Consensus in Design

A study of interdisciplinary team conversation and consensus reaching during the early phases of design

By

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PhD Thesis Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of University Limerick.

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LIST OF PUBLICATIONS

Journal papers


Conference papers


ABSTRACT

The focus of this research is to explore how consensus is reached amongst teams during the initial phases of design projects. In building on previous studies on the social aspect of design, and on team cognition this research seeks to understand the cognitive processes and conversation activities used during the interactions of design teams to reach consensus. The research also examines other factors that were identified as having a potential bearing on the research focus; the difference between the phases of the design process, the difference between experts and novices and the impact of conflict. Four cases were studied across different design domains. The cases involved two bio-medical fellowship programs, an undergraduate product design project and a user experience design consultancy. Content analysis (CA) was used as the main method to analyse the data.

The research has contributed to a better understanding of how teams reach consensus while solving complex unstructured design problems. The findings show that during team interactions design teams alternated between 4 cognitive process types: knowledge processing, critical thinking, creative thinking and meta-cognition. Six conversation activities were identified which supported these cognitive processes; domain knowledge, analogies, arguing, mental simulations, scenarios and building on and were instrumental in enabling teams to reach common ground and consensus.

The cognitive processes and conversation activities used were also found to be dependent on the objectives of the different phases at the initial phases of the design process. Experts were found to be more successful than novices at building consensus due to a greater and more effective use of the cognitive processes and conversation activities.

Conflict has the potential to be a barrier in reaching consensus however this research found cognitive conflict to have a contributory effect on consensus as it encouraged the elaboration and negotiation of information and perspectives. This prevented teams reaching premature consensus and misunderstandings. Conflict was found to be more appropriate at the problem definition phase and the concept development phase but not at the ideation phase. It was also more beneficial in more unstructured problems. Experts were better able to benefit from conflict and at times appeared to deliberately instigate it to broaden the perspectives of topics being discussed.
DECLARATION

I hereby declare that this thesis is entirely my own work, and has not been submitted for any other awards at this or any other academic establishment. Where use has been made of the work of other people it has been fully acknowledged and referenced.

________________________
I would like to acknowledge a number of people who helped me over the duration of my PhD;

I would like to thank my supervisors Dr Ann Ledwith and Dr Raymond Lynch for their guidance and direction throughout the study. I would also like to thank the Product Design & Technology team for their moral support and encouragement. Thank you to Muireann and Niall for participating in peer auditing and a special thanks to Muireann for her support and critique of the work. I would finally like to thank the participants in the studies who generously gave up their time.
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ABBREVIATIONS

A&E Accident and Emergency
BAO Bachelor of Obstetrics
BCh Bachelor of Surgery
BE Bachelor of Engineering
BMI Body mass index
CA Content analysis
CRM Customer relationship management
ECG Echo Cardiogram
FA Flight Attendants
GP General Practitioner
HU Hogeschool Utrecht
LLB Bachelor of law
MB Bachelor of Medicine
MBA Master of Business Administration
MRI Magnetic resonance imaging
MSc Master of Science
NG Nasogastric
PhD Doctor of Philosophy
R&D Research and Development
1 Overview

This thesis examines the cognitive processes and conversation activities used by teams to reach consensus during the initial phases of the design process. This chapter begins by providing a background to the research area. This is followed by the aim and the research questions that will be addressed to meet the aim. An outline of the thesis structure is then provided.

1.1 INTRODUCTION AND BACKGROUND

Design has evolved from a narrow focus on aesthetics towards innovation and product development which involves complex problem solving and interdisciplinary collaboration (Beucker 2004, Kolko 2005, Grasso and Martenelli 2007). Team cognition refers to how knowledge related to the functioning of the team is organised, distributed and represented to allow teams to co-ordinate their efforts (Kozlowski and Ilgen 2006). Team cognition has become an important area of research to understand the performance and behaviours of multidisciplinary teams (McDonough 2000, DeChurch and Mesmer-Magnus 2010, McDonnell 2012). It has also been shown that team cognition is related to team behaviour and performance (DeChurch and Mesmer-Magnus 2010). How information is processed collectively by a team has become critical to understanding effective team performance. For heterogeneous teams to be effective in solving a task they need to be able to manage the collaboration process, share and integrate diverse information and reach common ground and agreement to co-ordinate their efforts. Many of the studies in the design field have followed individual designers (Cross 2004, Lawson 2004), or homogenous design teams from one design discipline (Stempfle and Badke-Schaub 2002, Valkenburg and Dorst 1998), or specific strategies of designers such as analogical reasoning (Ball and Christensen 2009). More recent studies have focused on the social aspect of design (Bucciarelli 1994) and shown that designers create their own common language to communicate about the product being designed (Dong et al. 2005, Lloyd 2000). Design can also be seen as negotiation where this common language is used to negotiate and progress the design process (McDonnell 2009, Stumpf and McDonnell 2002).
1.1.1 Design Problems

Many problems faced by designers are ill defined and require techniques beyond what is achievable by one discipline (Cross 2006, De Vere et al. 2010, Jonassen and Hung 2008). As a result designers are working on a broader set of design problems involving complex systems and working as part of interdisciplinary teams with the integration of specialist expertise (Moritz 2005, Wohlfarth 2002, Dym et al. 2006, Ostergaard and Summers 2009). Design problems are further complicated as there may be many ways and methods of solving them (Jonassen et al. 2006, Voss and Post 1988). Knowing which method is optimal can be difficult. Design problems may also have multiple solution options which may also be difficult to evaluate as there may not be an obvious correct answer. This poses difficulties for design teams and highlights the requirement of a team to reach consensus on a variety of matters. As there is no typical course of action to reach consensus and make decisions other strategies may therefore be required.

It has also been shown that the objectives and reasoning required in design varies across the phases of the design process and involves switching between divergent and convergent stages. These different emphases may have a bearing on how teams reach consensus. The differences between experts and novices problem solving strategies has also been a focus of design research (Ahmed et al. 2003, Cross 2004). In order to understand best practice it is necessary to understand these differences in order to guide novices and novice teams. The differences may be more significant when designing in teams, as rather than just solving the design task the team must also engage in the collaboration process, manage diverse views and potentially conflict.

1.1.2 Design team cognition

Much of the literature on shared cognition and consensus comes from cognitive and behavioural psychology. DeChurch et al. (2013) argue that this literature overemphasises cognitive states and the measuring of shared cognition rather than the cognitive processes to reach shared cognition. Collaborative design has increasingly become a focus of research. It has been found to be a discursive process where solutions are developed through talk in interaction as individuals contribute from their area of expertise (Luck 2009, McDonnell 2009, Kleinsmann et al. 2012). These studies have addressed levels and accuracy of shared cognition (Dong et al. 2013), the acquisition and integration of knowledge (Kleinsmann et al. 2010) and behavioural processes in design teams (Badke Schaub et al. 2010). While these studies in design
have contributed significantly to how designers solve design problems this research seeks to further understand how teams build shared cognition and consensus to move forward in the design process.

Effective team performance requires both similar cognitive models and distinctive knowledge structures (DeChurch and Mesmer-Magnus 2010). However it has been shown that many teams fail to optimally use their distributed information due to a poor understanding of each other, their task, and an overemphasis of agreement seeking at the expense of information elaboration (van Ginkel and van Knippenberg 2008). It has also been shown that arriving at consensus can be challenging for teams and is affected by cognitive diversity which can lead to conflict (Détienne et al. 2012, Badke Schaub et al. 2010, Ostrosi et al. 2012). While cognitive conflict is thought to have a positive effect on complex tasks like design and innovation (De Dreu 2006, Song et al. 2006, Badke Schaub et al. 2010) the literature is also mixed as to its actual benefits (Van Knippenberg and Schippers 2007). There exists limited empirical research on the impact of conflict amongst design teams except, Badke Schaub et al. (2010) who have focused on behavioural styles adopted during conflict. A core issue for research into groups’ effective use of distributed information therefore is to identify factors that are conducive to the elaboration, exchange, discussion and integration of information and perspectives (Kooij-de Bode et al. 2010). There is a need to understand how teams reach agreement during complex design and innovation problems.

1.2 AIM AND OBJECTIVES OF THE RESEARCH

Given that many design problems are solved by multidisciplinary teams it is critical to further the understanding of the cognitive interactions of design teams. The study sets out to identify the nature of design team cognition through a detailed content analysis of the discourse employed by design teams. This thesis addresses the cognitive processes and conversation activities used by teams in design problem solving to move from diversity to consensus during the initial phases of the design process. It addresses also the differences in the phases of the design process, the differences between experts and novices and the effects of conflict. See Figure 1.1.
Thus the aim of this study can be stated as follows:

To explore how consensus is reached during the initial phases of design and how it is negotiated within design teams.

Addressing the research aim entails understanding the meaning behind the discourse of teams and how this enables consensus reaching. It is about understanding how teams bring together the distributed knowledge of individual members, elaborate on that knowledge and reach consensus to collectively solve problems. As the objectives change over the phases of design projects it is important to understand if this impacts on consensus reaching. There may be variation between experts and novices which can better inform design practice. The impact of conflict and how it is negotiated will also have a bearing on consensus reaching. The overall aim therefore can be fulfilled by meeting the following research questions:

1. What are the cognitive processes and conversation activities used by teams during the initial phases of design?
2. How do the cognitive processes and conversation activities used by teams enable consensus during the initial phases of design?
3. What is the impact of different design phases on reaching consensus?
4. What are the differences between how experts and novices reach consensus?
5. How does conflict impact on consensus reaching in design teams?
A series of four case studies was conducted to understand how design teams work through problems both in practice and in education. Content analysis was used to analyse the team dialogue.

1.3 THESIS STRUCTURE

Chapter 2 is a review of the literature to understand the current theories in relation to the research focus. It begins with a review of the design and innovation literature and explores design problems and processes in this area. This is followed by a review of design cognition, framing, Schön’s reflective practice framework, design as a social process, developing a common language in design, design as negotiation and the cognitive processes used in design. This is followed by a review of teams, multidisciplinary teams, collaboration typologies and the collaboration process. The literature on team cognition, consensus, common ground and knowledge construction is then addressed which is followed by cognitive diversity and conflict. The chapter summarises the literature, which guides the direction and focus of the research. This is followed by the presentation of the conceptual model which underpins the research.

