- Its visual and spatial qualities.
- The way it provides easy access to particular quotations, codes and memo and allows the researcher to work with data in the form of text and/or graphics.
- The way it provides a platform for facilitating the cross-referencing of data and enabling the researcher to develop associations.

(d) Data interpretation

Data interpretation was driven by the theory of global precedence in gestalt. Global precedence is a simplicity-based hypothesis which states that the processing of information proceeds from global structures towards the analysis of local properties (Wagemans et al., 2012). The assumption is that conceptual insights are represented by a hierarchical system with nested relationships. The application of this insight to the interpretation of data is that I had to identify the more global concepts, which involved the aspectual intentions at the top of the hierarchy as demonstrated in Figure 2.6. The aspectual intentions had to form the essence of the participants' drive to find a solution. They therefore had to precede the local properties, which consisted of functional intentions, physical elements and implementation intentions.

After interpreting a coherent and fit for purpose solution through hierarchical thinking, I had to determine whether abstract thinking had moved closer to concrete thinking. Data for hierarchical thinking could only be interpreted where verbal utterances of aspectual and functional intention statements occurred in the same instance. The next step in interpreting hierarchical thinking was to search for tangible evidence of participants connecting functional intentions with physical elements and, by implication, meeting vague aspectual intentions. In other words, I looked for structural descriptions that specified the actual physical make-up of the artefact and connected it with its intended function. Lastly, the local properties found at the bottom of the hierarchy, known as implementation intentions, had to represent the designers' confidence about what they perceived as the most likely physical elements to fit the abstract intentions.

3.3.6 Quality assurance strategies

To ensure that the data is valid and reliable, quality assurance, which involves the verification of measures (Onwuegbuzie & Teddlie, 2003), has to be carried out. This study utilised TAPS protocol data (verbal data) supported by sketches (visual data) to achieve a logical and appropriate integration of rigorous and systematic QUAL+quan research strategies. However, in qualitative research, replication is not possible, as repeating the same research will not generate exactly the same results as before, owing to the dynamic nature of people (Merriam, 1998). The extent to which the explanations of quantitative results are seen as applicable, acceptable, and appropriate in research suggests that they are reliable and valid. Validity is the process of collecting valid evidence. Therefore, ensuring validity and establishing data trustworthiness require triangulation to check the extent to which conclusions based on qualitative sources are supported by quantitative sources (Maree, 2011). Such measures are therefore needed for this study to provide the quality that exists in construct-related validity and reliability.

(a) QUAL measures

Rigour in qualitative research is described by Denzin and Lincoln (1994) in terms of its credibility, transferability, dependability, conformability and authenticity. Credibility in qualitative studies is the ability of the researcher to make trustworthy inferences. To ensure credibility I attempted to provide rich contextualised descriptions of my findings to enable the reader to critique my findings in a meaningful way (Pyett, 2012). I furthermore revisited the data while constantly testing interpretations by staying close to the underlying theory of extended cognition as well as my own constructions of participants' meanings (Finley, 2002). Triangulation was used to enhance credibility (see Figure 3.1 p.45). Triangulation reduces the risk of chance associations and helped me (the researcher) to formulate better explanations of actions (Maxwell, 1996). Credibility through triangulation in this research was established by using three pairs of participants, the sketches produced by the participants, and also their verbal protocols. I achieved triangulation by observing the differences and similarities between participants' data and internal single-group patterns. As an additional measure, I asked knowledgeable experts in the field of research design, as well as my supervisor, to scrutinise my coding and interpretation as well as my own readings and re-readings of participants' representations. My intention with triangulation was thus to keep my own voice as neutral as possible, as well as to identify some of the 'truths' in the reality of novice designers' cognition as faithfully as possible (Creswell, 2003) (see Figure 3.1, p.45). Constant consideration of the a-priori theoretical constructs provided by my conceptual (Figure 2.6) and theoretical framework assisted me in achieving this goal.

To ensure dependability and an audit trail to confirm the ability of the participants' authentic world, interviews for member-checking purposes were carried out with all three groups (see Figure 3.1, p.45). During these sessions, I aimed to understand what the participants thought about and the ways they connected intentions with their physical environment by producing faithful descriptions of their words. Following on from that, I took the descriptions and systematically organised and correlated them in terms of my conceptual framework, with the aim of reaching self-understanding in a deductive manner (Patton, 2008).

I also tried to enhance dependability by means of inter-rater reliability (see Figure 3.1 p.45), which was achieved by asking an independent design lecturer from a local university to identify the cognitive phases of one of the randomly selected groups in this study. The design lecturer identified the moments when the groups' cognitive processes moved between problem-structuring and problem-solving phases, using the same procedure for analysis of design problem phases that guided this study. The following formula determined the consistency of the agreement between the independent design lecturer and myself (Jackson, 2006):

$$\text{Inter-reliability} = \frac{\text{Number of agreements}}{\text{Total number of cognitive instances}} \times 100$$

$$= \frac{154}{170} \times 100$$

$$= 91\%$$

A review of the independent design lecturer's identification revealed that the small disagreement noted above (9%) could be attributed to the fact that problem structuring and problem solving sometimes overlap, which makes it difficult to distinguish where the one phase ends and the other starts (Goel & Pirolli, 1992). Sixteen instances of problem structuring which could have belonged to more than one cognitive phase were identified in the other cognitive phase.

I also tried to enhance dependability by means of the findings, as TAPS are context-bound and therefore limited in confirming results. Dependability indicates that, if the study were to be repeated in exactly the same way, the findings would correlate. I attempted to leave a clear audit trail (Lincoln & Guba, 1985) for an auditor to examine the documentation on which my research findings were based (Ericsson & Simon, 1993). The audit trail consisted of:

- The design brief given to the participants (Appendix A)
- TAPS protocol transcripts for each of the three groups (Appendix B)
- Sketches made by the participants (Appendix C)
- Plan of the QUAL and quan analysis procedure (see Section 3.3.5)
- Data structuring and analysis products of the three groups (Appendix D)
- Theoretical notes on the coding system to structure and analyse the data (Appendix E)

Ensuring that the risk in employing a mixed methods approach did not reduce the study's qualitative measure of transferability, I aimed to achieve a logical and appropriate integration of rigorous and systematic qualitative and quantitative research strategies (Onwuegbuzie & Teddlie, 2003). I attempted to provide sufficiently thick, rich descriptions to allow the readers of this study to determine whether transferability had been successful (Cohen et al., 2007). I also tried to achieve temporal identification of participants' verbal utterances with snapshots taken from the video recordings on the sketches made by the participants to enhance triangulation.

(b) Quan measures

The quantitative measures for quality assurance for this study required internal validity, task validity, face validity, content validity and construct validity. I made use of basic descriptive statistical methods ensuring validity of coding, interpretations and results. Validity required me to understand the data adequately and to represent participants' meanings (Onwuegbuzie & Teddlie, 2003). Reliability as a quantitative measure of quality was not raised, as I had no control over the naturalistic setting in which the participants could be true to their habitual ways of solving design problems.

Validity of the design task

Design problems are ill-structured and typically large in size, complex and vague (Goel, 1995). As this ill-structuredness plays a significant role during the early phases of the design process of designers, it was expected that the design tasks I gave the participants should be sufficiently ill-structured and representative of their design experience. I used internal validity in validating the ill-structured design tasks the participants were expected to solve (Goel, 1995). The validity of the design tasks as conceptualised for this study refers to the extent to which they comply with the requirements for ill-structured problems.

Face validity

The extent to which an instrument 'looks' valid has to do with face validity (Maree & Van der Westhuizen, 2009). Face validity cannot be tested or measured; I therefore had to get expert lecturers in the field of industrial design to agree on the face validity of the design tasks given to the participants. The industrial design lecturers from a local university in Pretoria confirmed the ill-structuredness of the design task which I had prepared for the novice design participants.

Content validity

As Cohen et al. (2007) explain, content validity signifies the extent to which the instrument includes the complete content of the particular construct that one intends to measure. I attempted to achieve content validity by conducting a concurrent TAPS, as it has been acknowledged (Ericsson & Simon, 1993) that this produces valid data on design thinking.

Construct validity

Construct validity is needed to standardise the interpretation and meaning-making of the scores resulting from the use of the instrument (Maree, 2011). Thus, construct validity in the context of this study has to do with how well the various levels of intentions, functionality and physicality covered by my conceptual framework measured hierarchical thinking amongst the three pairs of participants (Maree, 2011). The data-collection procedures consisted mainly of inter-construct validity employing criteria from the conceptual framework of this study, which was closely linked to criterion validity. Criterion validity is most likely the ultimate test of whether an instrument measures what it is supposed to measure. The correlation between scores on an existing instrument (criterion) and the instrument used in the current study is referred to as criterion validity (Maree, 2011). For this study, I kept to three internal quality conditions, namely relevance, consistency and memory (Ericsson & Simon, 1993).

Firstly, the underlying theory of the relevance to the given design task of verbalisations where participants made comments with no relevance to the task could not be considered pertinent or valid data. Secondly, internal consistency is achieved when a number of items are formulated to measure whether a certain construct produces a high degree of similarity among them. I attempted to achieve internal validity among the three pairs of participants by validating the role of global precedence in the hierarchical thinking of the participants in terms of a priori theory. The third condition, memory, relates to the belief that a sub-section of the information that participants look at in their protocols will be remembered (Ericsson & Simon, 1993). In other words, while thinking aloud, much of the information came to the participants' conscious attention and would be remembered and made available for successive retrieval. This remembering and retrieval of information allowed the participants to process and solve the design task and were seen as internally part of the same mechanism. As such, construct validity helped me to consistently apply TAPS as a unitary and standardised process.

3.3.7 Challenges as a result of my methodological choices

A characteristic of the research process was that some elements could be controlled while others were impossible to control. The first challenge implied by the methodological choices I made meant proper preparation and administering of the tasks which the participants had to perform (Ericsson, 2006). Poor planning and administration could have seriously affected the protocol results, but I prevented this by turning up on time and making sure that the venue the participants used was properly set up before each protocol session began.

A second challenge was to choose a sampling method that would ensure that the selected participants were representative of top-performing third-year industrial design students at the University of Johannesburg (UJ). To minimise the risk of not selecting the right students, I chose a purposeful sampling method from which most could be learned (Merriam, 1998).

The third challenge was to prepare one ill-structured design task which would be at the appropriate intellectual level of ability for all the participants (Goel & Pirolli, 1992). I involved experts in the field of industrial design to help formulate an appropriate design task.

The fourth challenge, that of maintaining control, was met by making minor adaptations to typical experimental protocol requirements, such as the number of groups, the nature of group members and the setting in order to enhance the naturalistic task environment (Haupt, 2013). I created a non-threatening safe environment in which the participants could be true to their habitual ways of solving design problems. To ensure control of the protocol structure, all three groups of participants were given the same design task (Van Someren et al., 1994). The output requirements of the design process for each protocol was also controlled, namely to produce verbal utterances and concurrent sketches, from problem structuring to the point when a satisfactory solution was generated (Goel, 1995). It was, however, a challenge to get one particular group to verbalise their thinking, as one of them would stop talking while sketching an idea. I would then prompt them to verbalise their thoughts. Studies using both the conventional and adapted verbal protocols have proved to be a key instrument to elicit scientific data in the design context (Cross, 2001b; Goel, 1995; Haupt, 2013).

The fifth challenge involved the sampling of units of analysis that would be representative of the participants' thoughts and would ensure internal as well as external validity, which necessitated creativity yet parsimony. This challenge was addressed by combining theories and approaches, combining visual analysis with verbal analysis, yet staying close to the theories from which my coding constructs ensued.

The sixth and last challenge was the fact that, in employing a mixed methods design, I faced the risk of reducing the complexity of the study through simplified quantitative processes. I therefore attempted, through the combination and integration of the mixed methods approach, to successfully represent the complexity of design cognition. The complex representation of design cognition was achieved by correlating the quantitative and qualitative parts of the data with one another, which provided richness, depth and confirmation of the findings and their interpretation.

3.4 Role of the researcher

As researcher, I acted as a non-participatory observer in a quasi-experimental setting during three separate sessions of concurrent TAPS protocols, as suggested by Cohen et al. (2007). As a result, I had to create uninterrupted 'normal' studio conditions in which the participants could be true to their habitual ways of solving design problems. It was not my aim to understand the socially and experientially constructed realities of the participants, but rather to identify some of the 'truths' in the reality of novice designers' cognition as faithfully as possible from a critical realist view point (Guba & Lincoln, 2008)

My role as researcher required me to provide the participants with particular information during the problem-structuring phase so that they could understand the context of the problem (Goel, 1995). My involvement was typical of what one would expect from an Industrial Design lecturer, not amounting to unnatural interruption and keeping keep the natural flow of the participants' thoughts as close as possible to their normal way of thinking.

I avoided getting involved during the rest of the participants' problem-structuring and problem-solving phases. This allowed me to focus on any signs, subtle or obvious, of participants engaging in thinking about potential solutions and not about understanding, structuring or solving the problem. I took on a critical realist position through observation during the participants' problem-solving phase while they engaged in sketching, reasoning and processing information. Because the participants were novices, I focused on the way and order in which they reasoned to establish gestalt, rather than wanting to interrupt them with my opinion of their thoughts.

3.5 Ethical considerations

As a researcher, I have to respect audiences and use non-discriminatory language. According to the University of Pretoria's research guidelines, the researcher also has to respect the rights of the participants in a study. Furthermore, reporting the research completely and honestly is important to the audiences who read and use the information from the study. To actively interpret the principles of this individual research project, I needed to tailor the ethical guidelines to suit the unique context of my study (Creswell, 2003). According to Cohen et al. (2007), a credible research design involves not only selecting participants and employing effective research strategies, but also adhering to research ethics. For this study, I observed all the ethical considerations specified by the Ethics Committee of the Faculty of Education, University of Pretoria. The strategies I employed in order to address the ethical requirements are discussed in this section.

As all participants are university students who can provide informed consent, the only permission I required from the institution was the permission to conduct research. I applied for permission from the Faculty of Art, Design and Architecture at the University of Johannesburg (UJ) to conduct my research with third-year industrial design students. A convenient time to speak to the third-year industrial design students at UJ was arranged with the responsible lecturer. I explained my research study to the students and asked them to participate voluntarily in my study. Those who wished to participate were asked to provide me with their contact details. I then selected the six top-performing students from the list with the help of UJ's industrial design lecturers. The students who had been selected received letters of invitation to participate which stated their right to voluntary participation, the purpose of the study, the advantages and risks, and the procedures. They were also reassured that no victimisation would take place should they decide to withdraw early from the study. Cohen et al. (2007) claim that one cannot anticipate what may be intrusive for each participant, so a typical protocol does not always fit all qualitative research. All six participants signed the informed consent letters, and no participants withdrew from the study (Cohen et al., 2007).

To control any challenges to confidentiality, anonymity and respect for privacy, I reassured the participants that I would not share any data with others, with the exception of my supervisor during the course of the research process (Cohen et al., 2007). I ensured the participants' privacy through anonymity and confidentiality during the disseminating phase of the study by not identifying any information with respect to their identities, personal information or the university where I was conducting the research. The participants' right to privacy was however violated during the course of the sample-selection and data-collection phases of the study, which I explained to them prior to conducting the study.

I ensured anonymity in the data-collection phase by modifying all the participants' information in the transcripts of the protocols and notes about sketches by creating pseudonyms. I also ensured that the demographic information was insufficient to identify participants during the dissemination phase of the study. The participants' identities were also kept anonymous in the dissemination of the findings. To ensure confidentiality, all the participants' names in the raw data, my research diary, DVDs, transcripts and other data were changed and kept in a secure environment.

Participating in this study might have had a positive impact on the participants through their allowing me into their physical and mental space (Cohen et al., 2007). I promised them a complete debriefing session on their thought processes during the protocols should they wish. The potential outcome and benefits of this research were explained to the participants at the beginning of the study. These benefits included a growing self-awareness of their own design process as well as their own reasoning skills in solving design problems (Haupt, 2013).

During my interactions with the participants, I protected their general and psychological well-being by respecting them as individuals. I did not expose them to any risks or harm, although they might have felt awkward verbalising their thoughts during the problem-solving activity. Participants might also have feared the discovery of their possible incompetence with regard to solving the problem. To make the participants feel welcome and to win their trust (Van Someren et al., 1994), I adopted a non-judgemental attitude towards them, because I wanted to create an atmosphere conducive to best performance. Participants also learned to trust my motives and research abilities when I explained my personal and academic interest in the thought processes of novices to solve design problems. Participants thus became aware of the educational benefits that this study holds. Their enthusiasm to learn more about their own reasoning skills and to make a contribution towards a better understanding of how to improve the education of designers was clearly expressed.

No information related to this study was withheld from the participants, nor did I mislead them in any way. I strived for a neutral and objective approach (Cohen et al., 2007; Van Someren et al., 1994) through the use of critical realist principles. As a non-participatory observer during the concurrent protocol studies I attempted to accurately describe the participants' thought processes. I therefore declare that I observed the principle of accuracy for reporting on the data I collected, which was not falsified or fabricated. I continually guarded against manipulating the data and reflected honestly on the inherent challenges of the study. I believe that, as an industrial design lecturer with a personal and professional interest in improving current design education practices, I was able to conduct this study in an ethical and competent manner.

3.6 Conclusion

In this chapter I explained the research process that I employed. I also justified the research methodology in terms of the purpose of the study and how best to answer the research questions. Furthermore, the strengths and challenges of selecting a mixed methods approach were discussed. Challenges I faced as a result of my methodological choice were also reported. In addition, my research role as a non-participatory observer in this study, together with the strategies I employed to obtain trustworthiness, validity and reliability to adhere to research ethics, was described. The following chapter deals with the findings, explaining how the data was interpreted, and provides the theoretical underpinnings of the inferences made to answer the research questions.

Chapter Four

Results of the Study

4.1 Overview of the chapter

In Chapter 3, I described the methodological part of my empirical study. I validated my research design, as well as other methodological choices, in terms of the research questions and the purpose of my study as framed in Chapter 1. This chapter seeks to answer the main research question of this study, namely:

What is the role of gestalt in Industrial Design students' hierarchical thinking in the design process?

Chapter 4 presents and discusses the salient results of the three protocol studies in which three groups of industrial design students worked in pairs to solve an ill-structured design problem. Section 4.2 provides an overview of the design task environment in which the participants solved the ill-structured design problem. This is followed by Section 4.3 where I discuss the distribution of distinct cognitive phases found in the TAPS across participants. In Section 4.4, I present the distribution of gestalt thinking guided by global precedence between the various types of intentions (aspectual intentions, aspectual intentions linked with functional intentions, functional intentions linked with physical elements and implementation intentions) amongst the problem-structuring and problem-solving phases. Section 4.5 provides the results of my study on novice designers' thoughts in problem structuring, and Section 4.6 presents the findings on problem solving. I conclude this chapter by explaining how novice designers in an extended design cognition context applied the gestalt principle of global precedence to solve design problems.

4.2 Design task environment

I managed to control some aspects of the design task environment in order to focus on particular phenomena and cognitive processes represented in the think-aloud protocols. One of these aspects was the input information, which was the deliberate formulation of design tasks that provided only a small amount of information in the design brief. The reason for providing a small amount of information was to give the participants unrestricted opportunities to search and access information internally as well as externally. Supporting external information and resources were equally available to all groups. Furthermore, I considered the extent of internal knowledge to be similar in all participants. Research on the early phases of the design process suggests that the knowledge novices use is primarily based on common-sense knowledge which is domain-independent (Lloyd & Scott, 1994; Popovic, 2003, 2004) The reason novices use domain-independent knowledge is that they lack the experience to know which conceptual thought is the best to solve the problem (Popovic, 2004). I therefore focused on the domain-independent processes, including knowledge that the participants accessed and transformed, to understand the role of gestalt in novices' hierarchical thinking (Goel & Pirolli, 1989; Liikanen, 2009).

I did not have control over the participants' ability to determine their own interpretation of the scope and complexity of the artefacts. Also, the way the participants used and transformed internal and external resources was not specified, except for the use of hand sketches.

The participants' task involved the design of a multi-purpose seating surface for people living in low-income housing (Appendix A). I did not provide the participants with information on specific materials or manufacturing processes to use, or what the intention was with a multi-purpose surface. Each group worked at the same venue in different time-slots and received the same brief, a computer laptop connected to the internet and a stack of magazines and books related to the design problem. The participants were free to use any of these support materials at any time during their design process.

The following section provides evidence of the intersections of extended cognition and global precedence in the thinking of novice designers during the early phases of the design process. In Section 4.3, I discuss the distribution of distinct cognitive phases found in the TAPS across participants. In Section 4.4, I discuss the distribution of various types of intentions amongst the problem-structuring and problem-solving phases. Section 4.5 provides the results of the novice designers' hierarchical thinking in the problem-structuring phase. Following on from Section 4.5, Section 4.6 provides the results of the novice designers' hierarchical thinking in the problem-solving phase.

4.3 Distinct cognitive phases

In Chapter 2, I elaborated on the nature and role of distinct cognitive phases, which consist of problem structuring and problem solving. It is common for these two phases to overlap at times, which makes it difficult to distinguish where the one phase ends and the other starts. This overlap is known as a 'leaky module' (Goel & Pirolli, 1989, p.30). The problem-structuring phase involves searching for information that has not been provided in the design brief, and which is needed in the design problem space to further inform understanding of the problem (as discussed in Section 2.3.1). I included this sub-section to establish whether distinct cognitive phases in the early phases of the three protocols existed, in order further on to answer the sub-research question on the distribution of intentions amongst problem-structuring and problem-solving phases. Thus, for this section I wanted to provide evidence that all the protocols demonstrated distinct cognitive phases, starting with problem structuring followed by overlapping and problem solving.