Chapter 3 provides an explanation of the methodology chosen, and why a case study approach was appropriate to fulfil the project aim. The chapter continues with an outline of the research design, data collection and data analyses. The main method used was case studies. Content analysis (CA) was chosen as the main method to analyse the data as it is suited to analysing social interactions and is qualitative, inductive, interpretative and constructivist (Hardy et al. 2004). The measures taken to ensure validity and reliability are also addressed.

Chapter 4, 5, 6 and 7 present the four case studies carried out. The first case study explores a project within a fellowship program in bio-medical innovation. The program is made up of interdisciplinary teams that follow an integrated design process to identify opportunities for new innovations in the area of medical devices. The expertise of the disciplines within the teams came from medicine, engineering, business and law. All of the participants in the study are experts within their area with several years’ experience along with post-graduate qualifications.

The second case study involves a collaboration project with third year undergraduate design students from the Product Design and Technology course at University Limerick (UL) and the Hogeschool Utrecht (HU) in the Netherlands. This allowed for the
opportunity to gain an insight into the activities employed by students to provide comparisons with expert design teams.

The third case explores a user experience design consultancy that follows a user centred design process to develop interfaces for web applications and digital devices. This approach is more of a traditional design rather than an innovation approach in that the goals of the project are clearer and the outputs more determinable than the Bio-innovate projects. All the participants used in the study could be described as experts with several years of experience in their field. This case provides an opportunity to study how professional design teams work together.

The fourth case explores a separate Bio-innovate team to the team represented in chapter 4. It involves a study over a 5 month period of the full program from problem definition to idea generation and concept development.

Each of the four chapters presents: the cognitive processes and conversation activities used during team meetings and how they were used to reach consensus.

Chapter 8 provides a cross case analysis of the four cases studied. The goal is to compare the cases and highlight the similar and contrasting features.

Chapter 9 presents a discussion on the overall findings. It brings together the main research findings from all of the studies. A new conceptual model is proposed which outlines new propositions and theories. The chapter shows how the findings build on the current literature to highlight the novel aspects of the research.

Chapter 10 presents the thesis conclusions. The chapter describes how the aims and objectives of the study are fulfilled and presents the contribution to knowledge of the thesis. The chapter closes by explaining the scope and limitations of the research and makes recommendation for how the work could be built upon in the future. See Table 1.1 for a summary of the thesis structure.
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2 Literature Review

2.1 LITERATURE REVIEW INTRODUCTION

This thesis addresses how teams reach consensus during the initial phases of design. This entails the identification of a problem or opportunity, the ideation of potential solutions to the development of a concept. The literature review begins by defining design, design problems and the cognitive processes used to solve them. It looks to literature from other disciplines such as behavioural psychology and organizational behaviour to address teams and understand the factors that impact on successful collaborations. It then reviews team cognition, consensus reaching, cognitive diversity and conflict. This is followed by examining the differences between expert and novices. The literature concludes by drawing the strands together that impact on consensus reaching within design. The main sections in this chapter are as follows:

Section 2.2 defines design and innovation and gives a brief description of the scope of those activities. It examines design problems and design processes.

Section 2.3 explores design cognition. It addresses Schön’s reflective practice framework, design as a social process, developing a common language in design, design as negotiation and the cognitive processes in design.

Section 2.4 addresses teams, multidisciplinary teams, collaboration typologies and the collaboration process.

Section 2.5 reviews team cognition and consensus; consensus reaching in teams, common ground and knowledge processing.

Section 2.6 addresses cognitive diversity and conflict.

Section 2.7 reviews the differences between experts and novices in terms of cognitive processes and methods, collaboration and approach to conflict.

Section 2.8 gives a summary of the literature.

Section 2.9 provides a conceptual model that has been developed from the literature to guide the empirical research.
2.2 DESIGN AND INNOVATION

This section seeks to define the scope of design. The term design is often used to describe a method for conceiving products services and systems (Cruickshank 2010). The Design Council (2007) view design as:

“An activity that translates an idea into a blueprint for something useful, whether it’s a car, a building, a graphic, a service or a process.”

While the designer may also spark the initial idea, design encompasses the process that translates an idea into a desirable, viable, commercially successful functioning product or service (Design-Council 2007). The Centre for Design and Innovation (2008) sees design thinking as the process that provides context for innovative solutions and involves applying multiple lenses to a problem that is not just the realm of a single specialist or discipline. Typically design practice begins when it is time to make these ideas tangible. This is emphasised in the following definition.

“Design is a creative activity whose aim is to establish the multi-faceted qualities of objects, processes, services and their systems in whole life cycles. Therefore, design is the central factor of the innovative humanization of technologies and the crucial factor of cultural and economic exchange.”

(ICSID 2013)

What is also significant for design is that it has become, a multidisciplinary activity as a result of the complexity of problems being addressed (Marxt and Hacklin 2005). Designers are taking on multiple roles and transcending traditional boundaries. They are applying transferable skills and thinking across a variety of settings giving rise to collaborative practices across disciplines (Milton 2016). This multidisciplinary nature means that no individual has all the knowledge required to execute a design task. Design is therefore a social process where knowledge is shared and integrated (Luck 2009, McDonnell 2009, Kleinsmann et al. 2012). This would suggest that consensus reaching plays an important part of the process as each team member may have a different stake in a project and different perspective on how it should proceed. Large volumes of diverse information must also be processed and agreed upon.
2.2.1 Design problems

Much of the research in the Naturalistic Decision Making (NDM) and consensus literature has focused on domains such as the military and the emergency services where personnel are faced with the task of making fast decisions (Klein 2008, Klein et al 2010). Design problems are unlike these types of problems where the goal is to come to an early resolution or a decision on specific and defined problem criteria. In addition there is no typical course of action to reach consensus and make decisions so other strategies are required. In order to understand the cognitive processes used by teams to reach consensus when solving design problems it is necessary to review the nature of design problems. Design problems are considered to be complex (Kendall 1989, Smith and Browne 1993), ill-defined (Thomas and Carroll 1979, Jonassen 1997) and un-structured (Goel and Pirolli 1989, Jonassen 2000) They involve conflicting goals, multiple solution methods, unanticipated problems, multiple forms of problem representation, distributed knowledge, constraints, cross collaboration and experience to solve them (Jonassen 1997, Lawson 1980, Goel and Pirolli 1989). Unstructured problems are further complicated as there may be many ways and methods of solving them (Jonassen et al. 2006, Voss and Post 1988). The designer frequently does not know which method is optimal or how to measure the benefit of different ones. The problem solver’s previous experience and professional experience guides a course of action (Jonassen et al. 2006). The goals in unstructured problems are often unclear with insufficient information to solve them (Chi and Glaser 1985, Sinnott 1989, Voss and Post 1988).

Often the problem statement gives no indication of the solution which makes the identification of a solution difficult (Rittel 1986, Lawson 1980). The validation of solutions is also difficult and there is often no simple way to determine if a solution is viable (Lawson 1980). There is no optimal design solution but alternative possibilities that allow subjective factors to determine the outcome (Lawson 1980, Cross 2001, Voss and Post 1988). A complex problem is typically characterized by a system of causal relationships wherein the effect of a change in one component may have difficult-to-predict consequences (Baty 2010).

Table 2.1 highlights the Characteristics of unstructured design problems.
Table 2.1 Characteristics of problem types (Jonassen 1997, Rittel and Webber 1984)

<table>
<thead>
<tr>
<th>Unstructured problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involve unknown or undefined problem elements.</td>
</tr>
<tr>
<td>Possess multiple solutions and solution paths.</td>
</tr>
<tr>
<td>Present uncertainty about which concepts rules and principles are necessary for the solution or how they are organised.</td>
</tr>
<tr>
<td>Have no explicit means of determining appropriate action.</td>
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<tr>
<td>Have vague or undefined goals and unstated constraints.</td>
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<tr>
<td>Have multiple criteria for evaluating solutions</td>
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<tr>
<td>Have no prototypic cases to reference.</td>
</tr>
<tr>
<td>Require learners to express personal opinions and beliefs about the problem which is an interpersonal and human activity.</td>
</tr>
<tr>
<td>Require learners to make judgments about the problem and defend them.</td>
</tr>
</tbody>
</table>

To conclude the nature of design problems would suggest that effective collaboration and decision making is critical to solving them and understanding how teams negotiate consensus is an important factor.

2.2.2 Design Processes

The design process involves a series of stages that involve different objectives and activities which may have a bearing on how teams interact and reach consensus at each stage. The typical design process is split into three stages. The analysis phase where the problem is understood, the synthesis phase where a solution is developed and the evaluation phase where the solution is tested (Jones 1992, Cross 2001). Similarly the Bio-design process for developing medical devices as developed by Zenios et al. (2009) uses the three key terms of: identify, invent and implement to describe the process. The identify phase is where the problem is defined and is seen as a critical phase in the process as teams must first understand the problems and needs associated with their chosen area before developing new solutions. Once a clinical need is identified the invent phase involves ideation and brainstorming. This phase concludes with concept development and concept selection. The implement phase focuses on the commercialisation of a product solution.

Likewise the “Double Diamond” design process as devised by the design council (2007) also outlines a typical design process. It is divided into the four stages of; discover, define, develop and deliver. The ‘discover’ and ‘define stages’ are concerned with understanding the problem and identifying user needs (problem definition phase). The development phase is where solutions are explored and created (ideation phase). This
The different objectives and modes of thinking at each phase may have a bearing on how consensus is reached. In addition understanding and defining a problem, finding a solution and developing it does not necessarily go in sequential order (Fallman 2003, Lawson 2007, Schön 1987). Most design processes involve iteration where the designer can go back and forth between each of the design stages. This is likely to complicate the consensus process as decisions may only be partial at any one time.

2.2.3 Conclusion

This section has defined design and various design processes to show that they follow a similar pattern. Design problems are highly unstructured and ill-defined and the design
process involves a series of phases that involve different objectives and methods which may have a bearing on how teams engage and reach consensus at each stage. A variety of different cognitive processes are used to negotiate the process and this is the focus of the next section.