Table 4.1 indicates that each group went through both phases of problem structuring and problem solving. The distribution of instances indicates what proportion of time was spent in each of the cognitive phases. From Table 4.1 it is evident that all the groups spent more time solving the problem than structuring it. I found that all the groups used domain-specific knowledge as well as information obtained during the design process by using their sketches to understand what the problem was and what they needed to solve. However, Group A's participants were more explicit in decomposing the ill-structured design problem into well-structured sub-problems, which made their design process more efficient (Ho, 2001). Group A's efficient problem structuring can be ascribed to fact that they had slightly more design experience than the other two groups, which I discovered in a follow-up interview. Furthermore, I found that each of the groups had unique types and sequences of activities in decomposing their design problems. Instances of problem structuring amongst the three groups only dominated at the beginning of the design task, but also reoccurred periodically throughout the task. This finding correlates with Goel and Pirolli's (1992) protocol studies of several types of designers (architects, engineers and instructional designers) where they also structured the problem first as a result of insufficiently provided information in the design task before solving the problem.

Table 4.1: Summary percentage of overall distribution of the two cognitive phases found in the TAPS across participants

	Phases	
Design group	**Problem structuring %**	**Problem solving %**
Group A	43	57
Group B	31	69
Group C	25	75

To establish where problem structuring instances occurred, I searched for statements about people, the purpose of the multi-purpose seating surface, and resources. I also identified as problem-structuring phases those instances when the participants were drawing upon prior knowledge, proposing ideas and adding concepts without committing themselves to a particular design. On the other hand, problem-solving instances were identified as those statements that gave detail and final form to some aspect of the multi-purpose seating surface. I also asked the question: Where did the participants elaborate and further their commitment to an already generated design or element? To identify overlapping, I asked the question: When did the participants simultaneously attempt to understand the problem and develop or detail ideas in that module?

4.3.1 Problem structuring

Instances of explicit problem structuring were evident when the participants read the design brief to make sense of the low-income housing context and how multi-purpose seating might be used. An example of such structuring is evident from Excerpt 4.1 (Group A's protocol), where they mentally created a problem-structuring space of a one-room house to see how multi-purpose seating could be used.

Excerpt 4.1

00:02:18 Katy:
It could be sponsored; it could be low-cost to be cheap. What about the multi-purpose?

00:02:25 Eric:

So maybe if it's like a low-cost house you would only have one room, so your seating might have to be your bed, you might use it for a *lessenaar*-type thing.

I considered the participants' attempt to structure the problem space when I could observe how they were applying their domain-specific knowledge of using a systematic sequence of design processes through formal instruction in design methodologies. Their first step was to construct new knowledge by deliberately searching for information to understand the given problem and what they were expected to achieve. This entailed establishing its scope, constraints, requirements and specifications. This inference is supported by studies on novice design students: when given an ill-structured design problem, they ask 'what', 'where' and 'how' questions "to break down the problem and to identify constraints and criteria" (Kelley, 2008, p.57) . An example of such structuring is evident from Excerpt 4.2 (Group A's protocol).

Excerpt 4.2

00:07:51 Katy:

Which is hard, you need to research it maybe; you would need to research that.

00:07:54 Eric:

Maybe, yes. And also, but where would they use seating, for instance, do they use it to study, to dine, do they just need a space to lounge around or to be seated on, so what type of seat, what purpose must the seat [serve], what must the seat look like, is it a lounger or is it like a bench, do they have big families, do they bring their friends over and ...?

4.3.2 Problem solving

The cognitive phase of problem solving is when the information and detail relating to the problem are taken into consideration (Goel & Pirolli, 1992). I found explicit strategies in the participants' problem-solving phases, which consisted of detailed statements about some aspect of the design to give final form as seen in Excerpt 4.3 (Group B's protocol).

Excerpt 4.3

00:33:24 David:
Oh are you thinking is this actually sort of flush on that line?

00:33:29 Tsepo:
Yes.

00:33:30 David:
The thing is if it meet[s] flush on that line there it would have we would have to take it downward for this if it did need to slide past here because this, if these are flush, this face and this face, what it means then is that this is quite wide in that respect, the same width as the outside edge.

4.3.3 Overlapping

Instances of overlapping were evident where elements of problem structuring and problem solving overlapped as a result of sub-problems and the generation of conceptual solutions. Some of the participants' sub-goals were solved instantly, while others were solved at different times during explicit problem-solving phases. In some cases sub-goals were even ignored. Excerpt 4.4 illustrates how the participants from Group B made a decision as they raised a question to further structure their problem. Overlapping in Excerpt 4.4 was evident where problem structuring consisted of asking questions relating to a suitable material and material thickness for designing a multi-purpose seating surface. Simultaneously a solution was developed by proposing 16mm melamine face chipboard to keep the cost of manufacturing down, thereby making it affordable for their target market.

Excerpt 4.4

00:30:38 Tsepo:
And what is this wood?

00:30:39 David:
I think it would be a nice contrast if we looked at, we can even have like a darker-coloured wood as long as we do a nice contrast between the two so that they speak to each other, they communicate that they are one piece together.

00:31:02 Tsepo:
And how thick is this?

00:31:03 David:
What now, the ... The actual thickness of the board? This would have to be manufactured standard board, so even if we looked at like 16mm, so it would have to have a slight thickness. It can even be like melamine face chipboard and like for the upper-market ones you could look at doing like solid wood or like a nice meranti or something stained nicely, sanded down, but for the lower income households this melamine like veneered with the same kind of wood so that it just wouldn't have the same like quality feel but obviously for cost of manufacturing.

The following section provides the distribution of various types of intentions amongst the problem-structuring and problem-solving phases.

4.4 Distribution of the various kinds of intentions amongst the cognitive phases

The aim of this section is to present the distribution of gestalt thinking guided by global precedence between the various types of intentions (aspectual intentions, aspectual linked with functional intentions, functional intentions linked with physical elements and implementation intentions) amongst the problem-structuring and problem-solving phases. Aspectual intentions serve as the overarching design aspect that mechanises the global precedence principle, which consequently forms the filter through which selections are made on all the subsequent levels of designers' hierarchical thinking (as discussed in section 2.6.1). This section is only a summary of the main trends I observed amongst the three protocol groups' hierarchical thinking; detailed descriptions are provided in Sections 4.5 and 4.6.

4.4.1 Aspectual intentions

The participants from all the groups considered the global precedence principle of gestalt thinking, which originated from distinct design aspects that gave meaning and direction to the way they selected and developed ideas, committed to some and rejected others. During the problem-solving phase, more instances of aspectual intentions were recorded compared to the instances in the problem-structuring phase, as indicated in Table 4.2. In the problem-structuring phase, very little thought had been given to detail in the object the participants were designing, as they were still in the thinking process of framing the problem. Furthermore, I found a logical connection that demonstrates a hierarchy of importance in their thinking, which correlates with Haupt's (2013) findings on hierarchical thinking.

Table 4.2: The distribution of aspectual intentions amongst the cognitive phases

Aspectual intentions	**Design groups**		
	Group A	Group B	Group C
No. of references in problem structuring	229	115	92
No. of references in problem solving	349	319	358

4.4.2 Aspectual intentions linked with functional intentions

In general I found that, when the participants interacted with various internal and external sources of information, including their design brief, domain-independent knowledge and novice design experience, functional thoughts materialised. I could also link their functional thoughts to their aspectual intentions (see Sections 4.4.2 and 4.5.2).The link between the participants' internal aspects and relevant functional intentions suggested a self-regulating mechanism in an attempt to achieve coherent gestalt (Kieran, 2011). Furthermore, the links between the functional and aspectual intentions during the problem-structuring phase were in all protocols fewer than those in the problem solving phase, as indicated in Table 4.3.

Table 4.3: The distribution of aspectual intentions linked with functional intentions amongst the cognitive phases

Aspectual / functional intentions	**Design groups**		
	Group A	Group B	Group C
No. of references in problem-structuring phase	17	11	6
No. of references in problem-solving phase	21	11	10

I also observed that the problem-structuring phase was dominated by analytical design aspects. The analytical aspects in turn were linked to functional thoughts with people-object related themes. Compared to the problem-solving phase, the design aspect most often implied in the protocols is that of 'formative'. The formative design aspect of the participants was identified as the aspect most often linked to their functional intentions, which related mainly to the theme of the object. Based on the results of this study, aspectual intentions seem to take priority over functional intentions in the hierarchy of novice design thinking.

4.4.3 Functional intentions linked with physical elements

The participants in all the groups connected functional intentions with physical elements and, by implication, vague aspects. As the participants turned their initial vague abstractions into detailed expressions of thought, I noted that their levels of specificity and amount of information increased. The increase in references to physical elements in all three protocols progressed from problem structuring to problem solving, as indicated in Table 4.4.

Table 4.4: The distribution of functional intentions linked with physical elements amongst the cognitive phases

Functional intentions / physical elements	**Design groups**		
	Group A	Group B	Group C
No. of references in problem-structuring phase	15	12	3
No. of references in problem-solving phase	28	30	23

Furthermore, I observed, through the participants' verbal utterances supported by visual representations, their use of general as well as domain-dependent knowledge in recognising which physical elements would appropriately create coherent gestalt with selected aspectual and functional intentions of the artefacts they were designing. However, the process of linking the various intentions and physical elements was a lengthy one, because the participants made several decisions using the same procedures to identify and explore sub-solutions in detail until they had made the right decision. Such trial-and-error application processes correspond with Popovic's (2004) findings on the difficulty novices have in deciding which representation is the best to solve the problem.

4.4.4 Implementation intentions

In general, each participating group had definitive instances where they hierarchically linked their physical elements to aspectual and functional intentions to meet their implementation intentions (see Section 4.5.4). These hierarchical links were characterised by close association with objects and their physical and functional properties. I also noted that the implementation intentions of the participants' solutions developed incrementally in the problem-solving phase and not when they structured the problem (Lloyd & Scott, 1994). Furthermore, the participants' implementation intentions materialised in the way their verbal statements increased in detail and specificity, supported by their sketches, which played a transformative role in establishing gestalt. The transformative role of establishing gestalt happened as the participants visualised (internally and externally) implementation through construction recombination and the manipulation of physical elements in the problem-solving phase (Haupt, 2013).

The following section provides the findings of my study on novice designers' hierarchical thoughts in problem structuring, and Section 4.6 provides the findings on problem solving. I explain both what the participants thought about and how these thoughts connected with each other. I focus in particular on thoughts about the artefacts they designed using an extended cognition theory of hierarchical thinking, and the philosophical aspectual notions governing their choices about the artefact, its functional aspects, its physical elements and implementation intentions.

4.5 Hierarchical thinking in the problem structuring phase

In this section, I contextualise the notion of hierarchical thinking using the gestalt principle of global precedence in the problem-structuring phase. This theme contains four sub-themes, namely aspectual intentions, aspectual intentions meeting functional intentions, functional intentions meeting physical elements, and implementation intentions. The problem-structuring phase involves searching for missing information which relates to various intentions on four levels to establish coherent gestalt thinking of global precedence. I found that the participants' problem-structuring phase was driven by aspectual intentions, functional intentions and physical elements, but not supported by implementation intentions. Implementation intentions are closely linked to the notion of making and propagating commitments, which typically takes place during the problem-solving phase and not when designers structure the problem (Haupt, 2013; Lloyd & Scott, 1994). In reporting on aspectual intentions, I decided not to discuss each design aspect that the participants considered, but to select from the four highest-scoring aspects (shown in Figures 4.1, 4.2 and 4.3) that guided their attention to select and develop ideas. These aspectual intentions are derived from Dooyeweerds' modalities framework (Appendix F).

4.5.1 Aspectual intentions

Aspectual intentions are abstract thoughts. As first sub-theme, it serves as the overarching design aspect that mechanises the global precedence principle, which consequently forms the filter through which selections are made on all the subsequent levels of designers' hierarchical thinking. Thus, aspectual intentions precede and are more global than local properties in guiding designers' attention to their intentions in a top-down fashion (as discussed in Section 2.6.1). When the participants referred to a particular aspect, their knowledge of the aspect was implied and not necessarily explicated. It also meant that the participants could choose when to apply and follow particular aspects, and when to disregard them without rejecting their validity. Furthermore, Dooyeweerd in Basden (2000) explained that aspects play a normative role and are complex, and that all aspects contain echoes of each other (as discussed in Section 2.6.1). Thus, I acknowledge that my coding and interpretation are left open to debate. In the following sections, I explain how the participants considered aspectual intentions during the problem-structuring phase using Dooyeweerd's model (Appendix F). I used the participants' vocal utterances to inform me about their aspectual intentions.

(a) Group A

The participants from Group A considered distinct design aspects which gave meaning and direction to the way they selected and developed ideas, committed to some and rejected others. Of fifteen possible abstract aspects, I identified fourteen aspects that the participants from Group A considered during the problem-structuring phase. In Figure 4.1, I have summarised the aspectual intentions and the number of times they were identified.

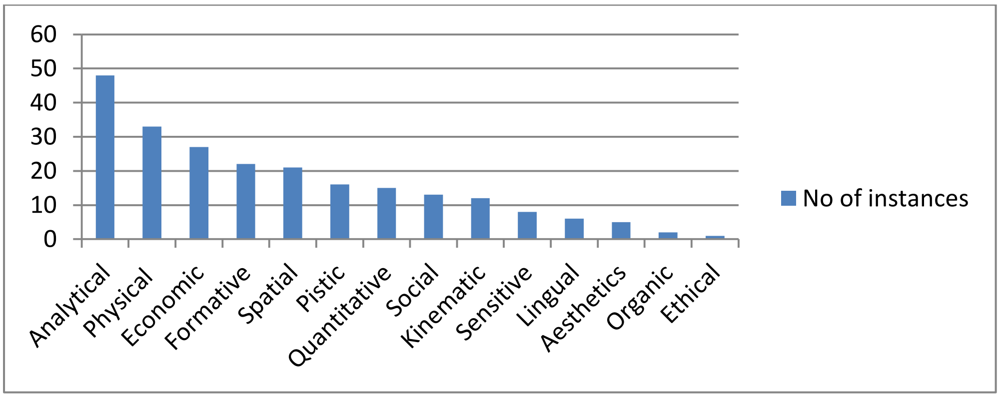


Figure 4.1: Group A's aspectual intentions in the problem structuring phase

Figure 4.1 indicates that the main trend in Group A's approach in structuring the ill-defined problem was to consider the analytical, physical and economic aspects most often, whereas organic and ethical aspects were considered the least. The pattern between the abstract aspects they considered and the ill-defined problem can be ascribed to their consideration of the gestalt principle 'global precedence' as the overarching intention to guide their embodiment actions to pay attention to their intentions in a top-down fashion (as discussed in Section 2.6.1). I found that the participants from Group A structured the ill-defined problem by demonstrating their aspectual intention to clarify the diverse requirements of people living in low-income housing. Group A's participants considered the analytical[1] aspect more than any of the other groups; I suspect this is because they spent more time in the problem-structuring phase than the other participants did. However, it is not within the scope of this study to explain the patterns. An example where the participants from Group A considered an analytical aspect in the problem-structuring phase is given in Excerpt 4.5.

Excerpt 4.5

> 00:07:38 Katy:
> We basically have to break it down to what do they do in their house and how we can incorporate the multi-purposeness of the seat into that.

In the context of their protocol, I could deduce that Group A's reference to 'break it down' implied their conceptual thinking. They categorised and clarified their understanding of people living in low-income housing in order to conceptualise what is needed before a multi-purpose seat can be designed. Group A's protocol indicated that they intentionally and incrementally worked on analysing what multi-purpose seating would work best for people in low-income housing as demonstrated in Excerpt 4.6.

Excerpt 4.6

> 00:27:39 Eric:
> It's just when I look at things that would double-up as a table and then you say here's your thing and then you've either got a chair or a table, you can't really dine like you think you can, you will always have to get more … decrease the cost of manufacture if they all look [like] exactly the same thing.

Excerpt 4.6 furthermore demonstrates that more than one aspect intersected an instance of utterance. This insight aligns with the philosophical view of Dooyeweerd in Basden (2000) that an inter-aspect analogy can exist between various aspects. This means that participants from Group A considered both analytical and economic aspects (Appendix F) in one instance, even though they were implied and not specified. They analysed the multi-purpose concept of having a chair and a table. As such, the vagueness of their statement correlated with the problem-structuring phase in which their aspectual thought of

[1] The analytical aspect is the ability to clarify or categorise something and think about it.

economics was produced. Other than the reference to cutting manufacturing costs by making the chair and table the same, they provided no detailed description of how the product would be made affordable for low income households.

(b) Group B

The participants in Group B considered eleven design aspects which I identified during their problem-structuring phase. In Figure 4.2, I summarise the aspectual intentions and the number of times they were identified.

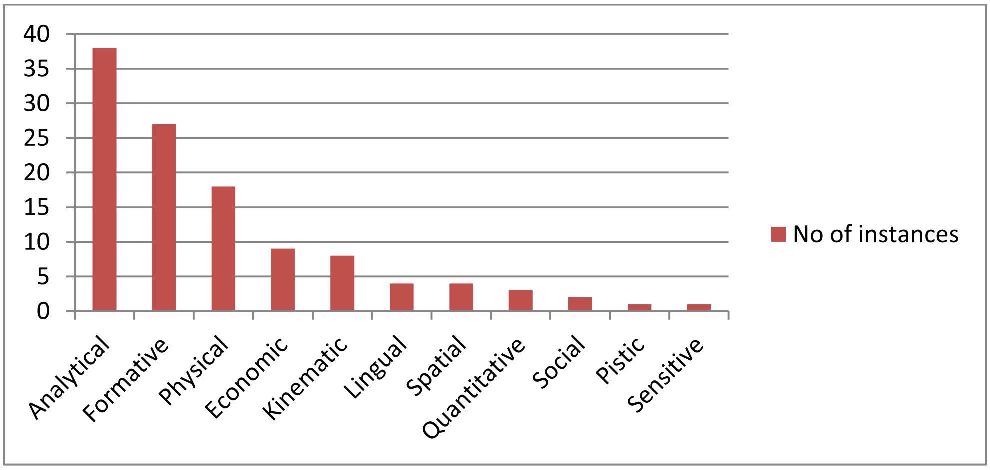


Figure 4.2: Group B's aspectual intentions in the problem structuring phase

Figure 4.2 indicated that the main trend in Group B's approach in structuring the ill-defined problem was to consider the analytical, formative and physical aspects most often, whereas pistic and sensitive aspects were considered the least.

The formative[2] aspect is implied in Group B's consideration of exploring different concepts, which occurred during their problem-structuring phase. The levels of vagueness in excerpt 4.7 bordered on abstractions. Participants from Group B did not elaborate or link this with any specifics of how they would construct a fold-out or what it would be used for. It is only through inference that I could interpret this instance (Excerpt 4.7) through consideration of its being a formative aspect.

Excerpt 4.7

00:16:08 David:

It could be a fold-out; it could be you just use a different part of it; it could be ...

I'm sure we could explore all of those aspects.

[2] The formative aspect is the deliberate creative shaping of things.

The participants in Group B realised that taking apart something that has already been assembled is counterproductive. This instance (Excerpt 4.8) occurred during their problem-structuring phase, where I made the inference that the aspect of economics, meaning 'frugal management of resources' (Basden, 2000), can be interpreted as economical use of time during manufacturing.

Excerpt 4.8

> 00:32:34 Tsepo:
> Yes how we could ... It's like there'd be a threshold point where it's no longer feasible to make it out of a pallet if you're manufacturing it so much because then it's counterproductive to having something that's already been made, taking it apart and rebuilding it as something else.

The general pattern I observed in Group B's introduction of aspectual intentions into their thinking processes developed mainly when the participants framed their problems in the problem-structuring phase with little thought given to detail in the artefacts. This demonstrates a hierarchy of importance in their thinking, as the lack of specificity and the qualifications of the aspects in Group B's protocol indicated to me that the laws leading particular aspects were implied, and not specific to them. This insight relates to the characterisation of aspects in philosophical studies (Basden, 2000), which states that specificity of content is implied and does not need explication.

(c) Group C

The participants in Group C considered eleven design aspects which I identified during their problem-structuring phase. In Figure 4.3, I summarise the aspectual intentions found in the protocol of Group C.

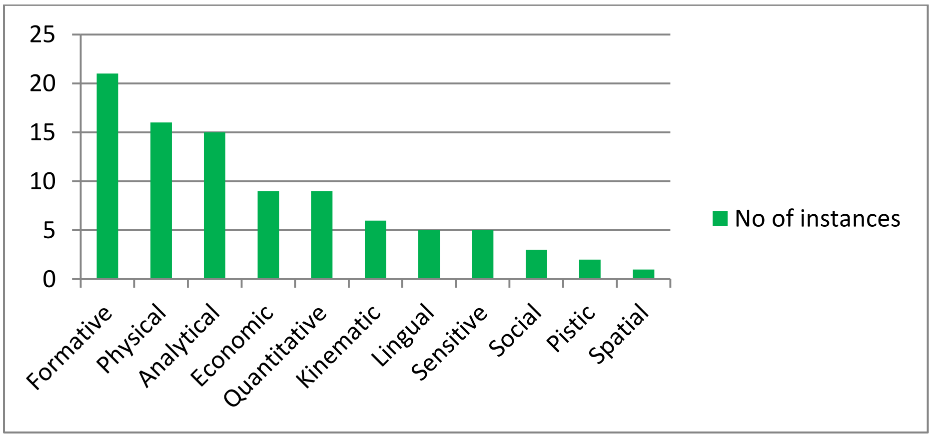


Figure 4.3: Group C's aspectual intentions in the problem-structuring phase

With very little time spent in the problem-structuring phase (Table 4.1, p.8), Group C mostly considered the formative design aspect followed by the physical and analytical aspects, whereas the pistic and spatial aspects occurred the least, as shown in Figure 4.3. The formative aspect is implied in Excerpt 4.9 during problem-structuring when they considered how a bench/seat could be made multi-purpose. The lack of specificity when storage was proposed indicated to me that they were deliberately thinking about how they could construct multi-purpose seating.

Excerpt 4.9

00:04:00 Ian:
So we've got sort of in multi-purpose. The one would be a bench or a seat.

00:04:35 Stanley:
What else? Storage?

In Excerpt 4.10, the design aspect the participants considered was that of economics. The aspect of economics refers to being 'penny wise', as suggested in Appendix F. In the context of their protocol, they indicated that they wanted to keep the manufacturing costs down. Their statement correlated with the problem-structuring phase during which the thought about economics came up. Other than the reference to not including a backrest, they provided no detailed descriptions of what manufacturing process or materials they would use to keep the costs down.