2.3 DESIGN COGNITION

Recent contributions to the design literature have centred around a number of paradigms including: experiential learning (reflective practice framework (Schön 1983)) and design as a social process (Bucciarelli 1994). Design paradigms seek to address how designers behave and carry out design activity at both macro and micro levels. These paradigms have led to a more constructivist view of design which is based on situated practice and human interaction rather than following of a set of scientific predetermined procedures (Lloyd and Busby 2001). Much of the literature contributing to these paradigms have focused on the analysis of language in design and how that functions in relation to developing objects, for example, (Lloyd 2000, Dong et al. 2005, Dong et al. 2013).

Strategies that support and give an understanding of the process have been addressed, such as analogy (Ball and Christensen 2009, Christensen and Schunn 2009, Hey et al. 2008, Gentner 2002). Techniques that enable an analysis of the processes such as linkography (Goldschmidt and Tatsa 2005, Van der Lugt 2005) are also a focus. Design can be seen as a negotiation process where knowledge must be shared and negotiated amongst team members to form a shared understanding during the process, for example, (Stumpf and McDonnell 2002, McDonnell 2012). Cognitive processes applied to individual design activities will be modified in a group context and different processes take place to integrate individual cognition with team cognition. By taking a closer look at this literature it is possible to understand the specifics of design language and the aspects of social interaction that will impact on consensus reaching in design. This section explores design cognition across the early phases of design highlighting the different strategies used at each phase. It addresses Schön’s theory of the reflective practitioner which has formed the foundation to many of the theories developed in this area, followed by the social aspect of design, the development of a common language and then the cognitive processes used in design.

Stempfle and Badke-Schaub (2002) propose that thinking in design can be reduced to four basic cognitive operations; exploration, generation, comparison and selection which in various combinations are applied to the goal and solution space of a problem. Exploration and generation widen the problem space while comparison and selection
narrow the problem space. This view of design cognition as divergent and convergent thinking is further explored at the early phases of the design process.

**The problem definition phase** involves examining and researching the nature of the problem so it can be fully defined for the purpose of that particular task and context. In an open brief it can extend to identifying that a problem or opportunity exists and discovering ‘needs’. This emphasises the development of deep user insights through observation and immersion in the user’s context (Brown 2009). Design projects therefore usually start with an incomplete specification of goals which can evolve and change as an understanding of the problem develops (Cross 2001, Cross 2004). Designers must have the cognitive skills of gathering and structuring research data, problem framing and creating patterns from the data that suggest solution directions (Cross 2011). Kolko (2010) describes this as synthesis where designers forge connections by organising and filtering gathered data into a cohesive structure for information building. The concept of problem framing as outlined in Schön’s reflective practice framework is further discussed below.

### 2.3.1 Framing, Schön’s reflective practice framework

‘Framing’ is a means of identifying, structuring and formulating problems in design through the creation of a new viewpoint or hypothesis to solve the problem (Schön 1983, Kolko 2010, Dorst 2011). Frames are moment by moment perceptions of specific units of the problem and continue cyclically throughout the problem solving process. A frame involves naming elements of the problem, framing the problem to form an interpretation, making a move towards a solution and reflecting on those moves, see Figure 2.2.
Schön believes that each design problem is unique and that the challenge for designers is to determine how each project should be approached (Schön 1987). His theory to handle individual tasks is based on a kind of knowing that is inherent in intelligent action. This ‘knowing in action’ can be achieved through the practice of reflecting on actions which he describes as ‘reflection in action’. This involves setting the problem to be solved by highlighting a few important features from what would otherwise be an overwhelming task (Kolko 2010). In order to frame a problem individuals need the skills to identify the key elements of the problem and how these relate together (Shalley and Perry-Smith 2008). A frame can be a set of statements that include a specific perception of a problem and a working principle that underpins a solution (Dorst 2011). It helps in highlighting the full nuances of the problem and can involve defining the problem in both concrete and abstract ways (Shalley and Perry-Smith 2008). Solvers may also reframe a problem to cast an original frame in a new perspective, to see things in a new way or looking at the problem from the perspective of someone else perhaps with a disability (Kolko 2010). Reframing not only simplifies and creates alternative views of a problem situation but also creates multiple possibilities in the solution space (Paton and Dorst 2011). This is an experiment where the problem solver(s) engages in a reflective conversation with the components of the problem (Jonassen 1997, Schön 1987). In
framing a problem, the solver must recognize the different perspectives and gather evidence to support or reject different proposals highlighting the importance of iterative consensus to do this in a team.

In creating a new frame the designer engages in a process of analysis in which a complex situation is read in terms of ‘themes’ (Lawson and Dorst 2009). Themes are a sense making tool to capture the phenomenon to be understood. Dorst (2011) gives an example of a theme in relation to a problem of law and order in a city at night. The theme to emerge was that the offenders involved were young and without previous convictions who became disorderly due to boredom as the night progressed. Using this theme the problem solvers framed the problem, not as an issue of preventing crime but as a need to provide recreation and entertainment for young people. Frame creation therefore is a process of exploring the broader problem situation, gathering clues that can lead to themes which in turn form the basis for the creation of a new frame (Dorst 2011). This process is used iteratively during early problem definition but also as a result of reflection throughout the problem solving process (Paton and Dorst 2011, Goel and Pirolli 1992).

While Schön’s model originated as a model of individual design behaviour he believes that design is a social activity, through reflective conversations with the design problem. Team framing is a collective activity that is performed through the exchange of knowledge between team members (Valkenburg and Dorst 1998) and frames are constructed through the dialogue of team collaboration (Dong et al. 2013). During team framing individual designers need to align their own focus with the team’s which can involve negotiation to develop a shared viewpoint. In a team context a frame can be considered as episodes of communication with topical cohesion. A conclusion to that topic or a change in topic marks the closure of a frame and the start of a new one (Kleinsmann et al. 2012).

It is only recently that attention has been directed to the extension of the reflective practice framework to a team setting (Stumpf and McDonnell 2002, Dong et al. 2013, Kleinsmann et al. 2012). While this framework is appealing to researchers it has some issues. One issue concerns a lack of formality and reliability of its vocabulary. There is no concrete agreement about what a frame is, how it is to be applied and at what level of scale. As noted by Stumpf and McDonnell (2002) this lack of formality and consensus in the definitions makes replicable analyses difficult, particularly when aiming to understand progression in a design process. While the model has been applied to team framing it does not take into account the process of how teams arrive at shared representations of
a frame. Stumpf and McDonnell (2002) in a study of team conversation detected frames through association and dissociation markers. A series of associations marks the existence of a frame. A dissociation can be seen as a suggestion by a participant to adopt a different perspective, and sequences of dissociations result in unfocused discussions which may lead to team conflict as they reflect a lack of a shared frame (Kleinsmann et al. 2012, Stumpf and McDonnell 2002). Framing and reframing in a team situation will therefore require team members to understand one another’s view points and communicate effectively to agree on each frame. As frames are established team members will need to agree that they have shared representations of each frame. Consensus is required therefore continuously as frames are updated. How frames are negotiated is a focus of this research.

Design also is not a matter of first fully defining the problem and then searching for a satisfactory solution concept but also about refining and developing the problem and solution space together (Cross 2001). Lawson and Dorst (2013) describe “analysis through synthesis”. This is where designers generate conjectures about possible solutions or partial solutions and use these conjectures as a way of exploring and defining the problem and the solution together (Cama et al. 2006, Kolodner and Wills 1996, Suwa et al. 2000, Cross 2001). As designers develop potential solutions the more they learn about the design problem. This has also been described as a process of ‘co-evolution’ of problem and solution (Maher and Tang 2003). The problem space and solution space co-evolve with a constant iteration of analysis synthesis and evaluation (Maher and Tang 2003, Dorst and Cross 2001). Engaging in a reflective conversation across problem setting and problem solving activities are important aspects of good design practice (Cross 2010, Adams et al. 2003). Schön describes reflective practice as problem setting and problem solving and believes that problem setting is as important as problem solving (Schön 1983). The more time a designer spends understanding and defining a problem the more likely they are to achieve a creative solution (Christiaans 1992). This is supported by Adams et al. (2003) following a study of design engineers. They conclude that engaging in a reflective conversation across problem setting and problem solving activities are important aspects of good design practice. A reflective practitioner will rationalise about the problem and solution through experimentation. The designer is both a creator in developing a solution and an experimenter, which gives the notion of the designer having a ‘reflective conversation’ with a situation (Valkenburg and Dorst 1998).
One of the biggest challenges for design problems is incomplete information (Jonassen et al. 2006) which also calls for co-evolution. The problem may begin in a structured format but becomes ill-structured as unanticipated problems and constraints arise. This makes the processes iterative due to the accommodation of new constraints. Changes in contextual constraints change the requirements of solutions. Jonassen (2008) suggests that for successful design solutions designers must address constraints through a process of decision making. On defining the initial set of constraints and requirements the designer continues to make decisions based on the constraints that emerge throughout the process (Jonassen 2012). This shows that consensus is required continuously throughout the process.

Similarly the emergent nature of information during design problem solving means that epistemic uncertainty is integral to complex unstructured design problems (Schlosser and Paredis 2007). In a study of the use of analogies amongst engineers Ball and Christensen (2009) found that analogising was a strategy used in situations of uncertainty to facilitate the resolution of that uncertainty. Using an analogy is the process of mapping knowledge from a source to a target domain with a supporting system of relations or representations between the two. This process of comparison encourages new inferences and problems may be viewed in new insightful ways (Christensen and Schunn 2007, Hey et al. 2008). Analogies are also used in problem identification, problem solving and in explaining concepts (Christensen and Schunn 2007). Similarly mental simulations were found to be associated with uncertainty and that levels of uncertainty dissipate to baseline levels over the course of simulation use (Ball and Christensen 2009, Christensen and Schunn 2009). A mental simulation is where a sequence of interdependent events is consciously enacted or run through mentally to determine cause and effect relationships (Gentner 2002). While similar to scenario use, mental models are an evaluative strategy in design to assess proposed concepts by imagining the functionality and use of the design and its interaction of use with end users. They enable designers to reason about new possible states of a product in terms of its qualities features and functions (Ball and Christensen 2009). Ball and Christensen (2009) found that analogies were often embedded or partly embedded within mental simulations. These types of simulations were generative in developing concepts, evaluative in subsequent simulation runs and explanatory in explaining the nature of the simulation to others.

While the process involves a co-evolution of the problem and solution the ideation phase is focused on creating a breadth of ideas and benefits from considering as many
different concepts as possible. Designers introduce intentional variation into conceptual product designs (Yilmaz et al. 2016). Ideation is associated with divergent thinking and conceptual breadth with a wide search across categories of knowledge for diverse information that can be used to explore ideas (Dym et al. 2006, Ferreira and Lacerda dos Santos 2009). The creation of alternatives solutions and divergent thinking are directly correlated (Shalley and Perry-Smith 2008). Divergent thinking places emphasis on choice and quantity of output. It requires flexibility and fluency of thinking, a variety of perspectives and making unusual associations. Brainstorming is a common technique applied during ideation to allow team members to build on the ideas of others (Seidel and Fixson 2013, Kelley 2001). During ideation the aim is not to select a single solution but instead to create several that show promise for further development (Baty 2010).

In furthering this, studies using linkography found that influential ideas were richly interlinked with other ideas (Goldschmidt and Tatsa 2005, Van der Lugt 2005). Linkography within design, focuses on links among design moves or design ideas. A link means that an idea builds on a previous idea generated. Goldschmidt and Tatsa (2005) found that the more meaningful and helpful the idea, the denser the network of links it is connected to. They propose that the number and density of links are indicative of the quality and creativity of the process, and the end product that the process leads to. Good ideas are critical ideas, in the sense that they generate a large number of links, and very good ideas are those that spin the largest number of links among themselves and other ideas. Goldschmidt and Tatsa (2005) found that intensive interlinking among design ideas, design decisions or design moves, is the hallmark of good and creative design. Therefore if ideas are linked to other ideas this suggests that the ability of team members to communicate in the exchange of ideas and the linking of ideas from other team members will be critical to successful team practice in design. This shows the importance of examining team conversation to understand how design team members link to another’s contribution to achieve progress.

A number of other techniques can be employed to support ideation such as analogical reasoning which involves transferring ideas from one domain to another (Dorst 2011, Ball and Christensen 2009) or conceptual combination which is the synthesis or merging of separate concepts to create a new idea (Shalley and Perry-Smith 2008). Yilmaz et al. (2016) identified an additional 77 heuristics that support idea generation which include adapting and modifying ideas to create new ideas. This phase therefore may not be
about trying to reach consensus on solution directions but about delaying consensus to create breadth.

At the **concept development** phase the focus is to narrow the solution options with the comparative analysis and evaluation of solutions which is associated with convergent thinking (Crawford and Di Benedetto 2008, Ulrich et al. 2011). Techniques used at the concept development phase include prototyping to both validate ideas and ‘build to think’ (Brown 2009). It involves convergent thinking as it is made up of logical deduction and a systematic approach including evaluation, deduction and the prioritization of a problem. It is analytical and focuses on critical details (Ferreira and Lacerda dos Santos 2009). At this stage the design team will be trying to converge and make decisions on a final solution which will require consensus.

To conclude the early part of the design process has a number of distinct phases that overlap and run iteratively and call for a variety of cognitive processes and strategies. While many of these processes are applicable to individual design, aspects of the social process of design may impact on team cognition. The next section looks at the social aspect of design.

### 2.3.2 Design as a social process

An important contextual change in design is the need for collaboration. Work on complex projects requires the knowledge and skills of individuals from different disciplines. Cross-disciplinary team participation, demands an ability to negotiate team processes and decision-making. This depends on the contribution of others in the form of discussion and knowledge exchange in order to form productive collaboration (Poggenpohl 2015). Wenger (1998) states that learning is an intrinsically social process and occurs in communities of practice. Communities of practice involve shared histories of learning and practice, in an ongoing, social, interactional process as participants negotiate new meanings, and learn from each other (Wenger 1998). Learning is an interplay between social competence and personal experience through a dynamic, two way relationship between participants and the social learning systems in which they participate in (Wenger 2000).

Design can also be viewed as a social activity in that it is the outcome of an organized human effort to define requirements and produce an output. It requires the collaboration of a wide range of individuals and stakeholders, each with different competencies,
knowledge, agendas and interests. (Ghaemmaghami and Bucciarelli 2003). Unlike the well-defined process that are ascribed to design this social aspect brings with it uncertainty and ambiguity (ibid). In order to communicate, design teams need to develop a common language.

2.3.3 Developing a common language in design

Bucciarelli (1994) uses the term "object worlds" to describe the multidisciplinary nature of engineering design in which teams define and negotiate decisions. Object worlds involve the use of ordinary language in such a way that the concepts and ideas and relationships among the elements of an object world require new learning, like the learning of a new language (Bucciarelli 2002). ‘Object worlds’, refer to the thoughts, actions and objects within which participants in engineering design engage in when working on any specific aspect of a project. The definition of a technical object calls for negotiations between the different object worlds, and the stakeholders involved may need to compromise. Bucciarelli (1994) states that each participant possesses an embedded set of technical values and representations that act as a filter during design team exchanges, and that the resulting design is an intersection rather than a summation of the participants’ contributions.

Interactions across disciplines can be supported by boundary objects which include artefacts (such as tools, documents or models), processes and discourses in the creation of a common language to communicate and negotiate meanings. However in teams, boundary objects do not necessarily bridge boundaries as team members may misinterpret. Therefore cross disciplinary communication creates challenges in creating a common language and vision. Bucciarelli (1988) defined three types of discourse in design: constraining, naming, and deciding. Design objects are given shifting physical and social constraints by different participants with differing perspectives in a design team, and agreement about constraints is the first step in the process. The naming of elements can reduce constraints, before decisions are formulated.

A number of subsequent studies have also addressed design as a social activity with its own common language. Lloyd (2000) found in an ethnographic study that design consists of the construction of social agreements. Storytelling was a mechanism observed in the development of a common language in design. In describing a product, designers will construct a language in the form of a narrative to convey an ongoing experience with the product and the design process. In the continual telling and re-telling
of experience a language is built up which can be used to negotiate the factors
influencing the final design. However while a common language is developed this can be
used to create different stories about the same object. Despite having created a shared
language designers do not always share the same story about the object and the design
vocabulary may be defined as much by common disagreement as by common
agreement (Lloyd 2000).

Dong et al. (2005) in a study based on latent semantic analysis found that the
construction of shared representations emerge through language-based communication.
He observed that the overlap in word choice in designers’ language-based
communication reflects a shared frame for the design team. A common frame is
necessary for the co-ordination required for successful team work in design. Words and
phrases used by designers make up a narrative including, personal experience,
specifications, negotiations, and resolutions. The outputs, including specifications
reconcile the conflicting interests and express the shared agreements of the design team
members. The semantic coherence of the language used is a metric of the congruency
of the communication (Dong et al. 2005). Dong (2005) proposes that teams with
coherent communication, towards the end of design phases are more likely to have
better results than teams with incoherent communication. He found that when speakers
further contributed to each other’s utterances, this resulted in an increased level of
coherence. Constructive conversations were where the knowledge of each designer was
expressed through conversation, to develop coherent discussions. What these studies
show is that designing in teams requires the development of a common language.
However these studies have also shown that the development of a common language
does not necessarily mean, that teams can agree on a shared perspective and frame. So
while they may be able to name project elements, they may not be able to achieve a
common frame. Therefore negotiation must occur.

2.3.4 Design as negotiation

The persuasive behaviour of design is reflected in studies such as Stumpf and
turns team members both share and integrate knowledge through negotiation to align
their knowledge base with that of the team’s (McDonnell 2009, Stumpf and McDonnell
conversational turns of an architect and his clients, that each party contributes from their
own area of expertise, and responds to others invitations to supply information and
expertise. In building on this Deken (2012) confirmed that novice-expert consultation meetings, were opportunities for novices to acquire information from experts and create new knowledge.

Stumpf and McDonnell (2002) have described the social aspect of design to be about moving towards consensus and using argumentation to steer negotiations and resolve conflicts. They focused on the interaction among team members to understand how frames get established and how they shift as design progresses. They found that the creation of frames in design is a persuasive activity, and that during problem framing, designers use argumentation to establish and shift frames. A new frame is informed by the previous one, in that relevance's from previous frames are carried over and used to inform the ongoing process. Hence design can be seen as a process of negotiation and consensus reaching (Bucciarelli 1994). This shows the importance of discourse within the process and the importance of creating shared understanding.

As outlined, designing in teams can also be faced with uncertainties and ambiguities over the brief, along with disagreements. It can involve the pursuit of parallel lines of inquiry, that may be inconsistent and with only partial information (McDonnell 2012). McDonnell (2012) examined the conversation activities amongst two software engineers to understand how the design process moved on productively. Signalling tentativeness was found to overcome disagreements and uncertainties to enable the design process to progress. Dong et al. (2005) identified linguistic cues called ‘projection of possibilities’ as a means for contributors to propose ideas in a manner in which the proposers own commitment to the idea is not fixed. This is through offering ideas and signalling that they are open for negotiation. Tentativeness was also used as a strategy to simplify a task and to defer issues that could impede progress (McDonnell 2012). Rather than addressing disagreements, the designers worked around the disagreement, deferring the issue to a later time. While designers were successful in enumerating design alternatives and developing a shared language to ‘name’ or technicalise elements of the problem, they each formed different terms and therefore did not reach a shared frame which would indicate agreement. This appears to be a strategy in the collaboration process, to identify and name aspects of the project to encapsulate the disagreement or object despite a lack of shared frames in order to maintain progress (ibid). While deferral appears to be a successful strategy in design to maintain progress at some point disagreements must be addressed and reconciled and how this done is an important line of enquiry for this research.
While designing in teams is language based, this language can reveal the thinking of a
design team. Four main cognitive processes have come through the literature as the key
thinking types in design.

2.3.5  Cognitive processes

In order to understand how design teams reach consensus it is also necessary to
understand the thinking processes used during the design process. By understanding
design cognition and the goals of each phase it is possible to understand how this then
relates to where and how consensus is reached as teams collaborate. A cognitive
process refers to:

_The mental process of both thinking and reasoning that people go through to discover,
  analyse and solve problems. The “internal processes by which learners select and
  modify their ways of attending, learning, remembering and thinking.”_ (Gagne et al.