Excerpt 4.10

00:03:31 Stanley:
Well it has to be multi-purpose, so a bench is ideal for using it as a bed and you can kind of define how many people [indistinct] if you get a backrest kind of thing having unnecessary material cost as well, it needs to be as cheap as possible.

In this first sub-theme of abstract intentions, I took the participants' attempt to structure the problem into consideration when I could observe what they thought was important to aim for. The main trend I observed is that all the participating groups started to develop their ideas by formulating abstract aspectual intentions in the problem-structuring phase, but with little thought given to detail about the artefacts. This sub-theme leads me to conclude that Dooyeweerd's model is useful in identifying the abstract thoughts of novice designers. In the following sub-theme, I identify how the participants linked their aspectual intentions to meet end-functional goal intentions during the problem structuring phase.

4.5.2 Aspectual intentions linked with functional intentions

This section relates to the functional intentions of the participants during their problem-structuring phase. The functional intention determines what the artefact's intended purpose or function is: objects are assumed to be doing things in relation to the designers' intentionality (Kroes & Meijers, 2002)(as discussed in Section 2.6.1). Thus, the functional intention is an answer to the question 'What is it for?' (Kroes, 2006, p.139). I present evidence of how aspectual intentions are linked to functional intentions in the participants' problem-structuring phases in order to get a hold on the global precedence of aspectual intentions. To understand the interactions furthering the development of the abstract thinking into concrete thinking, I traced the utterances where aspectual and functional intention statements occurred in the same instance.

(a) Group A

I considered Group A's attempt to develop the problem space when I could observe how they interacted with various internal and external sources where attention to aspectual intentions triggered the mindfulness of functional intentions. In Figure 4.4, I have summarised the number of functional intentions linked to specific aspectual intentions in Group A's problem-structuring phase.

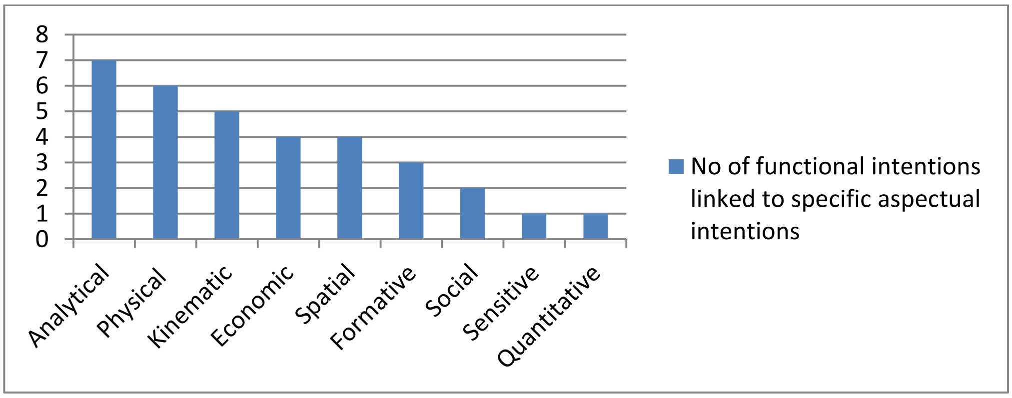


Figure 4.4: Group A: Number of functional intentions linked to aspectual intentions during problem structuring

Figure 4.4 indicates the main trend in Group A's approach, in which most of their functional intentions were linked to analytical, physical and kinematic design aspects while the smallest number of functional intentions were linked to sensitive and quantitative aspects. Group A's first apparent voicing of a functional intention (refer to Appendix D) came from reading the design brief (Appendix A). Originating from the instructions in the brief and their conceptual understanding of the size of a low-income house, Excerpt 4.11 demonstrates how they searched for information to structure the problem. I could deduce from Excerpt 4.11 that Group A thought of low-cost housing as a house which consists of one room only, in an attempt to structure the problem. Furthermore, the participants from Group A inferred the function of sitting, sleeping and studying from their conceptual understanding of low-income housing as an abstract spatial[3] aspect. The participants in Group A demonstrated the way they connected all the functional intentions of sitting, sleeping and studying in one space as a result of reading the brief and their conceptual understanding of low-income housing.

Excerpt 4.11

00:02:25 Eric:

So maybe if it's like a low-cost house you would only have one room, so your seating might have to be your bed, you might use it for a lessenaar-type thing.

While Eric from Group A was thinking aloud, Katy, the other team member, listed the purposes of the seat, as illustrated in Figure 4.5.

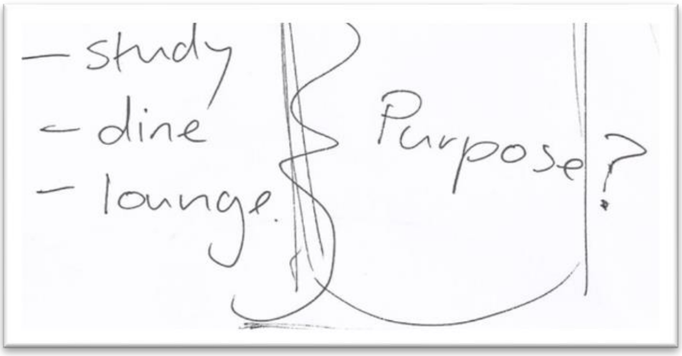


Figure 4.5: The functional intentions Group A ascribed to their concept

Another case emerged (Excerpt 4.12) where overlapping occurred between the problem-structuring phase and the problem-solving phase as Group A linked a design aspect with functionality using an external source. Through perception, the internet as an external source was used to search for examples of multi-purpose furniture to structure the problem when they saw ideas that could help them solve the problem. Group A linked the function of 'pop-up to sit' to the abstract aspect of kinematics[4], as well as linking the economic[5] aspect to the functional intention of sitting and sleeping. The participants from Group A demonstrate in Excerpt 4.12 how they linked the kinematic aspect of "pop-up" as an intended function to change a bed into a seat where one could sit and have breakfast. The kinematic aspect can also be linked to the economic aspect in Excerpt 4.11, where one room is optimally used by combining a bed and a seat as one artefact.

[3] Spatial aspect refers to continuous space.
[4] The kinematics aspect refers to change or movement.
[5] The economic aspect refers to frugal management of resources.

Excerpt 4.12

00:16:56 Eric:
Oh there's also that other link. You see that little table there where it's a bed but you can pop these ends up so that you can sit on this and then you can have breakfast.

This case clearly shows how global precedence worked where the concept of 'changing direction' as an aspectual intention is relevant to the 'pop-up' idea which is a functional intention.

(b) Group B

I was able to observe and count instances of Group B making very few links between aspectual and functional intentions during the problem-structuring phase as summarised in Figure 4.6.

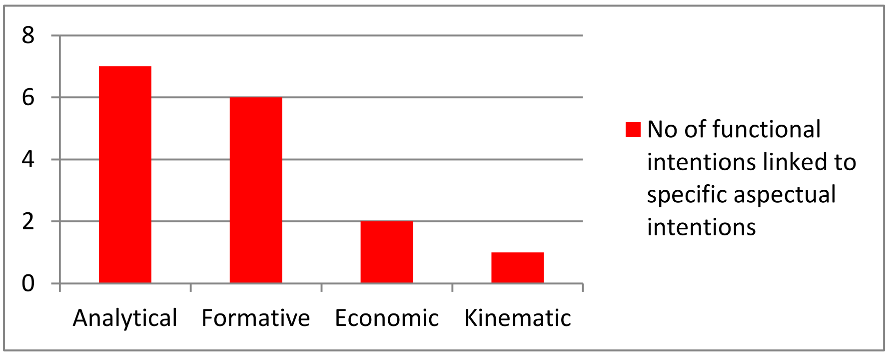


Figure 4.6: Group B: Number of functional intentions linked to aspectual intentions during problem structuring

Figure 4.6 presents evidence of the small number of functional intentions linked to specific aspectual intentions observed In Group B's approach to structuring the ill-defined problem. As illustrated in Figure 4.6, functional intentions were linked only to four design aspects, namely analytical; formative; economic and kinematic, compared to Group A who linked functional intentions to nine different design aspects. From Group B, David's conceptual understanding after reading the design brief and his internal social-technological knowledge led him to link his functional intention to an analytical design aspect. Excerpt 4.13 suggests that David used the analytical design aspect to categorise a study area as a secondary function.

Excerpt 4.13

> 00:06:06 David:
> Okay let's think, if we're going to be looking at a multi-purpose seating surface for low-income households, what would they be using it for other than the seating, what could we look at, possibly maybe a study area?

In Excerpt 4.14, David internally processed a suggestion made by his group partner by linking his functional intentions to a formative design aspect. The formative and economic aspects suggest the deliberate creation of one-piece furniture that will function not just as a seat, but also for sleeping, eating, and book storage.

Excerpt 4.14

> 00:08:40 David:
> Yes if we target, yes, that sort of thing, so we could even then look at one piece of furniture that would target both sleeping area, sitting area, book storage, food eating area, everything like that. I like that idea.

(c) Group C

In general, I observed that Group C's participants linked their functional intentions mainly to physical design aspects as an approach to structuring the ill-defined problem. In Figure 4.7, I summarise the number of functional intentions Group C linked to specific aspectual intentions in their problem structuring phase.

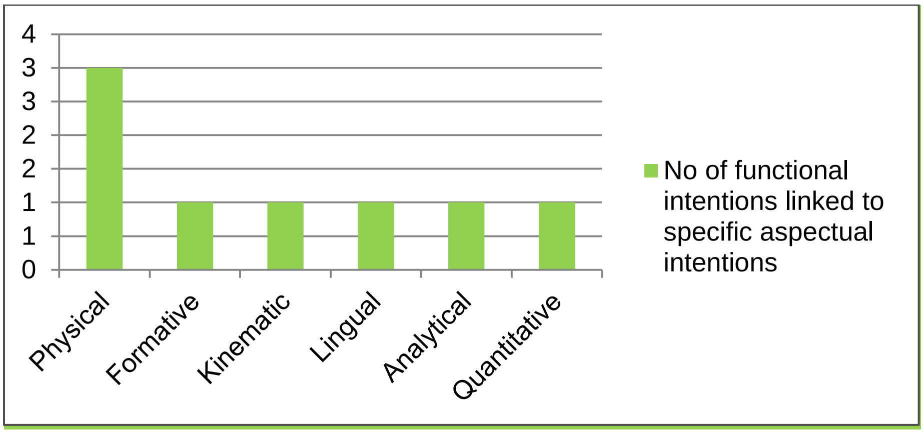


Figure 4.7: Group C: Number of functional intentions linked to aspectual intentions during problem structuring

The participants in Group C progressed in their problem-structuring phase by demonstrating their consideration of design aspects as an internal process which they linked with functional intentions. Excerpt 4.15 is one such example which suggests the robust aspect of physicality[6] in order for an artefact to function as something to sleep and sit on.

Excerpt 4.15

00:08:54 Stanley:
I think it also needs to be quite robust, it's going to be used, if it's going to be used as a lot of different things like sleeping, sitting on it and maybe aesthetics isn't the most important thing, like the structure or integrity of it and like what you can do with it, because if your house is only just big enough for everything you have in it, you want to maximise it and have done the items that are in it except for …. [interruption.].

Further on in Group C's problem-structuring phase, internal sources of domain-independent knowledge triggered the link between the quantitative design aspect and a functional intention. I found the quantitative aspect linked with the functional intention, which was to determine how many people they were going to design seating for (Excerpt 4.16).

Excerpt 4.16

0019:39: Ian:
We're looking at ... How many people do you think we need to make this seat, I mean would you want to make something that will fit three people or are we going to make something that fits one person?

In general, I observed patterns where each participating group interacted with various internal and external sources of information, including their design brief, domain-independent knowledge, novice design experience, the internet and magazines in order for their aspectual design intentions to set off functional intentions. This interactivity between the occurrence of conceptual understanding of the design problem and the occurrence of processes of discovery by integrating perceptual information demonstrates how the participants' gestalt thinking develops (as discussed in Section 2.6) in the presence of a variety of sources of information. Furthermore, I observed that, on average, amongst all three groups the design aspect most linked to functional intentions was the analytical aspect, as shown in Figure 4.8.

[6] The aspect of physicality refers to energy, mass and forces, which should not be confused with physical elements that are structural descriptions that specify the actual physical make-up of an artefact.

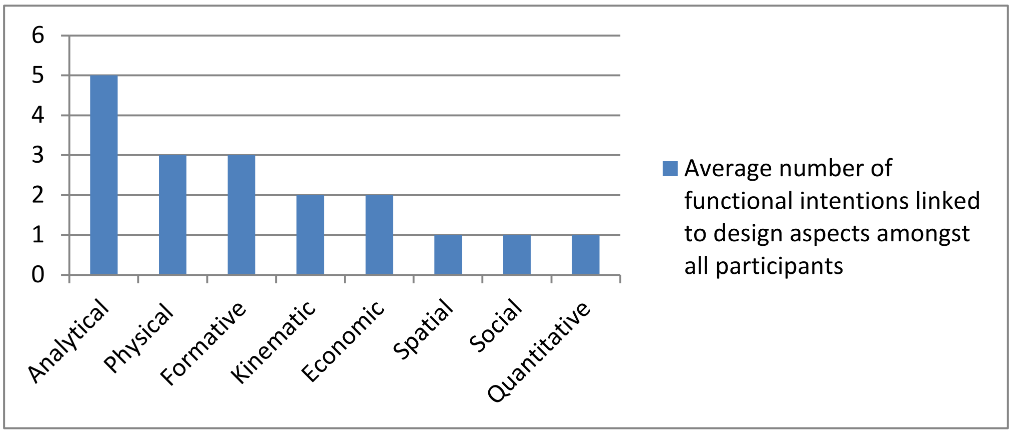


Figure 4.8: Average number of functional intentions linked to aspectual intentions during problem structuring of all participating groups

I considered the participants' attempt to link the design aspects with their functional intentions, which often consisted of object-context-related themes as well as people-object and object-related themes, as shown in Figure 4.9. This enabled me to determine the attention and knowledge that the participants used in order to structure how their hierarchical thinking developed between aspectual intentions and functional intentions (Appendix E). The design aspect of economics was most often linked to the functional intention with an object-context-related theme (refer to Section 3.3.5), whereas the analytical design aspect linked to the functional intention with people-object and object-related themes.

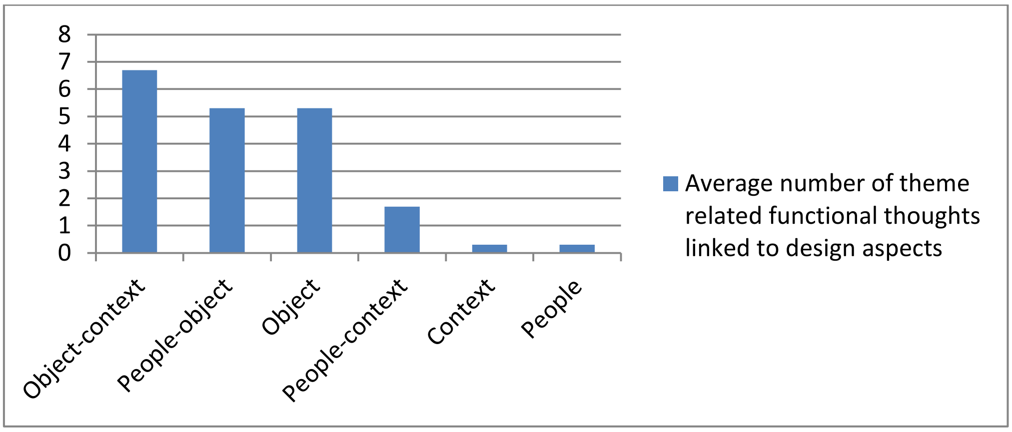


Figure 4.9: Average number of theme-related functional thoughts linked to design aspects amongst all participants

4.5.3 Functional intentions linked with physical elements

Sub-section three relates to the way in which participants connected functional intentions with physical elements (refer to Section 2.6.1), and by implication met with abstract design aspects as an emerging effect of global precedence in gestalt thinking. I searched for tangible evidence of instances where structural descriptions were given to specify the actual physical make-up of the artefact, connecting it with the artefact's use (as discussed in Section 2.6.1). I furthermore explain the way in which the participants considered physical objects and elements that they perceived and acted on in their task environment as they paid attention to selected or emerging elements (refer to Section 2.2.2) to structure the problem.

On average, formative, physical and analytical design aspects occurred most often amongst the three protocols when functional intentions were linked to structural descriptions of the actual physical make-up of the artefact, as indicated in Table 4.5.

Table 4.5: Number of instances where aspectual intentions and functional intentions were linked to physical elements in the problem-structuring phase

	Group A	Group B	Group C	
	No. of instances	No. of instances	No. of instances	Average no of instances
Formative	4	9	2	5.0
Physical	5	5	1	3.7
Analytical	5	6	0	3.7
Kinematic	4	3	2	3.0
Economic	6	1	0	2.3
Spatial	2	1	0	1.0
Sensitive	2	0	0	0.7
Pistic	2	0	0	0.7
Social	1	1	0	0.7
Lingual	0	2	0	0.7
Quantitative	0	1	0	0.3

The statistical findings as demonstrated in Table 4.5 highlight the trend that the participants' levels of abstract thinking seem to develop gradually when they connect their conceptual understanding of the problem to perceptual stimuli to concretise their ideas (refer to Section 2.6.1). The gradual development of concrete ideas of each group will be discussed in the following section.

(a) Group A

I could observe how participants from Group A developed a conceptual understanding of the ill-structured design problem, using their socio-technological knowledge from discipline-specific environments stored in their long-term memories and through external perceptual stimulation that emerged from their roughly drawn sketches. I noted that the participants' themes during their problem-structuring phase were mostly people-object-related when they linked their aspectual and functional intentions to specify the actual physical make-up of the multi-purpose stool. Furthermore, economic, analytical and physical design aspects occurred the most in Group A's protocol when functional intentions were linked to the physical make-up of their artefact (refer to Appendix D). Group A's constant interaction between their aspectual intentions, functional intentions and revisiting of external environment and perceiving physical elements reinforced their ability to align their intentions in a gestalt manner.

Excerpt 4.17 demonstrates how the participants generated information using domain-specific knowledge of modular designs and by searching through magazines in an attempt to further structure the problem. I also found the participants starting to refer to physical elements and connecting them to their functional intentions, as shown in Excerpt 4.17.

Excerpt 4.17

> 00:09:57 Katy:
>
> I was just thinking how to incorporate the study, dining and the lounge furniture into one, so at the moment I'm just drawing a dining room table, maybe to, I'm thinking of a modular system, somehow where they can all interlink. So possibly when you are dining they're vertical and then when you're lounging they're horizontal, maybe a studying and lounging can be the same formation. Can you please pass the magazines? Maybe we'll find something.

The formative aspect is implied in Group A's consideration when they linked their very first functional intention to construct seating for dining, lounging and studying into a modular piece of furniture that could be turned into different formations for accommodating different types of seating. While uttering the words in Excerpt 4.17, Katy produced a rough sketch to externally visualise her thought. She linked the formative aspect to the physical make-up of a modular system, as illustrated in Figure 4.10. In this case global precedence emerged where the concept of 'constructing a modular system' is relevant to different types of seating which in turn can be linked to 'dining vertical' and 'lounging horizontal'.

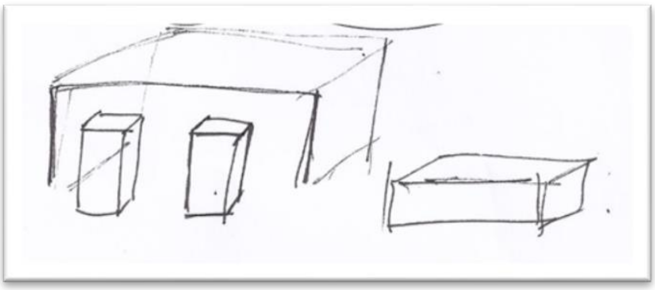


Figure 4.10: Katy's (Group A) visualisation of the physical make up of a modular system

Excerpt 4.18 is an example in which Group A generated information to structure the problem by considering an analytical design aspect. I deduced that 'probably not' referred to their conceptual understanding of what was not possible with a stool.

Excerpt 4.18

00:03:38 Eric:

Yes. Can you eat on your lap if you are on a stool like that? Probably not.

The analytical design aspect of clarification in Excerpt 4.18 further suggests the link between the physical make-up of a stool drawn earlier, as illustrated in Figure 4.11, and the functional intention of eating on your lap. This idea of eating on your lap comes from the idea of creating different types of seating which was mentioned at the beginning of their protocol, as demonstrated in Excerpt 4.17. However, the participant realised that it was not possible to eat on one's lap while sitting on a stool and discarded the idea. Excerpt 4.17 demonstrates how the participants used their sketch of a stool through the notion of perception-action to gather information to structure the problem.

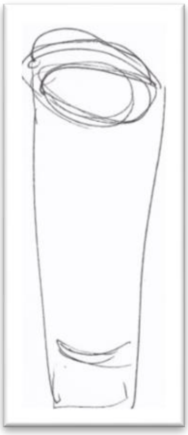


Figure 4.11: Sketch of a stool made by Group A

(b) Group B

I noted that Group B's general theme was people-object-related (Appendix D). Coherent gestalt thinking started to emerge as Group B linked their aspectual intentions and functional intentions to the physical make-up of their multi-purpose table/chair concept. I mostly found formative, analytical and physical design aspects in the same instances where links between functional intentions and physical elements were made (refer to Appendix D). Researchers including Lloyd and Scott (1994) and Popovic (2003, 2004) confirm my finding that novice designers tend to base their problem structuring on common-sense knowledge when given an ill-structured design problem. This is due to the fact that novices do not have immediate access to relevant domain-dependent knowledge (Popovic, 2003). Excerpt 4.19

demonstrates how one of Group B's participants in the problem-structuring phase used general knowledge to decide which type of reclaimed materials to use, for meeting his functional intention of creating a sleeping surface that can be turned into seating. It also became evident from Excerpt 4.19 how this Group B participant, David, internally processed his conceptual understanding using general knowledge to link his formative design aspect to the functional intention of durability for converting a bed into a seat.