Design is solution oriented and therefore relies on creative and critical thinking ability
(Cross 2006, Dorst 2011). Ill-structured problem-solving, the hallmarks of design also
requires meta-cognition to reflect on the appropriateness of the knowledge and
strategies used to reach the project goals (van Ginkel et al. 2009, Jonassen 1997,
Andres 2013). In addition the collaborative nature of design requires knowledge
processing in the sharing and integration of knowledge (Luck 2009, McDonnell 2009,
Kleinsmann et al. 2012). Creative thinking, critical thinking and metacognition are further
discussed in this section and knowledge processing is discussed in section 2.5.3.

2.3.5.1  Creative thinking

Creative thinking is associated with ideation and brainstorming. Creativity requires an
idea to be original and effective  (Runco and Jaeger 2012). It is a generative and
divergent form of reasoning that allows for the breaking of rules and the transcending of
frameworks (Bailin and Siegel 2003). Creative Thinking is the ability to imaginatively
create something new (Harris 2012) and leads to new insights, novel approaches, fresh
perspectives and a new way of understanding (Facione 1998). It involves generative,
divergent and lateral thinking with suspended judgement to create multiple ideas (Harris
2012). It requires flexibility and fluency of thinking, and demands readiness to change
direction. It means having a variety of perspectives, and making unconnected
associations. While critical thinking follows a linear process to arrive at a correct answer,
creative thinking is about generating possibilities. Creative thinking creates the ideas with which critical thinking works (Harris 2002).

Creativity is related to a person’s intelligence (Johansson-Skölöberg et al. 2013), and is boosted by knowledge and information (Li et al. 2007). Christiaans and Venselaar (2005) found a high correlation between process knowledge and creativity. This involves the knowledge of managing and monitoring the problem solving process. Information provides answers to “who”, “what”, “where” and “when” questions. Information is contained within knowledge and when both are combined provide answers for “how” and “why” questions. The use of irrelevant information in lateral thinking can also boost creativity (De Bono 1995). This suggests that the knowledge and information that is shared and negotiated within teams can be a potential stimulant for creative thinking.

Creativity can also be influenced by the type of critique from others. It has been shown that positive and negative affective states influence generative and creative thinking (Fiedler, 2000). During knowledge generation, positive appraisals are associated with the creation of knowledge and ideas, while negative appraisals are associated with ‘being stuck’. (Dong et al. 2009).

2.3.5.2 Critical thinking

While designing is a creative activity it also requires critical thinking. Critical thinking is convergent, logical deductive thinking and involves actively questioning and analysing information to gain knowledge and determine specific answers (Choi and Lee 2009, Paul et al. 1993, Hung et al. 2008). It includes problem-solving reasoning and decision-making (Wright 2010). It entails taking diverse and often opposing perspectives and objectively forming an opinion. It involves being able to evaluate a problem, make judgments and opinions about the problem and defend a position taken (Jonassen 2008, Voss and Post 1988). It is analytical and focuses on essential details, selection of ideas according to their relevance and simplifies problems considering the most significant details. This suggests that good critical thinkers will not be swayed to an easy consensus. In a Delphi study that asked experts to define critical thinking. Facione (1998) identified the following core skills: analysis, inference, evaluation and interpretation along with explanation and self-regulation.

**Analysis** is to identify the intended and actual inferential relationships among statements, questions, concepts, descriptions, or other forms of representation intended to express belief, judgment, experiences, reasons, information, or opinions.
Inference is to identify the requirements needed to draw reasonable conclusions; to form conjectures and hypotheses; to consider relevant information and to determine the consequences coming from data, statements, principles, evidence, judgments, beliefs, opinions, concepts, descriptions and questions.

Evaluation is to assess the credibility of data or other representations which are accounts or descriptions of another’s perception, experience, situation, judgment, belief, or opinion; and the logical strength of the relationships among statements, descriptions and questions.

Interpretation is to comprehend and form a meaning or significance of a wide variety of experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures, or criteria.

Explanation is being able to present in a coherent way the results of one’s reasoning.

Creative and divergent thinking are used to generate solutions in design. However a solution must meet the requirements and constraints fixed upon it which involves convergent and critical thinking to analyse the feasibility of solutions (Dorst 2011, Stempfle and Badke-Schaub 2002). This is where convergent thinking must be used when creating solutions to disregard non-viable options with divergent thinking used once again to create further alternatives upon analysis (Ferreira and Lacerda dos Santos 2009). Dym (2006) describes this as a convergent component of asking deep reasoning convergent questions, and a divergent component in which generative design questions are asked to create the concepts on which the convergent component can act. This highlights how thinking in design involves a back and forth of switching from convergent to divergent thinking. Feirerra and Lacerda dos Santos (2009) found that in order for design teams to avoid premature consensus which is a type of convergent thinking, divergent thinking and the elaboration of knowledge was necessary to ensure good decisions. This means that when teams are thinking divergently they are exploring options without focusing on decisions. However convergent thinking is a process of narrowing in order to make a decision. In order to manage how they are thinking and strategizing teams must also apply metacognition as discussed next.

2.3.5.3 Meta-cognition

Ill-structured problem-solving and decision making demands the use of meta-cognition (reflective thinking) to plan how to tackle the problem, monitor progress, evaluate the appropriateness of the strategies used and the knowledge of the team to reach goals, make decisions and develop solutions (van Ginkel et al. 2009, Jonassen 1997, Andres 2013, Hong and Choi 2011). In order to reach consensus and make high quality decisions meta-cognition is necessary to foster information elaboration to form a
thorough understanding of the task and reach decisions (van Ginkel et al. 2009). Facione (1998) states that meta-cognition is critical thinking applied to itself. It is about monitoring and correcting an interpretation that you have offered and reviewing and revising your own explanations. Reflective judgments are formed by evaluating opinions, relevant information, and available explanations and the constructing of plausible solutions for the problem and the understanding that the solution may need further evaluation (Cama et al. 2006). Facione (1998) identifies the two sub skills of meta-cognition as self-examination and self-correction. Reflective practice has been recognised as an essential component in design methods where multiple possibilities are explored and moves must be taken to converge on an appropriate one. Schön’s (1983) reflective practice theory proposes that the design process is based on a constructivist view of human perception and thought processes where the designer through action and reflection constructs their view of the world based on their experience. In this paradigm, design activities are based on actions and the ability to learn and make decisions from those actions. It involves a reflective conversation with the individual, the team and the problem situation where frames guide the design activity in both the problem and solution space. Hong and Choi (2011) define reflective thinking in the context of design as: conscious mental activities that examine designer’s courses of action, decisions, and their inner selves in given situations throughout a design process. By doing this, designers actively derive new thinking and make changes to improve unsatisfactory situations.

Most accounts of meta-cognition divide meta-cognition into meta-cognitive knowledge (what one knows about cognition) and meta-cognitive regulation (how one uses that knowledge to regulate cognition) (Schraw and Moshman 1995, Jacobs and Paris 1987). Many studies have made the distinction between knowledge types into domain-specific knowledge and general process knowledge (meta-cognitive knowledge). Meta-cognition involves the knowledge of when and where to use acquired strategies (Pressley and McCormick 1995). While the process for solving design problems can be generic, design problems are highly domain and context specific. Un-structured problem solving requires access to domain knowledge that is well organized (Shin et al. 2003, Jonassen 2008), and without it solvers use weaker strategies for searching for a path or solution (Chi and Glaser 1985). Knowledge from several domains is also required and due to the heuristic nature of the process general process or meta-cognitive knowledge is needed (Christiaans and Venselaar 2005, Pressley and McCormick 1995). Meta-cognitive knowledge can also compensate for the absence of relevant domain knowledge (Xun and Land 2004). Expert problem solving depends primarily therefore on having
appropriate domain knowledge and general process knowledge or meta-cognitive knowledge.

The main components of meta-cognitive regulation are; planning, monitoring and evaluating one’s problem solving strategies (Schraw and Moshman 1995, Flavell 1979, O'Neil Jr and Abedi 1996). Planning involves the selection of appropriate strategies and the allocation of resources to carry out a task. In problem solving it entails dividing the problem into sub-problems and devising a method for solving the sub-problems (Davidson 1996). Monitoring refers to one’s awareness and comprehension of task performance, and the ability to engage in periodic self-testing while learning or solving a problem (Schraw and Moshman 1995). In problem solving this involves monitoring information and solutions selected and comparing alternatives for each solution and the justifying of solutions (Kluwe and Friedrichsen 1985, Jonassen 1997, Xun and Land 2004). Evaluation refers to appraising the outcomes and regulatory processes of one’s learning (Schraw and Moshman 1995). Jonassen (1997) states that in problem solving this involves evaluating one’s performance after the implementation of a solution, appraising: (a) whether the solution produced is acceptable to all the parties involved (b) whether the solution is within the problem constraints articulated (c) whether the solution was elegant and (d) whether the effects of the solution could be optimized. Seidel and Fixson (2013) proposes that there are three domains across the design process that lend themselves to reflective practice; 1) reflection on the objectives where the needs of the project are clear, 2) reflection on the strategies which relates to how well ideas are debated, and 3) reflection on the process relates to the degree to which processes are debated and adapted within teams. Meta-cognition therefore can play a key role in ensuring that consensus comes from effective team performance.

In reformulating the definition based on the literature and for the purpose of this thesis a cognitive process in teams can be redefined as:

*The thinking and reasoning to discover, analyse and solve problems collaboratively.*

### 2.3.6 Conclusion

Recent paradigms of design view it in a constructivist way based on human interaction. Design progression has been shown to rely on social engagement in communities of practice where designers create their own common language to communicate about the product being designed. Design can also be seen as negotiation where this common
language is used to negotiate and progress the design process. While design teams have been shown to develop a distinct common language this does not mean that this language is used to align the knowledge and perspective of each team member to create a shared perspective. In addition the initial part of the design process has distinct phases that have different objectives requiring different cognitive processes. This is also likely to impact on how teams reach consensus and about what they must reach consensus on.

The next section looks to literature outside of design to understand teams, collaboration typologies, and the collaboration process.

2.4 TEAMS

Teams are of major importance in design because, with increasing product complexity, groups work together in order to accomplish problems they cannot solve individually (Stempfle and Badke-Schaub 2002, Design-Council 2007). Design is inherently a social process where many of the best solutions and ideas are generated collectively (Svihla 2010). Innovation and creativity are enhanced with better solutions to problems as a result of a pool of knowledge (Stark 2000, Dykes et al. 2009). Design collaboration serves to facilitate the sharing of ideas, expertise, resources and responsibilities (Chiu 2002). Schön believes that design is a social activity through reflective conversations with the design problem. Team framing is a collective activity that is performed through the exchange of knowledge between team members (Valkenburg and Dorst 1998) and frames are constructed through the dialogue of team collaboration (Dong et al. 2013). Teams can be defined as “two or more people who interact dynamically, interdependently and adaptively toward a shared goal sharing their knowledge and contributing their respective expertise to make decisions (Salas et al. 1992). Team effectiveness however is not automatic and hinges on the ability of teams to collaborate effectively towards solving complex problems (DeChurch and Mesmer-Magnus 2010). The ability of teams to share and co-ordinate knowledge and perspectives, approach problem solving and make decisions influences performance (Mol et al. 2015, Martins et al. 2012, Kooij-de Bode et al. 2010)

2.4.1 Multidisciplinary teams

Complex problem solving demands ‘a dynamic, continuous, and on-going problem-solving process’ that can be facilitated by crossing disciplinary boundaries (Steiner and Laws 2006). The advantage of Multidisciplinary teams is that individuals take a more holistic approach to projects with a good understanding of other’s specialisms enabling
them to work effectively with colleagues. The most creative of endeavours in industry involve a mix of disciplines offering different perspectives and experiences (Volpentesta et al. 2008). Assumptions can be questioned and challenged allowing revised and better innovations to emerge (Lasker et al. 2001).

There are however barriers to effective team collaboration. Teams do not always produce the desired results due to incompatibilities, a lack of cohesiveness and unproductive conflict (Jackson 1996, Ostrosi et al. 2012). Communication can be an issue when team members do not share a common technical language or perspective and fail to exchange, discuss and integrate distributed information to reach quality decisions (van Ginkel and van Knippenberg 2008). Certain aspects of group structure may influence group processes and performance and includes whether the team is distributed or co-located, the levels of integration and leadership roles (Saunders and Ahuja 2006). Traditional management of teams is based on a senior leader who takes a command and control based approach to the management of the team with responsibility for decision making control (Tyler 2003). Integrated teams have a more flattened hierarchy with an emphasis on shared decision making (Chiocchio et al. 2011). The next section describes the typology of team types and the various levels of integration.

2.4.2 Collaboration typologies

The levels of collaboration between different disciplines can vary from ‘lighter’ collaborations to deeper and more immersive co-operation as outlined in Table 2.2. More integrated collaboration such as trans-disciplinary teams tend to be more successful as teams tap into collective creativity and have the greatest potential to produce highly novel and generative outcomes (Stokols et al. 2008, Burns et al. 2006). However they are more difficult to achieve and sustain than uni-disciplinary, multidisciplinary, and interdisciplinary projects due to their greater complexity and high aspirations for integration (Sanders and Stappers 2008, Stokols et al. 2008).
### Table 2.2 Collaborative Learning Typologies (Stokols et al. 2008, Rosenfield 1992)

<table>
<thead>
<tr>
<th>Collaboration Types</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uni-disciplinary</td>
<td>Uni-disciplinary is a process in which researchers from a single discipline work together to address a common research problem.</td>
</tr>
<tr>
<td>Multi-disciplinary</td>
<td>Multi-disciplinary is a sequential process whereby researchers in different disciplines work independently, each from his or her discipline-specific perspective, with a goal of eventually combining efforts to address a common research problem.</td>
</tr>
<tr>
<td>Inter-disciplinary</td>
<td>Inter-disciplinary is an interactive process in which researchers work jointly, each drawing from his or her discipline specific perspective, to address a common research problem.</td>
</tr>
<tr>
<td>Trans-disciplinary</td>
<td>Trans-disciplinary is an integrative process in which researchers work jointly to develop and use a shared conceptual framework that synthesizes and extends discipline specific theories, concepts, methods, or all three to create new models and language to address a common research problem.</td>
</tr>
</tbody>
</table>

### 2.4.3 The collaboration process

Chiu (2002) defines collaborative design as: “an activity that requires the participation of individuals for sharing information and organizing design tasks and resources.”

As the solving of complex unstructured problems requires the input of distributed expertise from a variety of disciplines with a diversity of knowledge (Jonassen et al. 2006, Steiner and Posch 2006), teams must share their goals and their teamwork strategies in order to be efficient (Gilson and Shalley 2004). When teams are multi-disciplinary the members from each discipline will have different ways of perceiving the situation, issues and tasks involved (Anderl et al. 2009). By developing a shared understanding teams can bridge these differences (Hinds and Weisband 2003). Teams need to establish common ground and an understanding and convergence of perspectives (Détienne 2006, Jonassen et al. 2006, Shaw 2010). Effective communication is critical for design teams in creating and sharing design information, decision-making and coordinating design tasks to develop a shared understanding (Chiu 2002, Détienne et al. 2012, Kleinsmann et al. 2007).

Letsky et al. (2007) describe four stages in the collaboration process for military problem solving; Knowledge construction, collaborative team problem solving, team consensus and outcome evaluation and revision.
• **Knowledge Construction** involves identifying the relevant domain information required and developing individual and team task knowledge.

• **Collaborative Team Problem Solving** is where the collaboration occurs among team members to develop viable solutions to the problem.

• **Team Consensus** is where the team reach agreement among several viable solution alternatives to the problem.

• **Outcome Evaluation and Revision** involves analysing, testing and validating the agreed upon team solution against the goal requirement(s). This includes an iteration loop for deriving other solutions for the problem if necessary.

These stages are similar to the design process in that knowledge construction is similar to the identify phase, collaborative team problem solving is similar to the solution generation phase while outcome and evaluation is similar to the implement phase. While this process is iterative it implies that knowledge construction only occurs at the beginning and that consensus is only needed on the selection of solutions. However the iterative and emergent nature of design problems would suggest that knowledge construction occurs throughout the process and that consensus is reached at several stages in defining the problem, framing and reframing as well as reaching solutions. In a study carried out on military personnel Hutchins et al. (2008) found that the overall collaboration process did not culminate in one final outcome or decision but a series of decisions throughout the process. Many decisions were taken along the entire problem solving process and were considered as mini-decisions in that they were not major or final decisions, but were critical in terms of the teams’ handling of the problem situation.

Five broad aspects of the collaboration process have been identified in the literature (Détienne et al. 2012, Meier et al. 2007, Mol et al. 2015);

1. Communication: *(Sustaining mutual understanding, dialogue management)*
2. Joint information processing: *(information pooling, reaching consensus)*
3. Coordination: *(task division, time management, technical coordination)*
4. Interpersonal relationship: *(reciprocal interaction)*
5. Decision making: *(the thought process of selecting a logical choice)*

Communication involves the sustaining of mutual understanding and dialogue management including turn taking and the co-ordination of communication processes. This is evident in design collaborations where a great deal of time is spent on cognitive
synchronization characterised by bidirectional communication such as asking for feedback and clarifications to increase understanding (Kim and Maher 2008).

Joint information processing refers to the co-construction of knowledge which is co-elaborated, appropriated and mutually accepted in collaborative problem-solving dialogues (Baker 2009). Meier et al. (2007) state that on the basis of pooling information, collaborators must make decisions on this information which involves evaluating the given information, collecting arguments for and against the options at hand, and critically discussing different perspectives to reach a consensus.

Coordination is necessary because of the requirement to manage sub tasks (task division) when time is limited (time management), or when group members depend on the same resources (technical coordination). In planning their work, collaborators must take into account the nature of tasks as well the resources within the team (Chiu 2002). Positive interpersonal relationships are required for successful collaboration and reciprocal interaction refers to respectful interactions where all members are treated equally. Teams will need to make decisions throughout the design process which in turn emphasises the need for consensus reaching. The focus of this research is to understand how teams achieve some of these aspects of collaboration particularly: sustaining mutual understanding, dialogue management, information pooling and consensus reaching.

2.4.4 Conclusion

This section highlights the importance of collaboration in design and shows that the diversity of the disciplines and perspectives of the team can add complication to the interactions and performance of the team. Integrated team members need to be able to manage a variety of factors to manage the team process. Designing in teams will not just be about applying the cognitive processing discussed in previous sections but also about knowledge exchange and construction. Team cognition which is discussed in the next section facilitates the processing of information, co-ordination, problem solving and decision making (Mol et al. 2015).

2.5 TEAM COGNITION AND CONSENSUS

Mol et al. (2015) define cognition as:
“An emergent state that refers to the manner in which knowledge is mentally organised, represented and distributed within a team and allows team members to approach problem solving and make assessments, judgements or decisions”.

Team cognition in short is about collective knowledge and a sharing process. It can influence all aspects of the collaboration process which in turn impacts on performance (DeChurch and Mesmer-Magnus 2010). It impacts on behavioural processes, which refer to team members acts that convert inputs to outcomes through cognitive, verbal, and behavioural activities directed toward organizing the task to achieve collective goals (Marks et al. 2001). It influences motivational states and interpersonal aspects of team functioning including cohesion, collective efficacy and trust (Mol et al. 2015).

Teams must have a common understanding about how to conduct a task reflected in the following definition of team cognition; *a shared repertoire of cognitive processes among team members that provides a framework for how the team goes about solving problems creatively* (Shalley and Perry-Smith 2008). Team cognition is evident when team members are actively working together to address problems by exploring multiple options challenging assumptions, seeking different perspectives, combining different viewpoints, reflecting on past actions, questioning ideas raised and actively evaluating different options as a team (ibid).