Excerpt 4.19

00:10:29 David:

What other reclaimed materials could we look at, there's the pallets, plastic crates, there's ...Because we obviously want some durability out of it, so hardboard and stuff [indistinct]. If we're going to be looking at incorporating maybe a sleeping surface onto it we need to think of cushioning then as well, because that could ..., cushioning when not in bed-form converted into seating surface like could the bed be made up of, say two cushions and one forms the back when placed on another surface and that surface then serves something else at that point, then.

Group B internally processed their conceptual understanding of the ill-structured design problem. Through the use of domain-dependent knowledge and the external perceptual stimulation that emerged from Group B's roughly drawn sketches, design aspects were linked to functional and physical elements. Excerpt 4.20 demonstrates the vague levels of specificity almost half an hour into Group B's protocol. In structuring the problem they linked the analytical aspect by clarifying the functional intention of creating seating with the physical elements of blocks which pull away on each side, as illustrated in Figure 4.12.

Excerpt 4.20

00:27:44 David:

Yes. Because essentially what it would mean then we might need to have cut-outs and then we could then negate the full functionality of that. Okay, so how can we approach it then from a different angle, how can we look at ...Could these be blocks that pull away on each side for the seating?

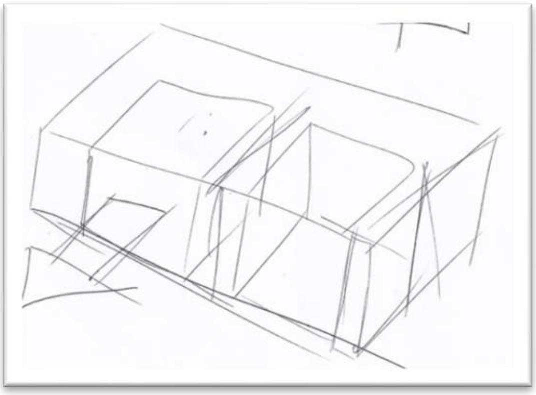


Figure 4.12: A sketch made by Group B of blocks that pull out to become seats

This case demonstrates how conceptualising as an analytical aspect mechanises the global precedence principle, which consequently forms the filter through which the functional intention of ‘creating seating’ is linked to ‘blocks that can pull away ’.

(c) Group C

I found only three instances during Group C’s problem-structuring phase where design aspects, functional intentions and physical elements occurred in the same instance (refer to Appendix D). An hour and fifteen minutes passed in Group C’s protocol before I could find evidence of their interacting with internal and external sources, where attention to aspectual intentions triggered the mindfulness of functional intentions that led to structural descriptions of their bed/bench concept in a gestalt manner. This demonstrated the significance of time needed for Group C to gradually structure and develop a coherent solution.

Excerpt 4.21 demonstrates how Group C structured the problem by considering information by adding concepts and proposing ideas, without committing to a particular concept. I deduced in Excerpt 4.21 the consideration of the formative design aspect, which implies the deliberate construction of angling two side panels (Appendix F), after the participant externally processed perceptual information that emerged from a hand-drawn sketch. This formative aspect of constructing a narrow bed and angling two side panels to the bed can be linked to the participants’ functional intention as well as to the physical make-up of their concept. The functional intention is to prevent a person from rolling off, which in turn is linked to the physical make-up of a bed with two angled panels at 5 degrees each. This case clearly shows how the global precedence principle of gestalt thinking worked where ‘constructing’ as an aspectual intention mechanised the functional intention to ‘stop people rolling off’, which again is relevant to a bed with ‘flappy bits’.

Excerpt 4.21

01:14:45 Ian:

And if we were making a bed do you think we could angle it (flappy bits) up slightly so that it would stop people from rolling off, I mean we're looking at about 5 degrees, that also means that if it does sort of settle a bit it doesn't go down, it doesn't it hang off, it rather would settle to be flat.

Further on in the protocol, the participants revisited the hand-drawn sketch of the 'flappy bits' which were also mentioned in Excerpt 4.21. A general pattern I observed in Group C demonstrates that perceptual stimulation of the participants' hand-drawn sketches led them to make links between aspectual intentions, functional intentions and physical elements. This confirms the notion of the perception-action embodiment principle, which claims that designers intentionally perceive information from objects (such as sketches) as part of the continuous iterative design process in extended design cognition (as discussed in Section 2.2.2).

Continuing Group C's search for missing information, the participants proposed to open and close the 'flappy bits' easily by adding a groove big enough for a person's hand. Excerpt 4.22 suggests the formative aspect, which is to achieve easy unfolding by linking the formative design aspect to the functional intention of lifting the 'flappy bits' up using your hand. The functional intention of lifting the 'flappy bits' up was linked to the physical description of a groove made in both 'flappy bits' that was big enough for a person's hand.

Excerpt 4.22

01:45:10 Stanley:

And then what we could do Ivan is just put a groove on the flappy bits that go out like that so that you can get your hand in underneath it and lift it up. Is that a possibility?

To conclude this sub-theme, during the problem-structuring phase the participants tried to understand what the problem was, what they needed to solve, and what its scope, constraints, requirements and specifications were. I identified tangible evidence amongst all the groups where aspectual intentions and functional intentions linked to structural descriptions of the artefacts as the participants searched for missing information. I observed a general pattern in which the participating groups interacted with various internal and external sources of information, including their design brief, domain-independent knowledge, novice design experience and their own hand-drawn sketches. This interactivity in all the participating groups between the occurrence of conceptual understanding of the design problem and the occurrence of processes of discovery by integrating perceptual information demonstrated evidence of gestalt thinking guided by global precedence (as discussed in Section 2.6.1). I also noted a people-object-related theme amongst all the participating groups when links between aspectual intentions, functional intentions and physical elements were made (refer to Appendix D). The following section provides the findings of my study on novice designers' hierarchical thoughts in problem structuring.

4.6 Hierarchical thinking in the problem-solving phase

In this section, I contextualise the notion of hierarchical thinking using the gestalt principle of global precedence in the problem-solving phase. Problem solving is the second cognitive phase, in which designers generate and explore the alternative solutions that emerged during the problem-structuring phase. The problem-solving phase can be sub-categorised into preliminary ideas, developing ideas and refining ideas (as discussed in Section 2.3.2). I noted that the protocol theme for all groups was generally object-related during their problem-solving phase (Appendix D). I furthermore found links where aspectual intentions were used to specify the actual physical make-up of the artefact, connecting it with the use of the artefact (refer to Appendix D). The pattern between the abstract aspects that they considered and the ill-defined problem can be ascribed to their consideration of the gestalt principle 'global precedence' as the overarching intention to guide their embodiment actions to pay attention to their intentions in a top down fashion (as discussed in Section 2.6.1). Formative, physical and analytical design aspects occurred on average the most amongst the three protocols' design aspects, functional intentions and physical elements, as indicated in Table 4.6.

Table 4.6: Number of instances where aspectual intentions and functional intentions linked to physical elements in the problem-solving phase

	Group A	Group B	Group C	
	No. of instances	No. of instances	No. of instances	Average no of instances
Formative	15	26	13	18.0
Physical	11	18	14	14.3
Kinematic	10	12	6	9.3
Lingual	4	9	3	5.3
Economic	7	4	2	4.3
Analytical	4	4	2	3.3
Spatial	5	3	1	3.0
Pistic	2	4	2	2.7
Social	2	5	1	2.7
Sensitive	5	2	0	2.3
Quantitative	2	4	0	2.0
Aesthetic	4	0	0	1.3

The findings of global precedence nested in the hierarchical thinking during the problem-solving phase are discussed under the following four sub-themes, aspectual intentions; aspectual intentions meeting functional intentions; functional intentions meeting physical elements; and implementation intentions.

4.6.1 Aspectual intentions

In the following sub-sections, I explain how the participants considered aspectual intentions during their problem-solving phases. In my reporting on aspectual intentions, I selected aspects based on the highest number of counts to select and develop ideas. As previously explained (Section 4.4), aspectual intentions are derived from Dooyeweerds' modalities framework (Appendix F) that mechanises the global precedence principle, which consequently forms the filter through which selections are made on all the subsequent levels of designers' hierarchical thinking. I used the participants' vocal utterances to inform me about their aspectual intentions.

(a) Group A

The participants in Group A considered distinct design aspects which gave meaning and direction to the way they selected and developed ideas, committed to some and rejected others. From fifteen possible aspects, I identified twelve aspects that the participants from

Group A considered during the problem-solving phase. In Figure 4.13, I summarise the aspectual intentions and the number of times they were identified.

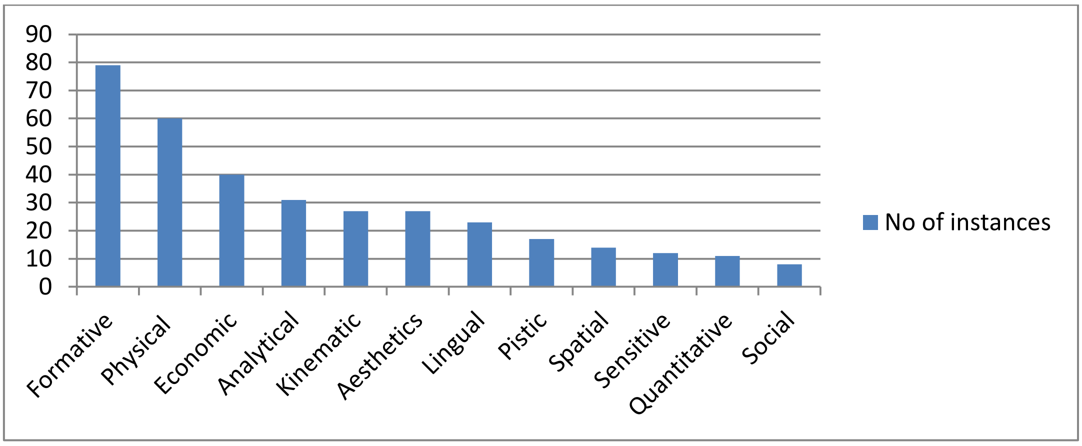


Figure 4.13: Group A's aspectual intentions in the problem-solving phase

Figure 4.13 indicates that the main trend in Group A's approach in solving the ill-defined problem was to consider mainly formative, physical and economic design aspects, whereas quantitative and social aspects were considered the least. I noted that Group A, in their problem-solving phase, generated and explored a modular system for multi-purpose seating accompanied with fast fluid drawings. During this instance (Excerpt 4.23) Group A considered the abstract aspect of physicality. I inferred the aspect of physicality (see Section 4.5.2, p.23) as a force to pull something out in order for it to become something else (Excerpt 4.23).

Excerpt 4.23

00:05:41 Katy:

You can pull that out; it can become something and then another thing.

This initial generation and exploration of some aspect of the design correlates with the problem-solving phase (refer to Section 2.3.2). The physical aspect of pulling demonstrated the abstract nature of the participants' statements and implied knowledge of modular systems. In the following instance (Excerpt 4.24) the participants from Group A considered the economic aspect which, according to Dooyeweerd's model (Appendix F), refers to frugal management of resources.

Excerpt 4.24

00:03:49 Eric:

Or these little rollers connected together, so maybe something sturdy like wire for instance that could keep everything that shape, in the right shape but also make it go flat and your whole family would have one of these and in the morning you can sit around the breakfast table on your own bed.

I deduced an economic aspect in their intention to save space in low-income housing. Group A's proposed concept was for each family member to use their bed not just for sleeping, but also, when rolled up, to use it as seating to sit around a breakfast table and have breakfast. In Group A's case, the introduction of aspectual intentions in their problem-solving phase demonstrates their abstract and non-specific nature in generating and exploring some aspect of their ideas.

(b) Group B

The participants from Group B considered eleven design aspects which I identified during their problem-solving phase. In Figure 4.14, I summarised the aspectual intentions and the number of times they were identified.

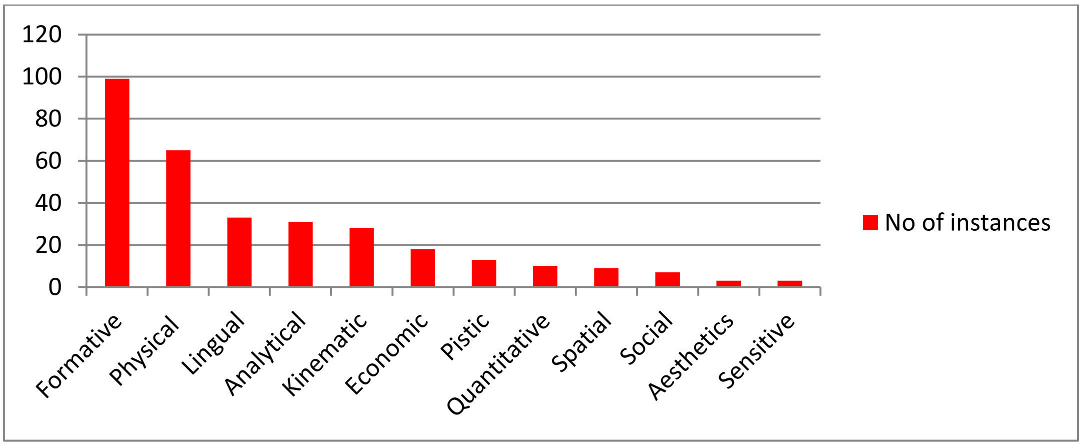


Figure 4.14: Group B's aspectual intentions in the problem-solving phase

Figure 4.14 indicated that the main trend in Group B's approach in solving the ill-defined problem was to consider the formative, physical and lingual design aspects most, and the aesthetics and sensitive aspects least. As the participants from Group B developed ideas through decision-making, they considered the formative aspect as captured in Excerpt 4.25. The formative aspect described by Dooyeweerd's model (Appendix F) refers to the constructing or shaping of things.

Excerpt 4.25

00:14:02 Tsepo:

Yes, I was thinking like if these are somehow sort of triangular then that way it means that this piece could be removed and then it could be used as sort of a recliner.

In the formative aspect they suggested constructing a recliner by removing some sort of triangular piece. The abstract and non-specific nature of their ideas suggests that little thought had been given to detail about their artefact at this stage.

In another problem-solving instance (Excerpt 4.26), the participants generated ideas by connecting the lingual aspect which, according to Dooyeweerd's model (Appendix F), refers to the ability to externalise ones intentional meaning. The participants in Group B externalised their intentional meaning by drawing a number of side profiles as illustrated in Figure 4.15. This awareness corresponds with the gestalt theory of a coherent whole which, according to Shani (2012, p.6), can only be instantiated through relevant internal and external cognitive engagements that are 'synergically coordinated' to generate and develop a solution. Furthermore, in the same instance I interpreted the participants' use of the term 'geometric' as a formative consideration. In their articulation, formative considerations apparently governed their way of constructing geometric shapes.

Excerpt 4.26

00:09:37 David:

I'm just going to draw up a few side profiles to get an idea of how this is going to ...

00:11:17 David:

What are you thinking? Very geometric.

Figure 4.15: Group B externalising their internal meaning

The general pattern I observed in Group B's introduction of aspectual intentions into their thinking processes occurred primarily when the participants generated ideas in the problem-solving phase in cases where little thought had been given to detail about the artefacts.

(c) Group C

Similarly to Group B, Group C committed to some design aspects and rejected others. In Figure 4.16, I have summarised the aspectual intentions identified in the problem-solving phase and the number of times they were identified.

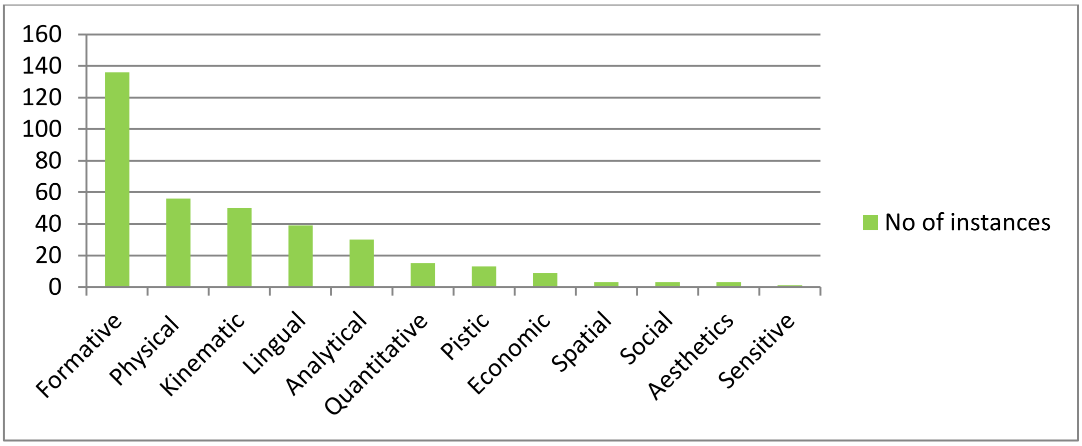


Figure 4.16: Group C's aspectual intentions in the problem-solving phase

Figure 4.16 indicates that the main trend in Group C's approach in solving the ill-defined problem was to consider mainly formative, physical and kinematic design aspects, whereas aesthetics and sensitive aspects were considered the least. The aspect of aesthetics is implied in Group C's consideration of a better look as they developed their idea of slanting table legs at an angle through decision-making (Excerpt 4.27). According to Dooyeweerd in Basden (2000), the aspect of aesthetics can be interpreted as harmony. The level of vagueness at this stage bordered on abstraction, because they did not explain what they meant by 'better look'.

Excerpt 4.27

> 00:12:03 Ian:
> Yes, I like the look of it better as well. I like the look of it better as well that it slants out.

Another design aspect which Group C considered was that of 'economics', which they voiced during their problem-solving phase to further develop their concept. In the context of their protocol, I interpreted their use of the words 'less material' as an economic consideration. In their articulation, economic considerations seemed to govern their suggestion to use material economically, as evident from Excerpt 4.28.

Excerpt 4.28

> 00:42:14 Ian:
> Or are we looking at like a sort of small piece like that in two places? So, that's, this is this thing here.
>
> 00:42:29 Stanley:
> It can go either way.
>
> 00:42:31 IAN:
> Or it would be less material if we use that.

The lack of information given about what they thought 'less material' meant suggested to me that Group C understood this to be a manifestation of the underlying laws of economics. They developed their idea further through decision-making by voicing their preference for using material economically as demonstrated in Excerpt 4.29.

Excerpt 4.29

> 01:21:39 Stanley:
> It would be the same material throughout though, it would be the same thickness [of] wood, the legs and for the top, so you would only need one material and then you could just cut them into thinner strips for the legs, I mean that would make sense for wood.

Aspectual intentions as a sub-theme lead me to conclude that Dooyeweerd's model is useful in identifying the abstract thoughts of novice designers as they elaborate and further develop their ideas through decision-making. Furthermore, the pattern observed amongst all the aspectual intentions that the groups considered and the ill-defined problem can be ascribed to their consideration of the gestalt principle 'global precedence' as the overarching intention to guide their embodiment actions to pay attention to their intentions in a top-down fashion (as discussed in Section 2.6.1). In the following sub-theme, I present evidence of how the participants in their problem-solving phases linked aspectual intentions with functional intentions.

4.6.2 Aspectual intentions linked with functional intentions

In sub-section two, I present evidence of how the participants through problem-solving actions generated ideas, selected ideas and developed ideas. I furthermore explain the way the participants linked aspectual intentions with functional intentions in order to get a hold on the global precedence of aspectual intentions. To understand the connections between aspectual intentions and functional intentions that mechanise emerging global precedence in gestalt, I traced the utterances where aspectual and functional intention statements occurred in the same instance.

(a) Group A

The participants in Group A interacted with various internal and external sources of information where attention to aspectual intentions triggered the awareness of functional intentions. In Figure 4.17, I summarise the number of functional intentions linked to specific aspectual intentions in Group A's problem solving phase.

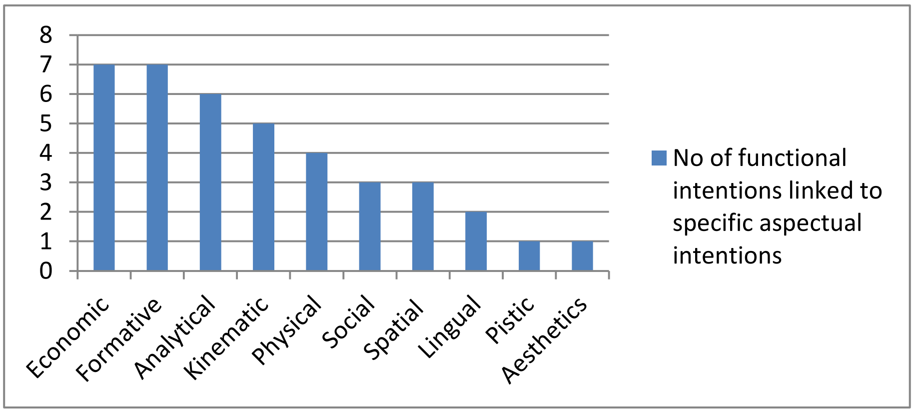


Figure 4.17: Group A: Number of functional intentions linked to aspectual intentions during problem solving

Figure 4.17 indicates the main trend in Group A's approach, where most of their functional intentions were linked to economic, formative and analytical design aspects while the smallest number of functional intentions were linked to pistic and aesthetic aspects. The participants connected the formative aspect with functionality using domain-independent knowledge as an internal source of information and the design brief as an external source of information. Excerpt 4.30 demonstrates how Group A proposed an idea by connecting their vague formative aspect of rolling something up so that it can be constructed into a multi-purpose designed object to make either sitting or comfortable sleeping possible. The participants at this instance have not made reference to detailed physical elements to concretise their abstract thoughts.

Excerpt 4.30

00:03:14 Eric:
Okay, looking at that low-income sort of living and multi-purpose thing my first sort of idea that comes in, could it be something where you, is it something that sort of rolls up like that and a person can sit, sit on that but at night it sort of you know ...

00:03:40 Katy:
Can become a bed.

00:03:41 Eric:
Can become a bed, so you've got some comfortable sleeping and ...