Information processing or the gathering, interpreting and synthesizing of key information is a key process that influences team output (Mol et al. 2015). The cognitive flexibility of a team to process information is influenced by the intra domain knowledge of the team. (Furr et al. 2012). The creative output of a team also stems from diversity and a team’s ability to integrate and apply diverse thought processes (Foss et al. 2008). Metacognition is essential to team interpretation and participation, and reflective judgements also involve the evaluation of social interactions (Leinonen and Järvelä 2003).

Decision making groups often fail to apply their distributed information sufficiently because they often do not have a good understanding of the task. Teams often focus on achieving common ground and agreement too early in a project and this can be at the expense of exchanging and elaborating distributed information (van Ginkel and van Knippenberg 2008). A concern during design problem solving is reaching agreement at the expense of the elaboration of the task information. This involves reaching consensus without common ground. Common ground may not be achieved in early consensus (Weinberger and Fischer 2006, Clark and Brennan 1991). Team reflection promotes the
degree to which group members develop shared task representations, emphasising information elaboration (van Ginkel et al. 2009). van Ginkel et al. (2009) showed that when team members have limited shared task representations the effects of team reflection are stronger which confirms that an important aspect of team reflection is to get group members to develop an appropriate and shared understanding of their task.

The literature on team cognition has recognised the importance of overlapping knowledge and beliefs amongst team members. Several constructs have been used to describe this mainly; shared mental models (Mathieu et al. 2005) collective cognition (West 2007) common ground (Clark and Brennan 1991) and cognitive consensus (Mohammed 2001). However much of this literature is focused on measuring the impact of shared cognition on performance, processes and motivational states (DeChurch and Mesmer-Magnus 2010, Badke-Schaub et al. 2007), the levels of sharedness amongst teams and the accuracy levels of the shared cognition (Dong et al. 2013, Lim and Klein 2006). What has not been a focus of the literature is how through conversations team members share and construct knowledge, and agree that they have reached mutual understanding to move forward in the process.

While it has been recognised that a level of shared understanding and beliefs are necessary for teams to collaborate it is important to understand how through conversation teams can arrive at a sufficient level of sharing to progress. While it is difficult to measure the accuracy and level of shared cognition amongst team members, verbal consensus where team members’ acknowledge that they have understood one another could reveal the cognitive processes and conversation activities that have led to a degree of sharing that the team believes is sufficient to proceed in the design process. In addition through the analysis of the verbal activity of team interaction it would be possibly to understand what the inputs are to team behavioural processes, and the performance of the team. Therefore consensus reaching in teams is a focus of this research to identify how teams participate to share information and execute design tasks.

2.5.1 Consensus reaching in teams

Collaborative design is an iterative and complex process of decision making (Ostrosi et al. 2012). Achieving consensus through collaborative interaction is a hallmark of design practice (Lu et al. 2007). The complexity and ill-structured nature of many design problems involve sets of inter-related decisions which require sequential and iterative
decision making processes (Jonassen 2012). Design teams must make decisions in terms of defining the design problem, articulating the initial set of constraints and specifications and make decisions about the solutions developed (Cross 2004, Ostrosi et al. 2012). Complex decisions may involve multiple options and multiple criteria. Decisions are not just formed through rational selection by solvers but are also influenced by individual’s personal beliefs and prior experience.

In order for teams to make decisions collaboratively they must reach consensus. Traditional views of consensus define it as unanimous agreement among participants and consensus building is defined as the process of seeking such agreement. (Susskind 1999). However, whether it is possible to achieve unanimous agreement in real world situations has been questioned by others (Herrera-Viedma et al. 2014, Peterson et al. 2005, Giordano et al. 2007). Consensus decision making is also considered to be aimed at attaining the consent but not necessarily the agreement of team members through the accommodation of the perspectives of all participants to arrive at a decision that will gain the most benefit for the group (Herrera-Viedma et al. 2014). Consensus does not always require unanimity. Softer views of consensus recognise that every discussion should involve an effort to hear and understand each participant (Chiclana et al. 2013, Peterson et al. 2005). Unanimity may be difficult to achieve where group members have diverse backgrounds and expertise and therefore more moderate definitions have been adopted to define consensus (Herrera-Viedma et al. 2014, Chiclana et al. 2013). Unanimous agreement can be unbenefficial to group decision making as it may mask or stifle the different viewpoints of the participants. A democratic process requires the recognition of different views which converge through discussion (Peterson et al. 2005). Consensus is not necessarily about getting a majority vote. Every opinion counts. Consensus accounts for dissent and addresses it, although it does not always have to accommodate it (Kacprzyk et al. 1992, Peterson et al. 2005). While individuals must have a chance to discuss their viewpoint, it may not be possible to accommodate all views and the team may need to move forward with what the group feels is best. Ness and Hoffman (1998) define consensus as:

“A decision that has been reached when most members of the team agree on a clear option and the few who oppose it think that they have had a reasonable opportunity to influence that choice. All team members agree to support the decision.”

Consensus and decision making can be considered as a dynamic and iterative discussion process where individuals are persuaded through rational argument and
debate to change their opinions step by step until a consensus is reached (Herrera-Viedma et al. 2014, Giordano et al. 2007). According to this perspective, participant’s preference values are gradually shifted away from their original preferences to preferences similar to that of others (Fedrizzi et al. 1999, Giordano et al. 2007).

Basic models of consensus decision making involve, collaboratively generating a proposal, identifying unsatisfied concerns, then modifying the proposal to attain a convergence on agreement. Newer models focus on the process of group collaboration and how collaboration can foster group decision making. Hartnett (2011) outlines the following steps in the consensus oriented decision making model (CODM) which aims to foster collaboration:

- Framing the topic
- Open discussion
- Identifying underlying concerns
- Collaborative proposal building
- Choosing a direction
- Synthesizing a final proposal
- Closure

This model is similar to the collaboration process outlined earlier but emphasises the agreement aspect of the process by identifying underlying concerns of individuals. As design is emergent underlying concerns may also emerge throughout the process so the linear nature of this process may not be representational of design practice.

Much of the literature on decision making has focused on how groups negotiate to reach consensus on decisions. An integral part of a group’s effort is dedicated to resolving differences in how members conceptualise problems while much less is known about how teams negotiate to reach consensus on the interpretation of issues (Mohammed and Dumville 2001). The next section looks at the concepts on shared understanding in teams where a working definition is put forward for consensus and common ground two constructs which adopted in the research phase.

2.5.2 Common ground, cognitive consensus and shared mental models

Multidisciplinary teams are designed to be diverse in terms of the discipline and functional areas of expertise of the team members. Diversity can be related to both task and relationships (Jackson 1996). For teams to reach consensus on matters they must
reach a shared understanding and shared representations about the issues being addressed. Of the various terms devised in the literature to address this, the following are a focus: common ground, cognitive consensus and shared mental models. While these constructs originated in separate fields they are very similar, however common ground and cognitive consensus are more similar. Common ground and cognitive consensus are discussed first and their similarities highlighted. Both are then contrasted with shared mental models and then consensus. The section then concludes with the constructs adopted for this research.

Common ground is the basis for collaborative communication across disciplines and the integration of conflicting concepts or theories. Common ground refers to the knowledge, beliefs and assumptions that conversational participants have in common and their awareness of this (Clark 1996). It is a shared cognitive frame of reference (Bromme, 2000). Common ground includes information that comes from the bases of community membership, physical co-presence, and linguistic co-presence (Clark and Marshall 1981). Every act of communication presumes a common cognitive frame of reference between the partners of interaction called common ground. All contributions to the process of mutual understanding serve to establish and continually maintain this common ground (Bromme et al. 2001). Common ground is required when people (or disciplines) use different concepts or terms to describe the same thing, and when people take opposing positions on a particular issue stemming from conflicting assumptions or values (Repko 2008). Creating common ground is like building a bridge in order to span a chasm. The near side is the place of conflicting insights and the lack of a common language, the opposite side is the product of the process of integration (Repko 2008). Repko (2008) defines interdisciplinary common ground as:

“One or more theories, concepts, and assumptions by which conflicting insights can be reconciled and integrated.

Bromme’s (2000) theory of cognitive inter-disciplinarity holds that common ground is an important condition for knowledge sharing among different perspectives. Common ground is an ongoing interactive process where assumed mutual knowledge and beliefs are updated (Clark and Brennan 1991). The negotiation of common ground is essential for complex problem solving in multidisciplinary teams, because common ground is needed to afford the sharing of knowledge and the subsequent construction of a shared problem representation (Bromme 2000). The process of updating common ground on a moment by-moment basis in conversation is called “grounding.” Grounding, according to
this theory, is a collective process by which participants try to reach mutual beliefs. Creating common ground involves bringing out potential commonalities and underlying conflicting insights so that these can be reconciled and integrated (Repko 2008). Stempfle and Badke-Schaube (2002) found that when teams bypassed grounding this led to a premature evaluation of ideas.

Similarly cognitive consensus is defined as the similarity among group members regarding how key issues are defined and conceptualized (Mohammed and Dumville 2001). It refers to the interpretations and opinions of the team with regard to information and issues pertaining to the group. It describes collective representations of issues, is socially constructed and relies on agreement (Mohammed 2001). Groups with a greater degree of cognitive consensus are more likely to address, interpret and communicate about issues (Mohammed 2001). Common ground is also a collective process by which participants try to reach mutual beliefs. It is acknowledged that understanding and mutual belief can never be absolute in that the participants can never have or know that they have identical beliefs (Clark and Brennan 1991). While common ground leads to constructed knowledge it is difficult to verify that this is mutual knowledge where each team member has an identical representation of that knowledge. This is supported by Lee (2001) who states that mutuality with a 100% certainty of sharedness is not attainable or possible.