During Group A's protocol, fast fluid drawings was made (Figure 4.18) which at this stage (Excerpt 4.31) acted as an external source of information to stimulate the participants' perception in order to develop an idea further. I deduced that Group A implied 'pull that out' as an aspect of physicality to meet the brief's multi-functional requirement. Excerpt 4.31 suggests that the force required to pull something out will allow the artefact to function first as one thing and then, after it has been pulled out, as another.

Excerpt 4.31

00:05:41 Katy:
You can pull that out, it can become something and then another thing.

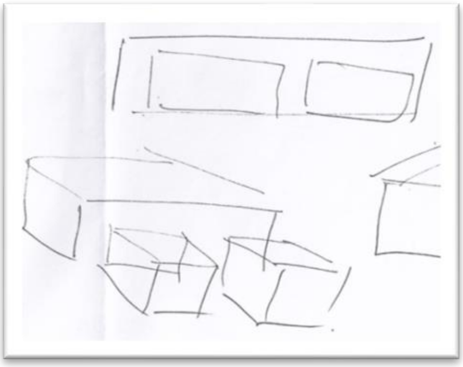


Figure 4.18: Group A externalising a physical aspect

This case clearly shows how global precedence emerged where the concept of 'pull out' as an aspectual intention mechanises the functional intention of becoming multi-purpose.

(b) Group B

I considered Group B's progress in solving the design problem when I could observe explainable patterns in which they made links between their design aspects and functional intentions. A summary of the number of functional intentions linked to specific aspectual intentions in Group B's problem-solving phase is illustrated in Figure 4.19.

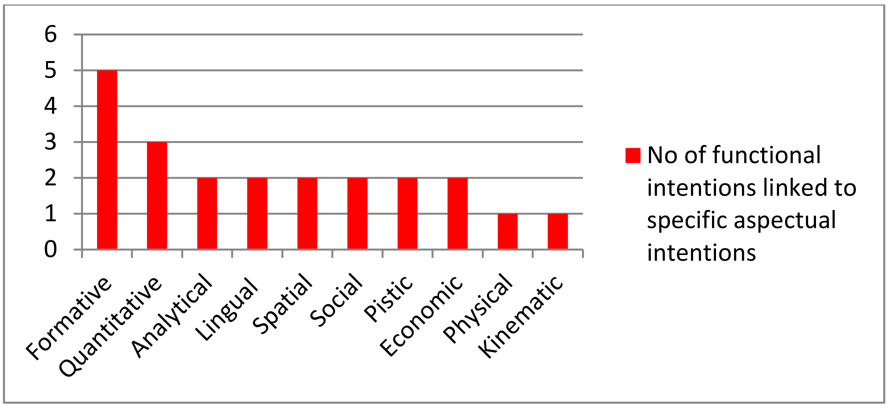


Figure 4.19: Group B: Number of functional intentions linked to aspectual intentions during problem solving

Figure 4.19 indicates the main trend in Group B's approach, which was that most of their functional intentions were linked to formative, quantitative and analytical design aspects, while the smallest number of functional intentions was linked to physical and kinematic aspects. I noted that Group B combined various internal and external sources of information, including their design brief, domain-dependent knowledge and personal preferences to link their design aspects with the functional intentions for their designed object.

Excerpt 4.32 demonstrates Group B's consideration of the economic aspect of optimising space by linking it to their functional intention of 'many aspects of multi-functionality'. I could deduce that the 'many aspects of multi-functionality' referred to sitting, eating, sleeping and book storage, which had been mentioned earlier during their protocol's problem-structuring phase and which they now used to develop their ideas.

Excerpt 4.32

00:16:48 David:
Because I'm liking the idea of if we look at something that covers as many aspects of the multi-functionality, essentially optimising the space that it would take up to cover all of those things.

Excerpt 4.33 is another example where Group B used internal and external sources of information including the design brief, personal preferences and their roughly drawn sketches to develop their ideas. I deduced that Group B's intention was to create comfortable seating for a family of four in a small space. Excerpt 4.33 suggests the link between the quantitative aspect of average family and the economical use of space, which is connected to the functional intention of comfortable dining seating for two adults and two children.

Excerpt 4.33

00:59:33 David:
There['s] needs to satisfy, first there needs to be seating comfortably [for] two, there's a dining area and three needs to be four, so it would essentially be then comfortable seating, a dining/eating area and for the average type of family that would be in that house, two adults, maybe two children. So we need to then look at something for four people that would fit comfortably into that space, we can still approach this concept then, I think, I don't know, what do you think if we looked at designing this?

This case clearly demonstrates how global precedence worked where the concept of 'space' as an aspectual intention is relevant to 'seating comfortably' which is a functional intention.

(c) Group C

Group C's participants, like those in Group A and Group B, made more links between aspectual and functional intentions in their problem-solving phases than in their problem-structuring phases. A summary of the number of functional intentions linked to specific aspectual intentions in Group C's problem-solving phase is illustrated in Figure 4.20.

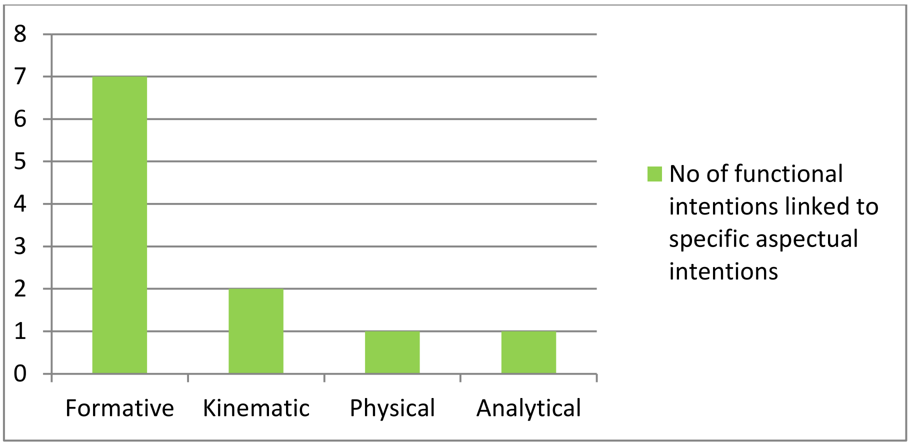


Figure 4.20: Group C: Number of functional intentions linked to aspectual intentions during problem solving

Figure 4.20 indicates the main trend, where Group C primarily linked their functional intentions to the formative design aspect. I observed the participants interacting with various internal and external sources including their novice design experience, domain-independent knowledge and conceptual drawings, where attention to aspectual intentions triggered the awareness of functional intentions. This confirms what I observed in the other two groups, namely the need to integrate perceptual stimuli and internal meaning-making of information in a coherent manner to develop and generate solutions (refer to Section 2.6).

Excerpt 4.34 demonstrates the generating of ideas where the participants considered the formative aspect of constructing one frame to be slightly smaller than the other, with the functional intention of making two different-sized frames to fit into each other.

Excerpt 4.34

00:48:13 Ian:

But then are we going to make one smaller than the other one so that they can fit into each other or do we make the loop so that ... If we made one smaller than the other one, that one could fit into the other one.

During the problem-solving phase, quick free-hand drawings were made (Figure 4.13) which in this instance (Excerpt 4.35) acted as an external source of information to generate ideas. Ian, a participant from Group C, first considered the formative aspect of looping, but then linked his functional intention of simplifying the operation with the formative aspect of drilling, as captured in Excerpt 4.35. Figure 4.21 illustrates how the participant changed his thinking from looping to drilling holes by drawing the drilling holes concept on top of the looping concept.

Excerpt 4.35

00:52:03 Ian:

Unless we drill a hole through it, so instead of having it looping around you just have that profile that's bending and then have holes drilled there you know, extending, running through the holes, because then it would be a simple operation of just drilling through it because it's not running on the high stress point because the main force is going to be from here down this length, there's going to be no force along this section of the frame because it's going to be anchored here and here by these pieces.

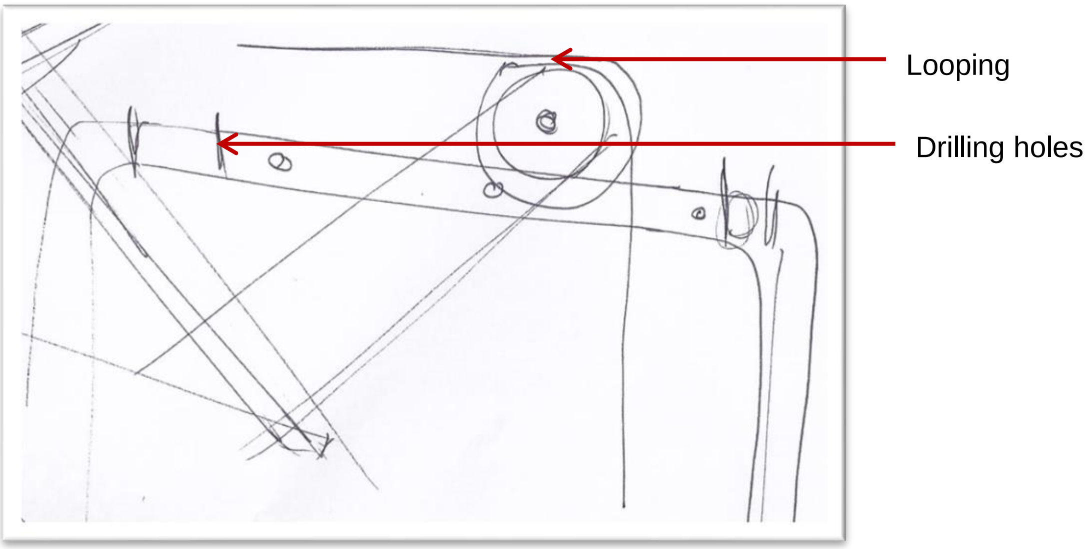


Figure 4.21: Group C externalising the concept from looping to drilling holes

To conclude this sub-section, it seemed evident that in all the groups there was a consistent pattern involving the link between aspectual intentions and functional intentions. The formative aspect consistently served amongst all the groups to support their ideas most and to transform their abstract intentions into functional intentions, as illustrated in Figure 4.22.

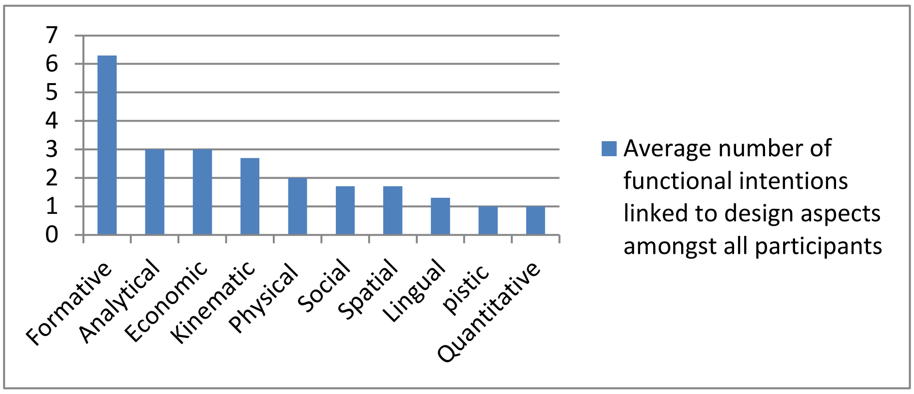


Figure 4.22: Average number of functional intentions linked to aspectual intentions during problem solving

Furthermore, I observed that the participants' functional intentions consisted primarily of object-related themes when they linked them to their abstract design aspects, as shown in Figure 4.23.

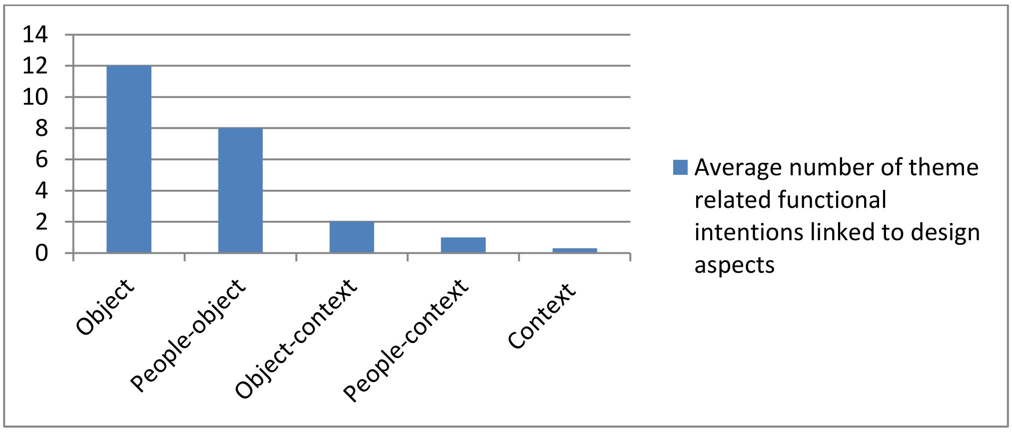


Figure 4.23: Average number of theme related functional intentions during problem solving

The internal alignment of mostly formative, analytical and kinematic design aspects seems to have triggered their functional intentions, which implies a self-regulating mechanism that drives the participants to achieve coherent gestalt (Kieran, 2011). This insight demonstrates the hierarchy of the participants' design thinking, where aspectual intentions take priority above functional intentions.

4.6.3 Functional intentions linked with physical elements

In sub-section three, I present evidence of how the participants developed and refined selected ideas through decision-making to link functional intentions with the actual physical make-up of the artefact and, by implication, met with abstract design aspects.

(a) Group A

During Group A's problem-solving phase, I observed a rapid increase in detail and specificity once they had made the decision on the stackable kitchen cupboard/stool concept. I found the increase in detail and specificity developed mainly in multiple sub-cycles through the participants' external perceptual stimulation that emerged from their hand-drawn sketches as well as through conceptual understanding using domain-dependent knowledge in search of a coherent gestalt solution. I noted that the participants' themes during their problem-solving phase were mostly object-related when they linked their aspectual and functional intentions to specify the actual physical make-up of the stool (refer to Appendix D). This insight demonstrates Group A's ability to concretise their abstract intentions. Furthermore, formative followed by physical and then kinematic design aspects occurred the most in Group A's protocol when linked to functional intentions and the physical make-up of their stool concept (refer to Appendix D).

Excerpt 4.36 is one example where Group A in their problem-solving phase refined their ideas. The refinement of ideas consisted of statements of detail which gave formal shape to the door that covered the hole in their stool concept. Furthermore, Excerpt 4.36 is the result of Group A's process of using domain-dependent manufacturing knowledge as a formative aspect to integrate the functional intention of protecting the end-users from hurting themselves by adding the physical elements of a little plastic grommet and a plastic 'lining-type thing' around the opening. This case demonstrates how constructing a finger-hole as formative aspect mechanises the global precedence principle, which consequently forms the filter through which the functional intention of 'don't hurt yourself' is linked to 'plastic grommet'.

Excerpt 4.36

00:45:59 Eric:
Yes, drilled into the metal and roll-formed and there is a, obviously a hole over there behind the door and there's a little plastic grommet that goes into the hole so that you don't hurt yourself.

00:46:15 Speaker:
Cut yourself.

00:46:17 Eric:
It will also have maybe a plastic lining-type thing around the hole so that when you reach in and out you don't shave your ...

Excerpt 4.37 demonstrates Group A's process of developing a solution through decision-making by integrating perceptions of their task environment with their own internalised ideas. I interpreted the participants' words "put them where you want them" as a kinematic design consideration. In their articulation, kinematic design considerations apparently governed their way of movement. The kinematic aspect of movement was linked to their functional intention of adding a rope to the stool, with the idea of lifting the stool and moving it around to where it is needed. Their reason for adding a rope handle was to make it easier to lift and move a stool filled with potatoes.

Excerpt 4.37

> 00:43:25 Eric:
> Yes, picking up a thing full of potatoes, just to sit on them, so it would probably not be used as seats in the end, so putting rope on them is quite an easy way to just lift them and put them where you want them seeing that they are containing stuff that you would be using in your kitchen.

(b) Group B

It was only much further into Group B's problem-solving phase that their levels of specificity and amount of information, which increased visibly in the participants' verbal as well as visual representations, became evident. The themes for Group B's protocol during their problem-solving phase were mostly object-related when they linked their aspectual intentions and functional intentions to specify the actual physical make-up of the table/chair concept. Furthermore, formative followed by physical and then kinematic design aspects occurred the most in Group B's protocol when linked to functional intentions and the physical make-up of their table/chair concept (refer to Appendix D).

The main trend observed in Group B's approach in developing solutions was processing their thoughts through conceptual insights and perceptual stimuli. I found that Group B's participants used novice design experience from long-term memory and perceptual stimulation, using their hand-drawn sketches to consider the formative aspect as captured in Excerpt 4.38. To construct the table and chair so that it could be moved as one, the formative aspect was linked to the details of the actual physical make-up of the artefact. Excerpt 4.38 demonstrates how the physical elements of the chair and table are specified in order to achieve the functional intention of moving them around easily as one piece.

Excerpt 4.38

01:25:57 David:
Yes, if it's a slight recess into the top of the chair, just slightly dimpled down area and then under the table has just the opposite just to, so you could move it still as one piece around easily. Yes that would work. That's a little too thick.

Figure 4.24 illustrates how Group B constructed a solution to lock the chair and table together with the intention of moving them around.

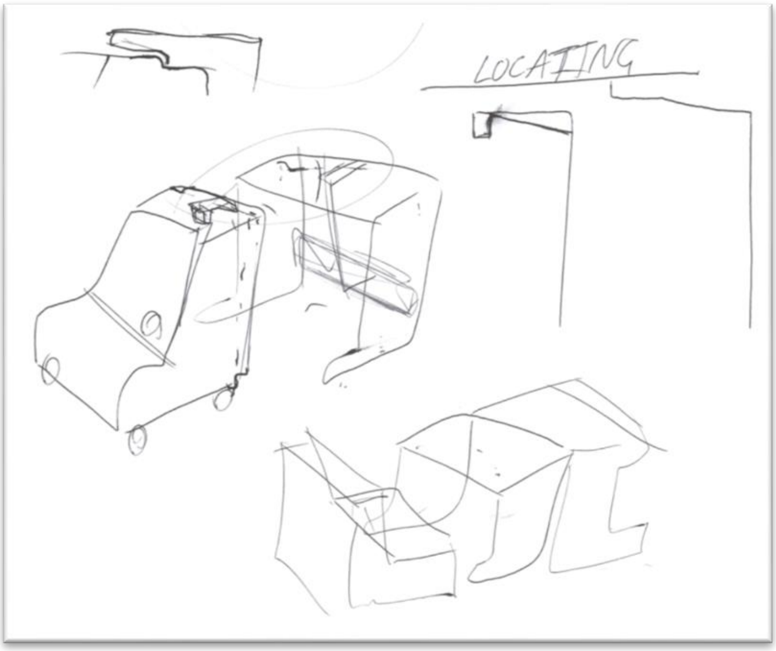


Figure 4.24: Group B's concept of locking the chair and table together to increase mobility

In this case, global precedence emerged where the formative aspect of constructing a multi-purpose table and chair mechanised the functional intention 'to move it around easily' which in turn led to the detail in the artefact of 'recess into the top of the chair …. and under the table has just the opposite.'

(c) Group C

I found the links between aspectual intentions, functional intentions and physical elements to be nine times greater in Group C's problem-solving phase than in their problem-structuring phase (refer to Appendix D). I noted the general theme to be mostly object-related when they linked their aspectual and functional intentions to specify the actual physical make-up of the bed/bench concept (refer to Appendix D). Furthermore, the physical design aspect followed by the formative aspect and then the kinematic aspect occurred the most in Group C's protocol when linked to their functional intentions and the physical make-up of their bed/bench concept (refer to Appendix D). As the participants from Group C developed selected ideas, they internally and externally processed information. Group C applied novice design experience from long-term memory and through perceptual stimulation using their hand-drawn sketches to consider the design aspect of physicality, as captured in Excerpt 4.39. Group C's attention to the design aspect of physicality could be linked to specify the actual physical make-up of the artefact and connected with the use of their artefact to develop a solution. By incorporating cams, which are a type of knock-down fitting used in the assembly of flat-pack furniture, and considering the physical design aspect of forces in their design, Group C demonstrated their use of domain-specific knowledge. Excerpt 4.39 suggests that Group C is making decisions to develop one part of their concept by using their knowledge to make the link between the physical element, which is to add a cross-brace to the legs, and their functional intention, which is to stop the legs from splaying out.

Excerpt 4.39

> 00:35:37 Stanley:
> The main force is going down, so the cross-brace is going to brace the legs from splaying out, so all of that, all that actually really needs to do is stop it from kicking in and because of the way it's angled it's pushing it into the cam, so there's never going to be, you know, unless those bolts sheer they can't actually, they can't kick out this way, so I mean does that make sense?

Excerpt 4.40 is an example where Group C internally processed domain-independent knowledge from long-term memory to consider the pistic[7] design aspect by linking it to the physical make-up of the artefact and connecting it with their artefacts' use. Excerpt 4.40 demonstrates how the participants linked their pistic aspect of 'belief' to the physical element of a 25mm mat and the functional intention, arguing that the mat is comfortable enough to sleep on.

Excerpt 4.40

> 00:48:50 Stanley:
> The mattress would be a 25mm mat to sleep on, which would be enough to, you know it wouldn't be like giving it to one of your whatever, Rest Assured beds but it would be comfortable enough. I mean people sleep on high-density foam mattresses, those are always sort of fairly hard, but you get used to it.

To conclude this sub-theme, I learned that all the groups interacted with various internal and external sources including their design brief, domain-specific knowledge, novice design experience as well as the sketches they made to develop their ideas. I identified tangible evidence of aspectual and functional intentions being linked to structural descriptions of the artefacts during the participants' problem-solving phases (refer to

[7] The pistic aspect described by Dooyeweerd in Basden (2000) refers to commitment, belief or certainty.

Appendix D). The result of adding physical elements to the abstract nature of aspectual intentions seems to further transform the participants' abstract thinking into concrete thinking. This insight confirms the gestalt principle 'global precedence', which states that processing information follows the self-organising principle, which determines that global structures progress in detail and specification towards analysis of local properties (as discussed in Section 2.6.1). In the following sub-theme, I present evidence of how the participants implemented their intentions.

4.6.4 Implementation intentions

The fourth sub-section relates to the way and order in which physical elements, aspectual and functional intentions are linked to meet the designers' implementation intentions, which in turn enabled to make and propagate their commitment to their ideas. The distinguishing characteristic of implementation intentions is the reference to an activity, for example, 'you can "put" the truck here' and 'you can "transport" things here'. Furthermore, the condition for qualifying as an implementation intention is that the objects the participants referred to had to be the object they were designing and not an existing object, unless the latter was incorporated into the current design (Haupt, 2013). The following sections demonstrate how global precedence emerged as each of the three participating groups implemented their thoughts.

(a) Group A

I found a general pattern where Group A's implementation intentions emerged when they developed their ideas through decision-making by connecting their physical elements to aspectual and functional intentions. One such example is demonstrated in Excerpt 4.41 where the formative aspect is suggested in order to develop a simple solution to a problem they had identified in their stool concept. To make the stool multi-purpose, a storage compartment was added, which was to be filled with potatoes. Filling the stool's storage compartment made it heavy, and an easy solution for when you wanted to move the stool or to pick it up (functional intention) was simply to add a rope handle (physical element) to the stool.

Excerpt 4.41

> 00:58:40 Eric:
> I'm just thinking, and it's to simplify this even more, are they just sort of little stools like this that you can put your potatoes in because it's got a very nice like rigid handle, so obviously if they are full of potatoes they would be quite heavy but you can pick them up with a rope, put them there and sit on them. Maybe they'd just look nice because they've got a little backrest.

The functional intention of adding a rope is supported with a quick sketch, as illustrated in Figure 4.25

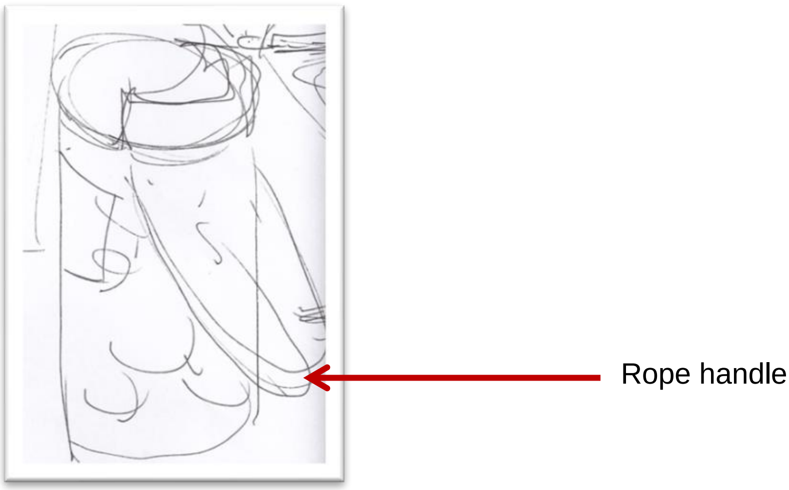


Figure 4.25: A concept where Group A added a rope-handle with the intention of picking up the stool

Excerpt 4.42 demonstrates how the participants' level of detail increased by specifying nylon or plastic material for the rope.

Excerpt 4.42

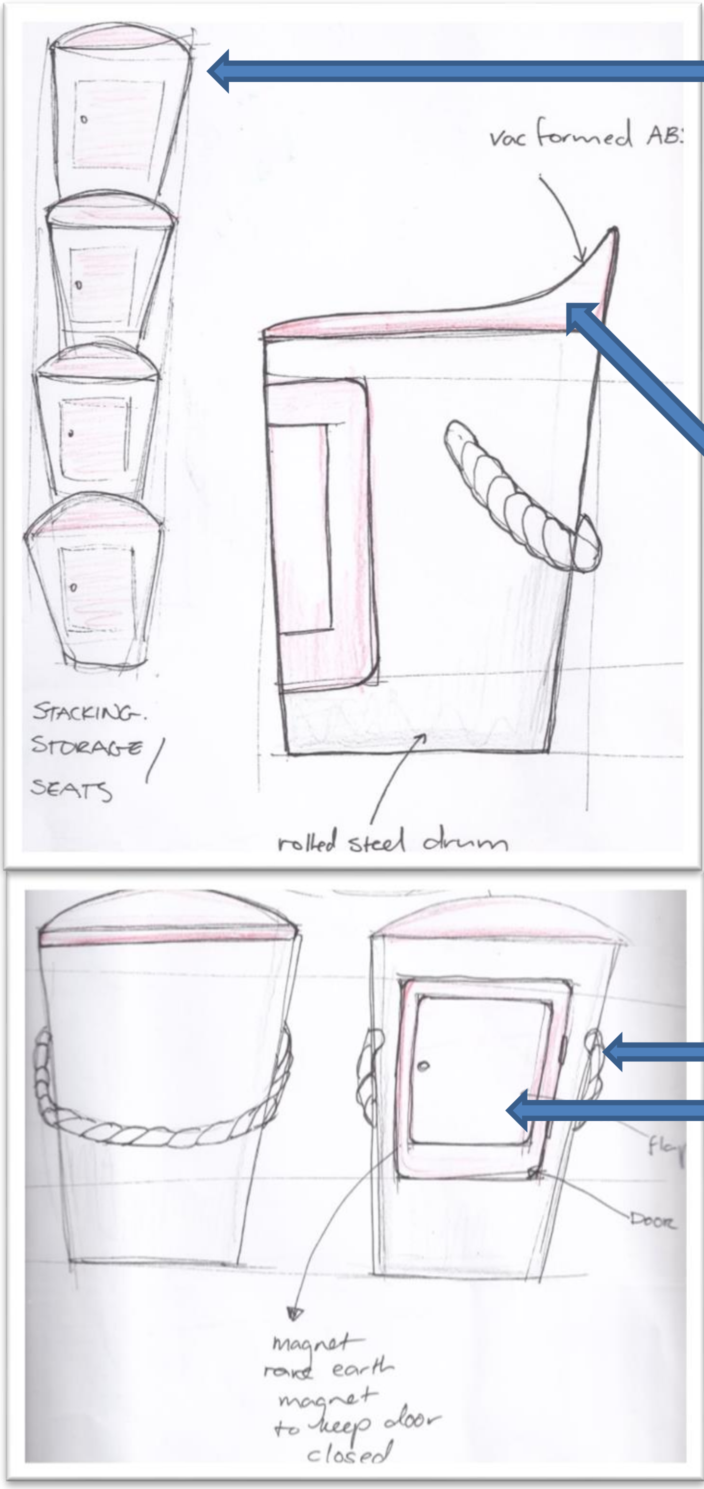
01:04:49 Eric:
And there's a, at the very bottom there's a little big hole for ... So you can store stuff in the top and you can just put some few, like your onions in the bottom, the potatoes, that's sort of just thrown in because you just need one or two from, and then it's got little backrests fit together and a nice, beautiful, like one of those, those [indistinct] ropes that you'd use, but a nylon one or a plastic.

Furthermore, the activity of making a knot for fixing the rope to the stool is demonstrated in Excerpt 4.43.

Excerpt 4.43

00:53:17 Eric:
We are thinking just a hole that's reinforced either with rolled into a lip or with this additional washer that's fastened to it and then you just push the rope through and knot it.

From the vague sketches made earlier in Figure 4.25, their ideas became clearer and subsequently their sketches became less ambiguous so as to demonstrate their commitment to implementation intentions, as illustrated in Figure 4.26. The main trend I observed is that Group A reacted to their internal and external task environment to establish coherent decision making.



This sketch supports the implementation intention of stacking the storage seats.

01:34:59 Eric:
"Yes, so if you were, if you are stacking them like this there will be a little backrest, and the next one will be there with the opening over there and sort of that's what it would look like."

This part of the sketch supports the implementation intention of having a little backrest.

00:59:10 Eric:
"*And a little backrest maybe just to make people feel that oh, that is a chair*."

This part of the sketch supports the implementation intention of having a rope to unstack the stools as well as storage compartment for potatoes.

00:01:29 Eric:
"*Oh true. And they would each have their big rope that you can take them off and have a seat for your guest or you can keep them in their arrangement that they are in for your family but they each have kitchen storage. And the thing is like to make them look like you can store your potatoes in there it's okay, you can sit on them and they do fit in the living space, that's okay too, so it's like perfect for the kitchen ..."*

Figure 4.26: Group A's visualisation of ideas once they committed to implementation intentions

(b) Group B

I observed Group B as they developed their ideas, a general trend where implementation intentions emerged through global precedence. Excerpt 4.44 suggests the formative aspect of constructing a modular unit. I found it very interesting that both Groups A and B considered the aspect of modularity. I later discovered that the participants had been given a class project where they had to design a modular unit. This furthermore supports the notion that it is not only expert designers who have the intention of achieving gestalt when designing by employing domain-specific knowledge as an internal source of knowledge (Popovic, 2003), but novice designers as well.

Excerpt 4.44

00:04:26 David:
You can look at a modular system.

I observed in Excerpt 4.45 the emergence of global precedence as Group B implemented their modular table/seat unit. The implementation intention is suggested when Tshepo from Group B articulated his formative aspect of modularity and the idea of linking functional intentions with the actual physical make-up of the artefact. The physical element which is specified as a one-seater modular unit is designed so that it can be arranged with three other units to accommodate a family of four. The activity of putting four units together to form a dining table for a family to sit and eat at, but then to also arrange the units as couches, qualifies as an implementation intention (as discussed in Section 2.6.1, Appendix E).

Excerpt 4.45

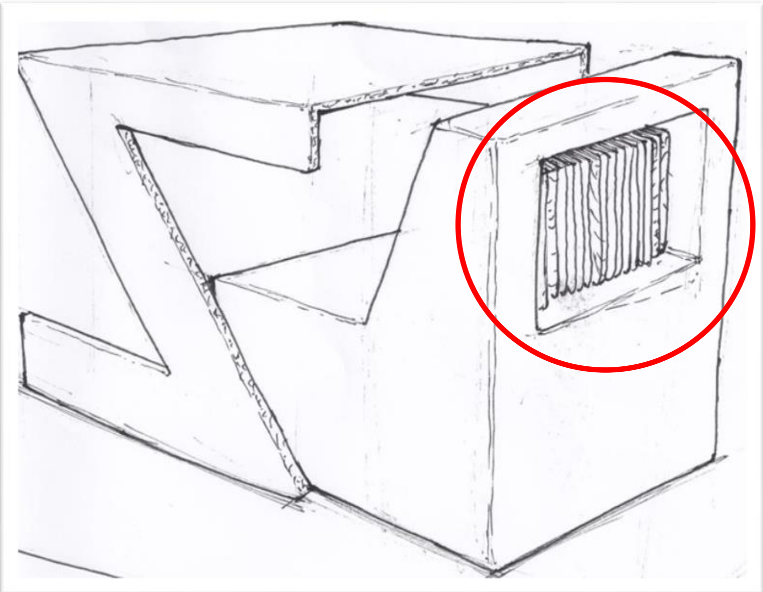
00:53:50 Tsepo:
It's intended for a one-seater, it does have the provision of doing more seats but in a one-seater arrangement you could arrange, say four of them together with all the desks, two on each side so a family of four could sit and eat and it could be split up into separate couches, or you could offer a set where there's two single ones and one double one where that would be probably more family orientated where there would be, the couple would sit on the double and then the two singles for the children.

I found Group B engaged in interactive perception-action cycles on a few sub-solutions in their protocol that were implemented into their design. An example of one such sub-solution where the functional intention and physical elements are linked to their implementation intention is demonstrated in Excerpt 4.46.

Excerpt 4.46

00:20:59 David:
…… because there would be that much included space in the back of the chair opening that as an option to store, if the space is quite tight and like you can have books stored in there and anything else, like whatever, in whichever space this thing would be used and whatever storage is needed in that space could serve to be that.

Excerpt 4.46 describes the physical element, which is an opening in the back of the chair, by linking it to the functional intention, which is to store. From the final sketch drawn by the participant I derived the implementation intention of storing books, as illustrated in Figure 4.27.



The implementation intention to store books in the backrest is derived from this sketch and supported by this utterance.

01:49:34 Tsepo:
"*Do you want to draw books in here or ...*"

01:49:38 David:
"*It's up to you, you can ...*"

Figure 4.27: Group B's visualisation of storing books as evidence of their commitment to implementation intentions

(c) Group C

In the way the participants from Group C made and propagated commitments, I observed similar trends of implementation intentions that played a facilitating role to those found in the protocol of Group B. An example of how a sub-problem started in the problem-solving phase as an aspectual intention is first demonstrated in Excerpt 4.47, before it was developed and implemented at a later stage as an implementation intention, as demonstrated in Excerpt 4.48.

Excerpt 4.47

00:32:43 Ian:

...Or if it's an angle like that then you can just align it so that when it can only go that far so that it locks into it so that it locks itself.

Excerpt 4.47 suggests the formative aspect of extending the leg at an angle by rotating the leg outwards. This aspectual intention is supported by a sketch which the participant drew in that instance, as illustrated in Figure 4.28.

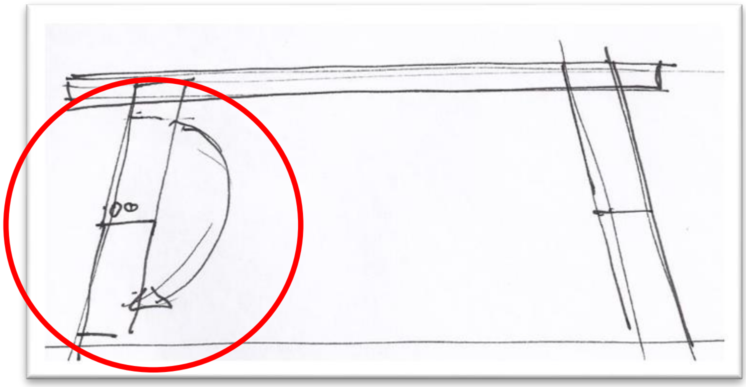


Figure 4.28: Group C's visualisation of the formative aspect to extend the legs at an angle

Excerpt 4.48 demonstrates how the participants implemented their formative aspect of adjusting the height of the bench by linking it to their functional intentions, which in turn connected with the actual physical make-up of their concept. To adjust the height of the bench they suggested making the legs fold in on themselves (functional intention) by adding robust door hinges (physical elements). This concept of using hinges to fold the legs in is illustrated in Figure 4.29.

Excerpt 4.48

01:03:35 Ian:

… you would also lift that whole bench up and fold the legs up one at a time. And when the legs are folded back into the, so they're halved, there will be a little clip that just holds the legs in place when you are using it as a bench. That could be a simple plastic moulded clip or even just another piece of wood that kind of, that wedges it in so that to get them out you need a little bit of pressure. The hinges are just robust door hinges that can fold in on itself.

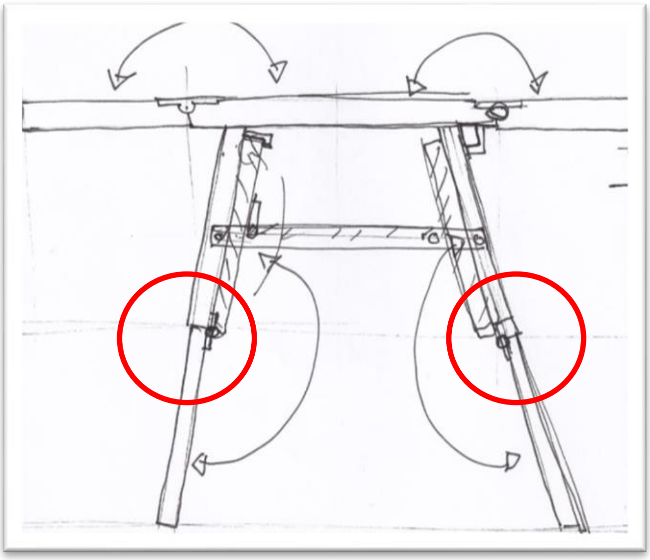


Figure 4.29: Group C's visualisation to implement hinges for folding the legs in

Excerpt 4.49 suggests the link between the functional intention and the physical element, which is to sleep on a 25mm mat, before the concept became an implementation intention later in their protocol, as demonstrated in Excerpt 4.50.

Excerpt 4.49

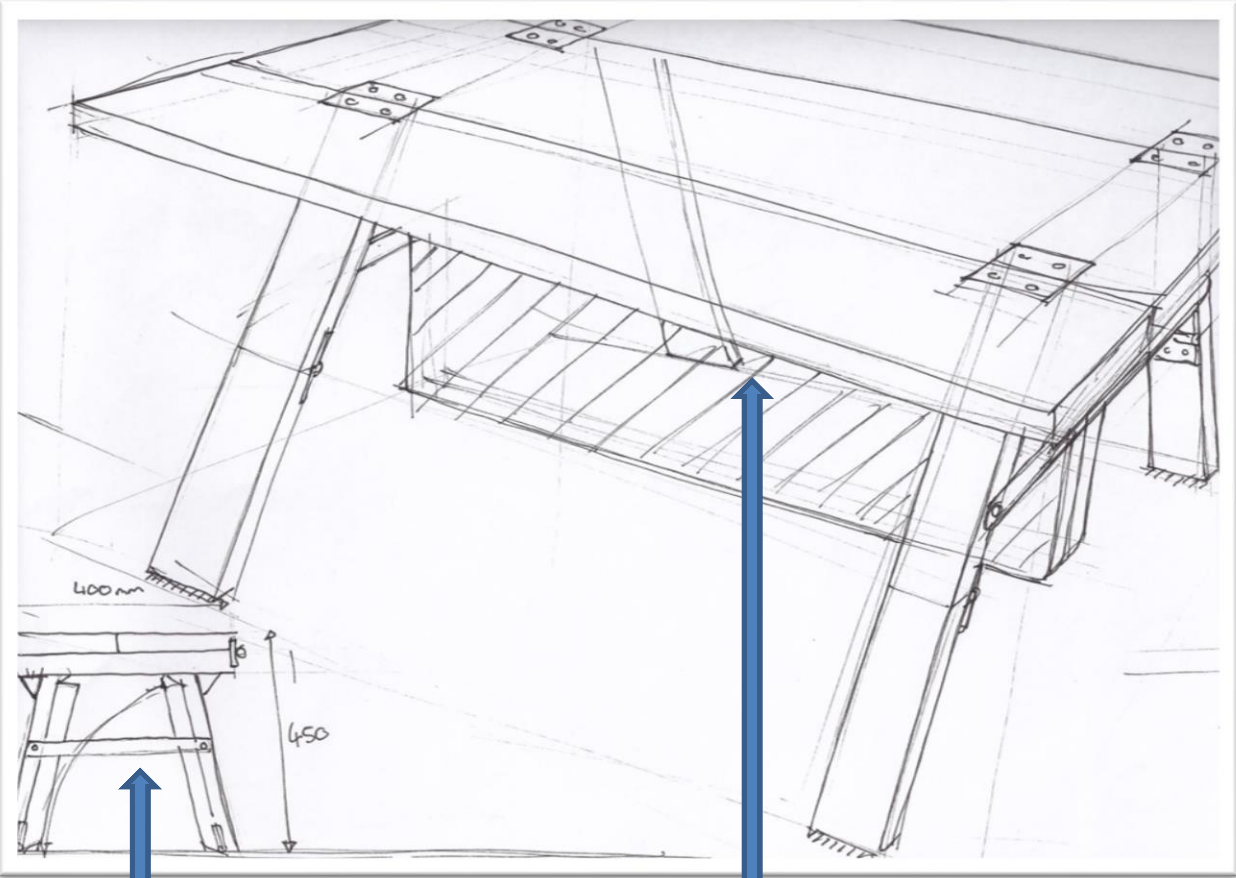
> 00:48:50 Stanley:
> Yes. The mattress would be a 25mm mat to sleep on, which would be enough to, you know it wouldn't be like giving it to one of your whatever, Rest Assured beds but it would be comfortable enough. I mean people sleep on high-density foam mattresses, those are always sort of fairly hard, but you get used to it.

As mentioned earlier, the distinguishing characteristic of implementation intentions is the reference to an activity. Excerpt 4.50 from Group C's protocol contains operational words, ('you can fold it back up, pull it out, use it as bench cushion, or … and fold it out') explicating how the participants intended to implement one of their suggested ideas for making their seating surface multi-purpose.

Excerpt 4.50

> 00:01:21 Stanley:
> We've used the ..., while the table is in, our piece of furniture is in table mode we've got a support for the mattress so that it can hang in the middle, either way it's not going to get dusty there, it's not going to get in the way if you are eating, you can sleep and sit at the table and not even know the mattress is there, and then you can fold it back up, pull it out and then use it as either your bench, cushion or your mattress and fold it out.

Figure 4.30 is the visualisation of Group C's ideas once they had committed to implementation intentions.



The smaller drawing on the bottom left is the implementation intention of the bench supported by this utterance. 00:31:32 Stanley: *'I'm just drawing a … view of the whole bench folded up …'*	The implementation intention to have a table and mattress derived from this sketch and supported by this utterance. 01:01:21 Stanley: *'…We've used the ..., while the table is in, our piece of furniture is in table mode we've got a support for the mattress so that it can hang in the middle…'*

Figure 4.30: Group C's visualisation of ideas once they had committed to implementation intentions

4.7 Conclusion

This chapter describes what I found by tracing the content of novice designers' thoughts to establish whether the connections made are hierarchically organised during the distinct cognitive phases of the design process. The participants' cognitive phase of problem structuring was characterised by intentionally searching for missing information to understand the given problem and what they were expected to achieve. The cognitive phase of problem solving, on the other hand, was characterised by taking information and detail relating to the problem into consideration to generate and develop ideas that gave final form to their concept. In addition, when the participants used internal and external sources of information, I established that all the groups spent more time solving the problem than structuring it. Instances of problem structuring amongst the three groups only dominated at the beginning of the design task, but reoccurred periodically throughout the task.

The participants' task involved the design of a multi-purpose seating surface for people living in low-income housing. I contextualised the notion of hierarchical thinking into four levels (aspectual intentions, aspectual linked with functional intentions, functional intentions linked with physical elements and implementation intentions) in the problem-structuring and problem-solving phases. The first level demonstrated all three groups' consideration for distinct design aspects, which gave meaning and direction to the way they selected and developed ideas. I found aspectual intentions served as the driving force to complete a coherent line of design reasoning following synergistically integrated internal and external distracting stimuli. The second level of hierarchical thinking revealed the participants' intention to define the functional nature of the artefact's purpose. I found the participants' aspectual intentions to take priority over functional intentions when they interacted with various internal and external sources of information. The third level of hierarchical thinking showed how the participants interacted with various internal and external sources of information including their design brief, domain-specific knowledge, novice design experience as well as the sketches they made. This interaction with various sources assisted them in recognising which physical elements would appropriately create coherent gestalt with selected aspectual and functional intentions of the artefacts they were designing. In the last sub-theme, definitive instances were found where the participants hierarchically linked their physical elements to aspectual and functional intentions to meet their implementation intentions. The participants' implementation intentions materialised in the way their verbal statements increased in detail and specificity, supported by their sketches which played a transformative role to establish gestalt. The transformative role of establishing gestalt happened as the participants visualised (internally and externally) implementation through construction recombination and manipulation of physical elements. I can therefore confirm that hierarchical structures of global precedence synergistically integrate and process the participants' conceptual understanding and perceptual stimuli to establish coherent gestalt.

In the following and final chapter of this dissertation, I summarise Chapters 1 to 4. I reach final conclusions by reflecting on my research questions in terms of my conceptual framework and findings, which result from this chapter. I thereafter conclude my study with recommendations for developing educational strategies for industrial design programmes.

Chapter Five

Summary, conclusions and recommendations

5.1 Overview

This study was about understanding the role of gestalt in the internal mental processes of three pairs of novice industrial design students during the early phases of their design processes. The purpose of this study was to examine and describe the ways in which these third-year design students reacted to their internal and external task environments to establish coherent decision making. Current literature on design cognition for novice designers does not sufficiently explain how they establish coherence and the ways they align intentions with information emerging from their physical environments. The importance of understanding novice designers' hierarchical way of thinking is that it might assist educators in guiding design students' thinking towards becoming efficient problem solvers. I adopted Haupt's (2013) approach to extended design cognition theory about hierarchical thinking as my conceptual framework firstly because it emphasises the methodological importance of the visual interaction of designers with their natural environment in design work. Secondly, extended cognition theory allows for the difficulty of explaining designers' need for visualisation (externally driven sources) but also for the kind of internal cognitive processes that solve design problems (Haupt, 2013). As such, the conceptual framework for this study was based on the hierarchical thinking model, which was conceptualised as a result of empirical research on expert designers to establish the links between various levels of intentions and physicality. Thus, gathering information during the problem-structuring and problem-solving process fitted well within this study's integrative theoretical framework to explain both the way and the order in which novice designers thought about the various aspects involved in finding appropriate solutions to design problems. The question of what the role of gestalt was in Industrial Design students' hierarchical thinking in the early phases of the design process was discussed.

This chapter first presents issues and trends drawn from literature on design cognition. I then answer the research questions that guided the inquiry and discuss the theoretical and educational contributions, followed by the limitations of the study and recommendations for further research. A short synopsis completes the chapter.

5.2 Conclusions drawn from previous chapters

The literature has shown that designing as a cognitive activity can be looked upon as a problem-solving activity in which the design problem and its solutions co-evolve during the design process (Zeiler et al., 2007). This implies that designers, during the design process, iteratively search the problem and the solutions, using the one as the foundation for the other in an attempt to find a coherent fit when evaluating different options (Maher & Tang, 2003).

Literature has further shown that theoretical assumptions of design cognition have led to the development of extended cognition. Extended design cognition theory developed through the integration of computational and embodiment theories and a focusing on the interactivity between internal processes and external sources of information to establish a coherent fit (Haupt, 2013; Kirsh, 2009; Shani, 2012). The implication of such integration supports designers' need for perception (accessing externally driven sources) as well as the kind of internal integrative strategies that structure a coherent solution. Coherence is brought about by gestalt thinking when designers create self-regulating perception-action feedback loops in their thinking by constantly drawing interrelations between their intentions on all four hierarchical levels.

However, gestalt theorists are criticised for being too vague when they insisted that people could construct new solutions based on their ability to understand in a holistic manner and to restructure unsuitable irrelevant structures into more relevant ones. This view is contested by Wagemans et al. (2012), who advocate the global precedence principle of gestalt thinking. In the moment of understanding at which the problem solution is coherently structured, some degree of global precedence occurs, which in turn drives the gestalt thinking in a design process (Wagemans et al., 2012). Global precedence entails conceptual insights and perceptual stimuli that are characterised by a hierarchical system with nested relationships. Nested relationships involve the constant interaction between the top and lower levels of conceptual insights and perceptual stimuli, where all the decisions on lower levels contain elements of the higher levels. As such, the globality of conceptual content corresponds with the level it occupies within the hierarchy. This implies that properties at the top of the hierarchy are 'more global' than those at the bottom, which are in turn 'more local'. Therefore, the role of gestalt in structuring a design problem remains relevant.

The literature in Chapter Two explains that the role of gestalt thinking in extended design cognition is naturally and logically very closely linked with external and internal processes and sources of information. The basis of the conceptual framework is that of global precedence in gestalt thinking and how it influences the way in which designers' external stimuli and internal cognitive processes interact by connecting functional intentions, physical elements and implementation intentions to aspectual intentions. Aspectual intentions serve as the overarching design aspect that mechanises the global precedence principle, which consequently forms the filter through which selections are made on all the subsequent levels of designers' hierarchical thinking (Haupt, unpublished).

5.3 Main research question and sub-questions

The main research question of this study is:

What is the role of gestalt in Industrial Design students' hierarchical thinking in the early phases of the design process?

To address the main research question and limit its scope, the key findings of each of the following five sub-questions are discussed in relation to the question.

5.3.1 Sub-question 1

I come to conclusions here by relating my findings to the first sub-question:

What aspectual intentions play a role in novice industrial design thinking?

Discussion

This study has established that novice designers considered the global precedence principle of gestalt thinking, which originated from distinct design aspects that gave meaning and direction to the way they selected and developed ideas, committed to some and rejected others. Based on Dooyeweerds' theory of aspectual modalities of reality (Basden, 2000), fifteen possible aspects were used to identify which particular aspect novice designers considered.

The data from this study, which I illustrated in bar graphs (Figures 4.1, 4.2, 4.3, 4.13, 4.14 and 4.16), indicated to me that novice designers' aspectual intentions served as the driving force in completing a coherent line of design reasoning following synergistically integrated internal and external distracting stimuli. The aspectual intentions that played a role in novice industrial design thinking are illustrated in Figure 5.1.

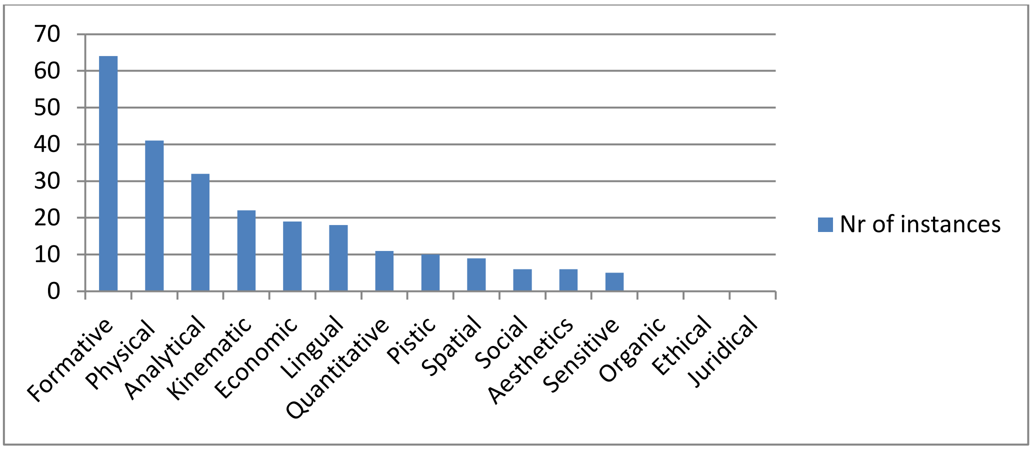


Figure 5.1: Aspectual intentions that played a role in novice industrial design thinking

On average, the aspectual intention most thought of in novice designers' thinking during the early phases of the design process was the formative aspect, followed by the physical and analytical aspects. The aspectual intentions that did not play a role in novice industrial design thinking were juridical, organic and ethical design aspects. Furthermore, I observed a general absence of specificity and qualification of aspectual intentions in the novice designers' verbal utterances, which suggested to me that the laws controlling particular aspects were inferred and not definitive. This insight correlates with the philosophical studies characterising aspects as abstractions (Basden, 2000), which claim that specificity of the content thereof is implied and does not need explication.

5.3.2 Sub-question 2

I come to conclusions here by relating my findings to the second sub-question:

How do novice industrial designers link aspectual intentions with functional intentions?

Discussion

The research revealed that, on the second (functional intentions) level of hierarchical thinking, novice industrial designers typically define the functional nature of an artifact's purpose or function: they are objects meant for doing things in relation to their intentionality (Chapter 2 Section 2.6.1). Thus, functional intentions answer the question 'What is it for?' (Kroes, 2006, p.139). The functional intentions of the participants were therefore used to identify the way and order in which their design aspects that they considered met their end-functional goal intentions. As such, functionality has a close connection with concrete objects and facilitates the need for designers' thoughts to simplify and concretise the abstract nature of their aspectual intentions (Haupt, 2013). To understand the interactions contributing to the development of abstract thinking into concrete thinking, participants' utterances were traced where aspects and functional intention statements occurred at the same instance. For example, Eric from Group A linked his vague formative aspect of rolling something up so that it could be constructed into a multi-purpose designed object with the functional intention of making either sitting or comfortable sleeping possible.

The study revealed that all three groups of participants demonstrated a consistent pattern in transforming their abstract intentions into functional intentions. The internal alignment of mostly formative, analytical and kinematic design aspects seems to have triggered their functional intentions, which implies a self-regulating mechanism that drives the participants to achieve coherent gestalt (Kieran, 2011). I found that, when the participants interacted with various internal and external sources, including their design brief, roughly drawn sketches, domain-independent knowledge and their design experience, functional thoughts materialised. The study revealed that participants' functional intentions primarily consisted of object-related themes when they linked them to their abstract design aspects. Based on the findings of this study, aspectual intentions seem to take priority over functional intentions in the hierarchy of novice design thinking.

5.3.3 Sub-question 3

I come to conclusions here by relating my findings to the third sub-question:

How do novice industrial designers link functional intentions with physical elements?

Discussion

With a focus on the third level of novice designers' hierarchical thinking, the findings of this study revealed how the initial vague aspects with which they linked the functional intentions of their envisaged artefacts later met with physical elements. The literature in Chapter Two explained that, in order to achieve a quality design solution, there must be an optimal fit between the physical elements and functional intention. This entails carefully selecting physical elements to realise the functional intention of the design. Any physical structure possesses particular perceivable properties including a weight, a shape, a size, a number of parts, materials with texture, inherent temperature properties and mechanical properties (Kroes & Meijers, 2002).

The study has established that when the participants considered physical elements, they were able to further transform abstract thinking into refined concrete thinking (Chapter 2 Section 2.6.1). Knowing how novice designers make the links, the types of knowledge they use and their ability to concretise abstract intentions has allowed me to detect when and how novices establish a coherent fit between physical elements and functional intentions and align selected physical elements with aspectual intentions (Haupt, 2013). For example, the result of Group A's process of using domain-dependent manufacturing knowledge as a formative aspect led to the integration of the functional intention, which was to protect the end-users from hurting themselves by adding the physical elements of a little plastic grommet and a plastic 'lining-type thing' around the opening of a finger hole.

The study showed that all the participating novice designers connected functional intentions with physical elements, and by implication vague aspects. As the novices turned their initial vague abstractions into detailed expressions of thought, I noted that their levels of specificity and amount of information increased. The increase in the number of references to physical elements amongst all novices progressed iteratively from problem structuring to problem solving. Furthermore, the study revealed that the novice designers interacted with various internal and external sources including their design brief, domain-specific knowledge, novice design experience as well as the sketches they made. This interaction with various sources helped them to recognise which physical elements would appropriately create coherent gestalt with selected aspectual and functional intentions of the artefacts they were designing. However, the process of linking the various intentions and physical elements was a lengthy one, because the novice designers made several decisions using the same procedures to identify and explore sub-solutions in detail until they made an appropriate decision. Such trial-and-error application processes correspond with Popovic's (2004) findings on the difficulty novices have in deciding which representation is the best to solve the problem.

5.3.4 Sub-question 4

I come to conclusions here by relating my findings to the fourth sub-question:

How do novice industrial designers link aspectual intentions, functional intentions and physical elements with implementation intentions?

Discussion

The literature in Chapter Two explains that the bottom level of hierarchical thinking consists of implementation intentions, in which designers declare activities that they think will support them in achieving their goals. The findings revealed that physical elements, aspectual and functional intentions gave novice designers the ability to make and propagate their commitment to their ideas. The distinguishing characteristic of implementation thoughts is the reference to an activity, for example, 'you can "pick" them up with a rope, "put" them there and "sit" on them'. Furthermore, the condition for qualifying as an implementation intention is that the objects the participants referred to had to be the object they designed.

The study revealed that the participants from all the groups had definitive instances where they hierarchically linked their physical elements to aspectual and functional intentions to meet their implementation intentions. These hierarchical links were characterised by close association with objects and their physical and functional properties. Furthermore, the participants' implementation intentions materialised incrementally in their verbal statements. They were characterised by an increase in detail and specificity supported by their sketches, which played a transformative role in representing gestalt. The transformative role of concurrently establishing and representing gestalt was seen as the participants visualised (internally and externally) implementation through construction, recombination and manipulation of physical elements. This behaviour of novices seems similar to that of experts described by Haupt (2013) and Goel (1995).

5.3.5 Sub-question 5

I come to conclusions here by relating my findings to the fifth sub-question:

What is the distribution of the various types of intentions amongst the problem-structuring and problem-solving phases?

Discussion

This study highlighted the need for the participants to constantly move backwards and forwards to find more information in order to structure their given ill-structured problems and solutions. As problems do not exist prior to solutions, but build up and elaborate simultaneously (Goel & Pirolli, 1992), problem structuring and problem solving constantly intermingle and overlap (Chapter 2, Section 2.3.3). By employing problem-structuring and problem-solving strategies, the participants secured their intentions and generated and developed thoughts from the information gathered that were consistent with one another and with their intentions to establish coherence.

During the problem-structuring phase, the participants attempted to understand the problem and what they needed to design, what its scope was, and what its constraints, requirements and specifications were. The participants drew upon their own design experience and domain-specific knowledge, as well as information obtained during the design process. For this purpose the used their sketches to align their thoughts with the design brief in an attempt to understand the problem. The participants also interacted with external sources of information to make up for information not presented, by employing limited control structures to consider multiple contexts and possible ideas without fixating on one idea early in their process. The cognitive phase of problem solving occurred amongst the participants when the information and detail relating to the problem were taken into consideration. The spoken words of the participants consisted of detailed statements where some aspect of the design was discussed. The study revealed that each of the groups had unique ways and sequences of activities in decomposing their design problems. Instances of problem structuring amongst the three groups only dominated at the beginning of the design task, but also reoccurred periodically throughout the task.

The distribution of gestalt thinking guided by global precedence amongst the various types of intentions (aspectual intentions, aspectual linked with functional intentions, functional intentions linked with physical elements and implementation intentions) amongst the problem-structuring and problem-solving phases in this study revealed the following:

On the first level of the hierarchical thinking model, distinct design aspects gave meaning and direction to the way the participants selected and developed ideas, committed to some and rejected others. During the problem-structuring phase, very little thought had been given to detail about the object the participants were designing, as they were still in the thinking process of framing the problem. As could be expected, in the problem-solving phase an average of 342 (70.2%) instances of aspectual intentions were recorded compared to only 145 (29.8%) instances in the problem structuring phase.

On the second level, links between the functional and aspectual intentions occurred more in the problem-solving phase than in the problem-structuring phase. On average 19 (44.2%) such links were made during the problem-structuring phase, compared to 24 (55.8%) links during the problem-solving phase. I found the problem-structuring phase to be dominated by analytical design aspects. The analytical aspects in turn were linked to functional thoughts with people-object related themes. This insight highlighted the need for the participants to understand the problem by unpacking it systematically before they could make links between aspectual and functional intentions. During the problem-solving phase, the design aspect most often implied by the participants was that of 'formative'. The formative design aspect of the participants was identified as the aspect most often linked to their functional intentions, which related mainly to the theme of the object. This insight indicated to me that there was a gradual development from abstract thinking to concrete thinking where aspectual intentions triggered the mindfulness of functional intentions.

On the third level, links between functional intentions and physical elements and, by implication, preceding by vague aspects, were found. As the participants turned their initial vague abstractions into detailed expressions of thought, I noted that their levels of specificity and amount of information increased, while they were being guided by their abstract aspectual thoughts. The increase in the number of references to physical elements in all three protocols progressed significantly from problem structuring to problem solving. On average, amongst the participants' problem-structuring phases, 2.0 (26%) links were made between different aspectual intentions, functional intentions and physical elements, whereas 5.7 (74%) links were made in the problem-solving phase.

The fourth level demonstrated definitive instances where the participants hierarchically linked physical elements to aspectual and functional intentions to meet their implementation intentions. However, the implementation intentions of the participants' solutions only developed incrementally in the problem-solving phase, and not when they were structuring the problem.

5.4 Contributions of the study

This section describes the contribution this study may make towards theories of design cognition and to the practice of Industrial Design.

5.4.1 Theoretical contribution

The main research question, namely *what is the role of gestalt theory in Industrial Designers' hierarchical thinking in the early phases of the design process?* implies a potential theoretical contribution to design cognition theory. This study revealed that coherent gestalt was instantiated when extended cognition actions synergistically integrated internal processes and external sources of information to solve design problems. The gestalt theory of global precedence characterised by hierarchical levels was evident as the Industrial Design students' thoughts developed. Their hierarchy of thoughts consisted of four levels, namely aspectual intentions, functional intentions, physical elements and implementation intentions. At each of these hierarchical levels, Industrial Design students thought of different things to help them understand a given problem and to find a coherent solution in the form of a conceptualised artefact. This confirms the centrality of global precedence in gestalt theory. It furthermore confirms the suitability of the four-level hierarchical model, suggested by Haupt (2013) in an expert context, to trace and map the thoughts and cognitive behaviour of novice industrial designers.

5.4.2 Industrial Design-related contribution

The practical contribution of this study, about Industrial Design students' hierarchical thinking in the early phases of the design process, may be seen as an opportunity for design educators to develop design activities in which students can consciously practise making links between various levels of intentions, functionality and physicality. This teaching strategy might allow Industrial Design students to structure their problem-solving activity and reduce the cognitive pressure, in order to be more efficient and productive with their time (Petrina et al., 2008). Making design students consciously aware of these hierarchical levels might allow lecturers to facilitate design students' thinking, to mirror expert design behaviour.

5.5 Limitations of the study

This section reports on the limitations of this study in terms of sampling, design task environment, protocols and video recording, and analysis stages.

Sampling

The study was limited to six top-performing third-year Industrial Design students working in groups of two. The challenge was to choose a sampling method that ensured that the selected participants were representative of top-performing third-year industrial design students. A small purposeful sample was used from which most could be learned. However, the small sample did not allow me to generalise my findings, and there is consequently a danger of non-representativeness. My decision to limit the target sample may be attributed to the large amount of information that is generally generated in cognitive studies, which makes reporting impractical.

Design task environment

Another potential limitation of this study relates to the inherent inability of a quasi-design experiment to provide a real-life design task environment. This weakness is related to one of the aspects generally present at university students, namely the consequences of not achieving the minimum grade. In my adapted experiment, the decisions and actions taken by the participants had no real consequences, either academically or practically. I attempted to counter this factor by selecting top-achieving and motivated students who were reportedly inclined to perform to their best ability when given any challenging design task.

Protocols and video recording

A further limitation of this study was the use of concurrent TAPS as a data-collection strategy to access the participants' thoughts. Although TAPS is of all observational research methods the most widely accepted (Cross, 2004), it is not possible to provide visible evidence of everything that the participants thought about. In an attempt to capture the participants' thoughts more comprehensively, I used multiple forms of data, namely video material, verbal protocols, and concurrent sketches for countering or confirming each thought. The advantage of this data-collection strategy in the study was the ability to keep track, trace and map the hierarchical thinking processes captured in the recordings of the protocols. This brings me to the limitations of video recording. Having only one camera limited the number of viewpoints from which participants' activities could be recorded. Having more than one video camera at the same time might have provided me with more angles and allowed me to focus on more than one object at a time.

Analysis stages

The research strategy discussed in Chapter 3 was based on a QUAL+quan mixed methods analysis to generate and validate interpretations, formulate inferences and drew conclusions. The use the QUAL+quan method nonetheless posed certain limitations. Coding the large set of complex qualitative data in a manner that was practical and meaningful to ensure validity and reliability was very time-consuming. However, I asked knowledgeable experts in the field of research design to scrutinise my coding and interpretation in addition to my own readings and re-readings of participants' representations. Furthermore, I faced the risk of reducing the complexity of the study through simplified quantitative processes. I therefore attempted, through the combination and integration of the mixed methods approach, to successfully represent the complexity of design cognition. The representation of complex design cognition was achieved by correlating the quantitative and qualitative parts of data with one another, which provided richness, depth and confirmation of the findings and the interpretation thereof.

5.6 Recommendations

This section offer recommendations to educational programmes in design and further directions for research.

5.6.1 Recommendations for education programmes in design

I recommend training programmes in design activities to develop design students' ability to make coherent cognitive links between various levels of intentions, functionality and physicality. Making design students consciously aware of these hierarchical levels might allow educators to facilitate design students' thinking and help them to become effective problem solvers.

Closely coupled with this recommendation is the ability to integrate internal iterative strategies of conceptual understanding of the structure of design problem and how and when to use external sources of perceptual information. Educators should consider creating learning activities where students are expected to intentionally pay attention to abstract thoughts that are relevant to intentions, and to actively engage with physical elements to look for specific external information. Learning how to synergistically integrate conceptual understanding of the design problem and external sources of perceptual information may contribute to the development of students' gestalt alignment of intentions to structure a coherent solution. I recommend that design students should consciously align gestalt intentions, which might help them to become effective in developing complex and dynamic thinking skills to mirror expert design behaviour.

I found that using freehand sketching during the early phases of the design process has advantages over the use of CAD software, as it allowed the participants to construct and manipulate concepts, which in turn encouraged extended cognitive actions. This means that the act of sketching in combination with perception seems to generate different kinds of thinking compared to CAD drawings. CAD software has the tendency to seduce designers into early commitment. In contrast, the vagueness and ambiguity of freehand sketching contribute to designers' gradual commitment to an idea, which might not be the case with CAD. I found evidence of the participants making hierarchical links supported by their sketches, which played a transformative role in establishing gestalt. I recommend that novice designers use methods of representation that promote externalised visual thinking in the early phases of the design process. I furthermore found that to keep thoughts flowing fast in the early phases of the design process, representational symbol systems should be used that do not slow novice designers' thought processes down or overstimulate them visually.

5.6.2 Recommendations for further research

I recommend the following studies in light of the findings presented by this study.

- This study could be replicated in other design domains such as engineering, architecture and fashion design to cover a wider novice design population in order to allow generalisation.

- A study to establish how much domain-dependent knowledge compared to domain-independent knowledge novice designers contemplate, and the way they connect it with their hierarchical thinking to solve design problems.

- Evaluation studies that explore the potential effect of interventions focusing on conscious verbalisation and application of hierarchical thinking in novices' design projects on the quality of their end-products.

5.7 Conclusion

The purpose of this study was to understand the role of gestalt theory in Industrial Design students in structuring and solving design problems. The results of the study and the discussions of the findings conclude that novice designers' gestalt thinking develops when the interactivity between the occurrence of conceptual understanding of the design problem and the processes of discovery is integrated by perceptual information. The theory of global precedence in gestalt thinking in an extended cognition context demonstrates that novice designers' conceptual insights are characterised by a hierarchical system with nested relationships. It was established that novice designer's hierarchical thinking is constructed through multi-directional thinking processes. The hierarchy of thoughts consists of four levels, namely aspectual intentions, functional intentions, physical elements and implementation intentions. I found that coherence was brought about by gestalt when novice designers created self-regulating perception-action feedback loops in their thinking by constantly drawing interrelations between their intentions and instructions on all four hierarchical levels.

References

Adams, R. (2001). *Cognitive processes in iterative design behaviour.* Dissertation, University of Washington.

Ahmed, S., Wallace, K. M., & Blessing, L. T. M. (2003). Understanding the differences between how novice and experienced designers approach design tasks. *Research in Engineering Design, 14*, 1-11.

Akin, Ö. (1993). Architects' reasoning with structures and functions. *Environment Planning B, 20*, 273-294.

Allen, T. F. (1996). *Hierarchy theory, a vision, vocabulary and epistemology*. New York: Columbia University Press.

Anderson, M. L. (2003). Embodied cognition: A field guide. *Artificial Intelligence, 149*(1), 91-130.

Asch, S. (2015). *Gestalt theory. Encyclopedia.com.* Retrieved 19 February 2015, from "Gestalt Theory." International Encyclopedia of the Social Sciences. 1968. Encyclopedia.com. (February 19, 2015). http://www.encyclopedia.com/doc/1G2-3045000461.html

Atman, C. J., & Bursic, K. M. (1996). Teaching engineering design: can reading a textbook make a difference? *Research in Engineering Design, 7*(7), 240-250.

Atman, C. J., Chimka, J. R., Bursic, K. M., & Nachtman, H. N. (1999). A comparison of freshman and senior engineering design processes. *Design Studies, 20*(2), 131-152.

Basden, A. (2000). The Aspectual Framework of Meaning. Retrieved from The Dooyeweerd Pages website: www.dooy.salford.ac.uk/contact.html

Behrens, R. R. (1998). Art, Design and Gestalt Theory. *Leonardo, 31*(4), 299-303. doi: 10.2307/1576669

Bickhard, M. H. (2008). Is embodiment necessary? In P. Calvo & A. Gomila (Eds.) *Handbook of Cognitive Science: An Embodied Approach*. Amsterdam: Elsevier Science.

Björklund, T. A. (2013). Initial mental representations of design problems: Differences between experts and novices. *Design Studies, 34*, 135-160.

Blessing, L. T. M., & Chakrabarti, A. (2009). *DRM, a Design Research Methodology*. Dordrecht: Springer.

Cardella, M. E., Atman, C. J., & Adams, R. S. (2006). Mapping between design activities and external representations for engineering student designers. *Design Studies, 27*(1 January), 5-24.

Carlson, N. R., & Heth, C. D. (2010). *Psychology the Science of Behaviour Ontario*. CA: Pearson Education Canada.

Christiaans, H. H. C. M., & Dorst, K. (1992). Cognitive models in industrial design education: a protocol study *Design Theory and Methdology* (Vol. 42, pp. 131-140).

Clark, A. (2006). Language, embodiment, and the cognitive niche. *Trends in Cognitive Sciences, 10*(8), 370-375.

Cohen, L., Manion, K., & Morisson, K. (2007). *Research Methods (6th ed.)*. London: Routledge.

Creswell, J. W. (2003). *Research Design: Qualitative, Quantitative and Mixed Methods Approaches* (2nd ed.). London: Sage Publications.

Cross, N. (1982). Designerly ways of knowing. *Design Studies, 3*(4), 221-227.

Cross, N. (1995). Discovering design ability. In R. Buchanan & V. Margolin (Eds.), *Discovering Design: Explorations in Design Studies* (pp. 105-119). Chicago: The University of Chicago Press.

Cross, N. (1999). Natural intelligence in design. *Design Studies, 20*(1), 25-39.

Cross, N. (2001a). Design Cognition: Results from protocol and other empirical studies of design activity. In C. Eastman, M. McCracken & W. Newstetter (Eds.), *Design Knowing and Learning: Cognition in Design Education*. Oxford: Elsevier.

Cross, N. (2001b). Designerly Ways of Knowing: Design Discipline Versus Design Science. *Design Issues, 17*(3), 49-55.

Cross, N. (2004). Expertise in design: an overview. *Design Studies, 25*(5), 427-441.
Cross, N. (2007). Forty years of design research. *Design Studies, 28*(1), 1-4.
Cross, N., Christiaans, H., & Dorst, K. (Eds.). (1996). *Analysing Design Activity*. Chichester, UK: John Wiley & Sons.
Cross, N., Naughton, J., & Walker, D. (1981). Design method and scientific method. *Design Studies, 2*(4), 195-201.
Danermark, B., Ekstrom, M., Jakobsen, L., & Karlsson, J. C. (2002). *Explaining society: Critical Realism in the Social Sciences*. London: Routledge.
De Vries, M. J. (2005). *Teaching about Technology: An introduction to the Philosophy of Technology for Non-philosophers* (Vol. 27). Eindhoven University, Netherlands: Springer.
Denzin, N. K., & Lincoln, Y. S. (1994). *Handbook of Qualitative Research. Thousand Oaks*. California: Sage.
Denzin, N. K., & Lincoln, Y. S. (2008). Introduction: The discipline and practice of qualitative research. In N.K.Denzin and Y.S. Lincoln (Eds.),*The Landscape of Qualitative Research* (pp. 9). Thousand Oaks, California: Sage.
Dixon, R. A. (2011). Selected core thinking skills and cognitive strategy of an expert and novice engineer. *sTEm teacher education, 48*(spring).
Dorst, C. H., & Cross, N. (2001). Creativity in the design process: co-evolution of problem-solution. *Design Studies, 22*, 425-437.
Dorst, K. (1997). *Describing Design: A Comparison of Paradigms.* PhD, Delft University of Technology, The Netherlands, Delft.
Eastman, C. (1970). On the analysis of intuitive design processes. In G. Moore (Ed.), *Emerging Methods in Environmental Design and Planning* (pp. 21-37). Massachusetts: MIT Press Cambridge
Eastman, C. (2001). New directions in design cognition: Studies on Representation and Recall In C.M. Eastman, W.M. MacCracken & W.C Newsletter (Eds.), *Design Knowing and Learning:Cognition in Design Education* (pp. 79-103). Amsterdam: Elsevier.
Economou, I., & Joubert, N. (2009). Towards an education strategy for promoting social, environmental and ethical awareness in visual communication education. *Image & Text, 15*, 40-53.
Ericsson, K. A. (2006). Protocol analysis and expert thought: concurrent verbalizations of thinking during experts' performance on representative tasks. In K. Ericsson, N. Charness, P. J. Feltovic & R. R. Hoffman (Eds.), *Cambrdige Handbook of Expertise and Expert Performance* (pp. 223-242). Cambridge, United Kindom: Cambridge University Press.
Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: evidence of maximum adaptation to task constraints (Vol. 47, pp. 273-305): Anual Review of Psychology.
Ericsson, K. A., & Lehmann, A. C. (Eds.). (1991). *Toward a general theory of expertise* New York Cambridge University Press.
Ericsson, K. A., & Simon, H. A. (1993). *Protocol Analysis Verbal Reports as Data (Revised Edition ed.)*. Massachusetts: Massachusetts Institute of Technology.
Feltovich, P. J., Ford, K. M., & Homan, R. R. (Eds.). (1997). *Expertise in context*. Cambridge: MIT Press.
Finley, L. (2002). "Outing" the researcher: The provenance, process, and practice of reflectivity. *Qualitative Health Research, 12*, 5311-5545.
Gero, J. S., & McNeill, T. (1998). An approach to the analysis of design protocols. *Design Studies, 21*(3), 21-61.
Gibbs, J. R. W. (2005). *Embodiment and Cognitive Science*. Cambridge: Cambridge University Press.
Gibson, J. J. (1977). The Theory of Affordances In R. Shaw & J. Bransford (Eds.), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology* Hillsdale, NJ: Lawrence Erlbaum.

Goel, V. (1995). *Sketches of Thought*. Cambridge: MIT Press.
Goel, V., & Grafman, J. (2000). Role of the right prefrontal cortex in ill-structured planning. *Cognitive Neuropsycology, 17*(5), 415-436.
Goel, V., & Pirolli, P. (1989). Motivating the Notion of Generic Design within Information-Processing Theory: The Design Problem Space. *AI Magazine, 10*(1).
Goel, V., & Pirolli, P. (1992). The structure of design problem spaces. *Cognitive Science, 16*, 395-429.
Gollwitzer, P. M., & Schaal, B. (1998). Metacognition in action: The importance of implementation intentions. *Personality and Social Psychology Review, 2*(2), 124-136.
Guba, E. G., & Lincoln, Y. S. (2008). Paradigmatic controversies, contradictions, and emerging confluences. In N.K.Denzin & Y. S. Lincoln (Eds.), *The Landscape of Qualitative Research* (pp. 255-286). Los Angeles: Sage Publishers.
Guindin, R. (1990). Knowledge exploited by experts during software system design. *International Journal of Man-Machine Studies, 33*, 279-304.
Haupt, M. C. (2013). *The Cognitive Dynamics of Socio-technological Thinking in the Early Phases of Expert Designers' Design Process.* PhD, University of Pretoria, Pretoria.
Haupt, M. C. (2014). Learning from experts: fostering extended thinking in the early phases of the design process. *International Journal of Technology and Design Education*. Retrieved from http://link.springer.com/article/10.1007%2Fs10798-014-9295-7#page-1
Haupt, M. C. (unpublished). *Gestalt revisited: hierarchical thinking in expert design*.
Hegeman, J. (2008). *The thinking behind design.* Master of Design in Interaction Design, Carnegie Mellon University Retrieved from http://jamin.org/portfolio/thesis-paper/thinking-behind-design.pdf
Hergenhahn, B. R. (1997). *An Introduction to the History of Psychology*. California: Brooks & Cole Publishing Company.
Ho, C. (2001). Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts. *Design Studies, 22*, 27-45.
Jackson, S. L. (2006). *Research Methods and Statistics: A Critical Thinking Approach*. Singapore: Thomson Wadsworth
Johnson, B., & Turner, L. A. (2003). Data collection strategies in mixed methods research. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of Mixed Methods in Social & Behaviour Research*. London: Sage.
Kavakli, M., & Gero, J. S. (2003). Strategic knowledge differences between an expert and a novice designer. In U. Lindemann (Ed.), *Human Behaviour in Design: Individuals, Teams, Tools*. Berlin: Springer.
Kelley, T. R. (2008). Cognitive processes of students participating in engineering-focused design instruction. *Technology Education, 19*(2), 50-64.
Kieran, S. (2011). Intention. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy (Spring ed)*. Stanford: Stanford University.
Kirsh, D. (2009). Problem solving and situated cognition. In P. Robbins & M. Aydede (Eds.), *The Cambridge Handbook of Situated Cognition* (pp. 264-306). Cambridge: Cambridge University Press.
Kroes, P. (2006). Coherence of structural and functional descriptions of technical artefacts. *Studies in History and Philosophy of Science, 37*, 137-151.
Kroes, P., & Meijers, A. (2002). The dual nature of technical artifacts – presentation of a new research programme. *Techné 6 (2)*.
Kruger, C., & Cross, N. (2001). Modelling cognitive strategiesin creative design. In J. S. Gero & M. L. Maher (Eds.), *Computational and Cognitive Models of Creative Design*. Australia: University of Sydney.
Liikanen, L. A. (2009). Exploring problem decomposition in conceptual design among novice designers. *Design Studies, 30*(1), 38-59.
Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. London: Sage Publications.
Lloyd, P., Lawson, B., & Scott, P. (1995). Can concurrent verbalisation reveal design cognition. *Design Studies, 16*, 237-259.

Lloyd, P., & Scott, P. (1994). Discovering the design problem. *Design Studies, 15*(2), 125-140.
Love, T. (2002). Constructing a coherent cross-displinary body of theory about designing and designs: Some philosophical issues. *Design Studies, 23*(1), 345-361.
Maher, M. L., & Tang, H. (2003). Co-evolution as a computational and cognitive model of design. *Research in Engineering Design, 14*, 47-63.
Maree, K. (2011). *First Steps in Research*. Pretoria: Van Schaik Publishers.
Maree, K., & Van der Westhuizen, C. (2009). *Head Start in Designing Research Proposals in the Social Sciences*. Cape Town: Juta &Company.
Maxwell, J. A. (1996). *Qualitative Research Design: An Interactive Approach.* Thousand Oaks: Sage Publications.
Maxwell, J. A., & Mittapalli, K. (2010). Realism as a stance for mixed method research. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of Mixed Methods in Social and Behavioral Research* (2nd ed.). Thousand Oaks, California: Sage.
McNeill, T., Gero, J., & Warren, J. (1998). Understanding conceptual electronic design using protocol analysis. *Research in Engineering Design, 10*, 129-140.
Merriam, S. (1998). *Qualitative Research and Case Study Applications in Education*. San Francisco: Jossey-Bass Publishers.
Mitcham, C. (1994). *Think Through Technolgy: The Path Between Engineering and Philosophy*. Chicago: The University of Chicago.
Mitcham, C., & Holbrook, J. B. (2006). Understanding technological design In J. S. Dakers (Ed.), *Defining Technological Literacy Towards an Epistemmological Framework*. New York: Palgrave MacMillan.
Morse, J. M. (2010). Procedures and Practice of Mixed Methods Design. In A. Tashakkori & C. Teddlie (Eds.), *SAGE Handbook of Mixed Methods in Social & Behavioural Research*. Los Angeles: Sage.
N.A. (2011). Department of Industrial Design Retrieved July 20, 2013, from http://www.uj.ac.za/EN/Faculties/fada/departments/industrial/coursesandprogrammes/NationalDiplomas/Pages/Three-DimensionalDesign.aspx
Nelson, H., & Stolterman, E. (2003). *The Design Way: Intentional Change In an Unpredictable World*. Englewood Cliffs: Educational Technology Publications
Newell, A. (1969). Heuristic programming: ill-structured problems In J. Aronofsky (Ed.), *Progress in Operations Research* (Vol. 3, pp. 360-414): John Wiley & Sons.
Newell, A., & Simon, H. A. (1972). Human Problem Solving: Englewood Cliffs, N.J.: Prentice-Hall.
Onwuegbuzie, A. J., & Teddlie, C. (2003). *A Framework for Analyzing Data in Mixed Methods Research. In aTashakkori & C. Teddlie (Eds.), Handbook of Mixed Methods in Social and Behavioral Research Thousand Oaks* Calif: SAGE.
Patton, M. Q. (2008). *Qualitative research and assessment methods* (3rd ed.). London: Sage.
Petrina, S. (2010). Cognitive Science. In P. A. Reed & J. E. LaPorte (Eds.), *Research in Technology Education*: University of British Columbia.
Petrina, S., Feng, F., & Kim, J. (2008). Researching cognition and technology: how we learn across the lifespan. *Technology Design Education 18*, 375-396.
Popovic, V. (2003). Expert and novice users models and their application to the design process. *Journal of the Asian Design International Conference, 1*.
Popovic, V. (2004). Expertise development in product design - strategic and domain specific knowledge connections. *Design Studies, 25*, 527-545.
Pyett, P. M. (2012). Validation of Qualitative Research in the 'Real World'. Retrieved from http://ace.upm.edu.my/~lateef/Handouts%20-%20dce%205920/validity%20in%20the%20real%20world.pdf
Radcliffe, D. F., & Lee, T. Y. (1989). Design methods used by undergraduate engineering students. *Design Studies, 10*(4), 199-209.
Reed, S. K. (2007). *Cognition. Theory and Applications* (Seventh International Student Edition ed.). Belmont: Thomson Wadsworth.

Richardson, M. H., Shockley, K., Fajen, B. R., Riley, M. A., & Turvey, M. T. (2008). Ecological Psychology: Six Principles for an Embodied–Embedded Approach to Behavior. In P. Calvo & A. Gomila (Eds.) *Handbook of cognitive science: an embodied approach*. Amsterdam: Elsevier Science

Schön, A. D., & Wiggins, G. (1992). Kinds of seeing and their functions in designing. *Design Studies, 13*(2), 135-156.

Scotland, J. (2012). Exploring the philosophical underpinnings of research: Relating ontology, epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English Language Teaching, 5*(9), 9-15.

Searle, J. R. (1983). *Intentionality: An Essay in the Philosophy of Mind*. Cambridge: Cambridge University Press.

Shani, I. (2012). Making it mental: In search for the golden mean of the extended cognition controversy. *Phenomenology and the Cognitive Sciences 12*(1), 1-26.

Simon, H. A. (1973). The structure of ill-structured problems. *Arificial Intelligence, 4*, 181-201.

Simon, H. A. (1996). *The Sciences of the Artificial (3rd ed.)*. Cambridge,MA: MIT Press.

Smit, P. (2010). SA's industrial designers face new threats, opportunities. Pretoria: SABS Design Institute.

Stassen, S. (2012). Building capacity with design education. Retrieved from Design SA website: http://sabs.designsa.org.za/article/building-capacity-design-education

Stauffer, L. A., & Ullman, D. G. (1991). Fundamental processes of mechanical designers based on empirical data *Journal of Engineering Design, 2*, 113-125.

Suwa, M., & Tversky, B. (2003). *Constructive Perception: A Metacognitive Skill for Coordinating Perception and Conception*. Paper presented at the Annual Conference of the Cognitive Science Society Hillsdale, NJ.

Tashakkori, A., & Teddlie, C. (2009). *Foundations of Mixed Methods Research. Integrating Quantitative and Qualitative Approaches in the Social and Behavioural Sciences*. London: Sage.

Tversky, B. (2005). Visuospatial Thinking. In B. Shah & A. Miyake (Eds.) *The Campbridge Handbook of Visuospatial Thinking* (pp. 1-34). Cambridge: Cambridge University Press.

Van Someren, M. W., Barnard, Y. F., & Sandberg, J. A. C. (1994). *The Think Aloud Method. A Practical Guide to Modelling Cognitive Processes*. London: Academic Press.

Viljoen. (2010). IDA World Design Survey Pilot Project South African Findings. In E. Kruger & J. Lange (Eds.). Pretoria: SABS Design Institute.

Vincenti, W. G. (1990). *What Engineers Know and How they Know it*. London: Johns Hopkins University Press.

Visser, W. (2004). Dynamic Aspects of Design Cognition: Elements for a Cognitive Model of Design (pp. 1-116). Rocquencourt: Institut National de Researche en Informatique en Automatique.

Visser, W. (2009). Design: one, but in different forms. *Design Studies, 30*(3), 187-223. doi: http://dx.doi.org/10.1016/j.destud.2008.11.004

Wagemans, J., Feldman, J., Gepshtein, S., Kimchi, R., Pomerantz, J. R., & Van Leewen, C. (2012). A century of gestalt psychology in visual perception: II. Conceptual and theoretical foundations. *Psychological Bulletin, 138*(6), 1218-1252.

Welch, M., & Lim, H. S. (2000). The strategic thinking of novice designers: Discontinuity between Theory and Practice. *26*(Summer/Fall).

Williams, C. B., Lee, Y. S., Paretti, M. C., & Gero, J. S. (2011). *Effects of design education on design cognition: A preliminary study of a sophomore design course*. Paper presented at the 41th ASEE/IEEE Frontiers in Education Conference, Rapid City, South Dakota.

Zamenopoulos, T. (2011). A complexity theory of design intentionality *Artificial intelligence for Engineering Design, Analysis and Manufacturing* (pp. 1-21). Cambridge, United Kingdom: Cambridge University Press.

Zeiler, W., Savanovic, P., & Quanjel, E. (2007). *Design Decision Support for the Conceptual Phase of the Design Process.* Paper presented at the International Association of Societies of Design Research, Hong Kong Polytechnic.