Similarly cognitive consensus relies on both unity and some diversity. Not every individual in a group must have an identical interpretation before shared cognition can emerge (Mohammed and Dumville 2001). While team members may express public agreement without holding private acceptance, cognitive consensus implies some degree of internal acceptance by individuals to the group’s interpretations. However different levels of internalisation may exist between team members (Mohammed 2001). A certain level of sharing must exist for cognitive consensus to occur and this entails both unity and some diversity (ibid). Cognitive consensus is the lens through which groups view and attend to issues and what is shared include assumptions, categories, causal maps which allow groups to form views (ibid). Cognitive consensus can be viewed as a scale of sharing; at one end of the scale members interpretations are more divergent with incongruent and idiosyncratic frames of reference, at the other end of the scale members have entirely identical and convergent frames (Mohammed 2001). The extremes of this scale are seen as dysfunctional for effective collaboration (Fiol 1994, Giordano et al. 2007).
While the literature on common ground and cognitive consensus come from different sources it would appear that there are little differences between them (HodHod and Magerko 2012). Clark and Schaefer (1989) state that during grounding the partners must understand and accept what the contributor meant to a criterion sufficient for current purposes. This means that there must be a consensus in the interpretation of meaning and then consensus on the position taken on that contribution. Participants must explicitly verify their understanding of each other’s contributions to a conversation, and to explicitly articulate their own positions on those contributions (Kirschner et al. 2008). Therefore while common ground can lead to consensus on a macro level in making decisions and taking action, consensus is required at a micro level in the course of building common ground. During a discourse, common ground can be witnessed through contributor’s verifications and acceptances which indicate consensus (Beers et al. 2006). To conclude common ground and cognitive consensus are different terms used to describe the same thing. Similarly framing as defined in the design literature also refers to a team’s moment by moment shared perception of elements of a problem (Dong 2005).

Common ground, cognitive consensus and framing are both similar to the concept of shared mental models in that both refer to a shared understanding of the assumptions and beliefs about issues relating to a task (Mohammed and Dumville 2001, Fuller and Magerko 2011). Shared mental models are characterized as knowledge or belief structures that are shared by members of a team to enable them to co-ordinate their actions and adjust their behaviours to the demands of a task (Klimoski and Mohammed 1994, Cannon-Bowers et al. 1993). There are however differences, shared mental models refer primarily to knowledge structures that are held collectively by a group, whereas common ground and cognitive consensus also include belief structures. While the knowledge structures of shared mental models require accuracy and correctness common ground and cognitive consensus are more subjective and evaluative in nature (Mohammed and Dumville 2001). Common ground cognitive consensus and framing are also distinguishable from shared mental models in that these are a state a group can reach at a specific point in time in that they are moment by moment perceptions of elements of a problem, whereas shared mental models refer to the cognitive structures built up over time in arriving at that state and focus on the entire problem (Fuller and Magerko 2011).

For the purpose of this research the term common ground is used to make a distinction between shared cognition and consensus. Common ground is different from consensus
as its goal is mutual understanding, while the goal of consensus is about mutual agreement. As common ground entails a private and internal acceptance of a shared understanding it is difficult to verify in teams, consensus however is possible to observe as it is associated with explicit agreement where individuals externalise and indicate their agreement to others. It can be assumed that when consensus is reached through discussion that some level of common ground has occurred. Consensus can be observed in the signalling of understanding to others, in the course of building common ground, and when making decisions and taking actions. Therefore verbal consensus can indicate that common ground has been achieved. For this thesis it is more important to determine how teams negotiate a sufficient level of common ground to reach consensus and move through the design process. Based on the literature the following working definition is used to define common ground:

*Common ground is a level of sharing of assumptions and beliefs and knowledge amongst team members with some degree of internal acceptance by individuals to the group’s interpretations.*

The literature in this section has also defined the factors related to consensus in team interaction. Based on this the following working definition is used to define consensus:

*Consensus is where members of the team externalise and publicly agree on a meaning or position which allows the team to move forward in a process.*

The next section addresses the process of sharing knowledge to reach common ground in teams.

2.5.3 Knowledge processing in teams

The cognitive processes of critical thinking, creative thinking and metacognition were addressed in section 2.5. Knowledge processing is the fourth cognitive process addressed in this study and involves the sharing and construction of knowledge in a group. Communication between participants is critical in collaboration as team members must understand the language and behaviour of the different disciplines involved in order to share and create new knowledge (Valkenburg and Dorst 1998). Communication is also important for resolving the practical issues of decision-making and coordinating tasks (Chiu 2002). Team knowledge is gained through an interactive process of sharing through conversations and collaboration (Jonassen and Henning
Collaborative design is seen as a discursive process where solutions are developed through talk in interaction where each person contributes from his/her own area of expertise (Luck 2009, McDonnell 2009, Kleinsmann et al. 2012). The co-construction of knowledge refers to the knowledge that is co-elaborated, appropriated and mutually accepted in collaborative problem-solving dialogues (Baker 2009). It involves a mutual process of building meaning, refining, or modifying a contribution (Baker 1994). Beers et al (2006) developed a framework to show how knowledge is taken from being implicit in the minds of individuals to becoming the explicit constructed knowledge of a team, see Figure 2.2.

![Figure 2.3 From unshared to constructed knowledge (Beers et al. 2006)](image)

While previous models outlined in the area of collaboration and consensus have shown that knowledge sharing and integration is an important component this model looks at this activity at a micro level to show how knowledge goes from being unshared to constructed through common ground. The route of unshared individual’s knowledge to a team’s constructed knowledge goes through three forms: external knowledge, shared knowledge and common ground, via four processes of; externalisation, internalisation, negotiation and integration. An individual’s knowledge is externalised when it is made explicit to others. This is then internalised by the other members of the group in an effort to understand the contribution. An individual’s beliefs, assumptions and perspectives come into play when trying to understand a contribution and therefore there is no guarantee that all members will arrive at the same understanding simply by externalising and internalising the knowledge (Shaw et al. 2003). A contribution is understood against the presumed perspective of the contributor as well as one’s own perspective (Bromme 2000). There is evidence to show that estimations of what other people know are biased in the direction of one’s own knowledge and misunderstandings may occur due to
incorrect assumptions about the other’s perspectives (Bromme et al. 2001). Therefore knowledge can be interpreted differently during externalising and subsequent internalising due to different perspectives. Negotiation of common ground must therefore take place for a contribution to be accepted by the team (Badke-Schaub et al. 2010). Negotiating of common ground can be afforded by making individual team members’ perspectives explicit to others. Team members must verify their understanding of another’s contributions and then articulate their own positions on those contributions (Kirschner et al. 2008).

Bromme (2000) proposes that common ground is a requirement for knowledge sharing amongst team members with differing perspectives. During knowledge construction participants contribute discrete chunks of knowledge. Given that meaning is negotiated in interaction, this means that these chunks of knowledge must be open to change and alternative meanings. Clark and Schaefer (1989) suggest that for a conversation to proceed, partners must mutually believe that they have understood the intention of the criterion of the contributor. This is described as the grounding criterion, which has become the process for the development of common ground, or degree of shared understanding, in conversation. Negotiation of common ground involves both negotiation of meaning and position. Negotiation of meaning in knowledge construction involves arriving at a shared understanding of the meaning behind a contribution made by an individual. It concerns making a private understanding of a contribution public, comparing the extent of how one’s own understanding differs from the intentions of others, receiving feedback and verifying. Individuals must see the perspectives of others first in order to understand a meaning. Before negotiation of position can take place individuals must first negotiate meaning. This means that individuals must first negotiate common ground before agreeing on a solution or a deal (Fisher and Ury 1982). They must articulate their interpretations and understanding of the contribution and make adjustments where necessary upon feedback. Negotiation of meaning is therefore an iterative process that takes place until the contributor and other team members believe that all members share an understanding (Clark and Schaefer 1989). Knowledge construction is based on the common ground that the team has built. This knowledge will broaden the common ground as the common constructed knowledge becomes part of the common ground (Beers et al. 2005).

Negotiation of position involves team members making known their opinions and stance on another’s contribution. Negotiation of common ground therefore is an on-going interactive process where shared beliefs and knowledge is gathered, updated and
revised (Clark and Brennan 1991). Through this “co-elaboration,” process, learning in interaction can thus be seen as a process of first sharing knowledge that is then co-elaborated during discussions (Baker 2009). The acceptance or rejection of a point of view requires knowledge related to that point of view which calls for negotiation of meaning and elaboration of knowledge (Lu and Lajoie 2008).

Negotiations start with a contribution through externalisation which is then received through internalisation. A contribution will be based upon the ideas, experience and background of the contributor. The receiver will compare what he/she believes the contributor intended to say with their own understanding of the contribution. Clarifications and verifications are usually required during the negotiation process. Clarifications allow the contributor to ensure that other team members understand their contribution while verifications allow the team members to ensure that they have understood the contributor (Beers et al. 2006). A contribution will then be either rejected or accepted. Conceptual change occurs when individual accommodate new perspectives and change their understanding of the concepts and conceptual frameworks that they use (Jonassen and Kim 2010). Argumentation, such as formulating a position, producing justifications and refutations can allow for negotiation of meaning and persuasion to a particular point of view (Baker 2003, Lu and Lajoie 2008). Negotiation of meaning occurs through argumentation in two ways: dissociating concepts and combining concepts. Dissociation and combination lead people to drop beliefs that are not well explained and to accept beliefs whose definitions are more elaborated (Schwarz 2009, Baker 2003). However negotiation need only continue until all parties believe that they understand one another sufficiently, and either hold the same position, or respect an opposing position (Beers et al. 2006).

2.5.4 Conclusion

This section has addressed consensus, common ground and knowledge construction in teams. For effective collaboration teams must be able to reach consensus which is not simply about the selection of concepts but is continuous throughout the design process to agree on beliefs and interpretations as well as to make decisions. Beers et al (2006) model of unshared knowledge to constructed knowledge is an appropriate model to use to outline the consensus process as it shows how teams reach common ground. While this model outlines a process to construct knowledge within a team it does not show the cognitive activity that supports this process. The literature does show that meaning must be negotiated. This study intends to address how through conversation teams negotiate
shared meaning. By including consensus as a factor within this process it would be possible to show the effectiveness of any verbal cognitive exchange between participants that was contributing to common ground and constructed knowledge. The next section looks at potential barriers to reaching consensus mainly cognitive diversity and conflict.

2.6 COGNITIVE DIVERSITY AND CONFLICT

Cognitive diversity is defined according to differences in the beliefs, thinking styles, knowledge, values, assumptions, and preferences held by the members within a team (Martins et al. 2012, Jehn et al. 1999). Cognitively diverse teams have more task-related knowledge, and can achieve better performance through the comprehensive processing and integration of this knowledge (Jehn et al. 1999). Team members with cognitive diversity may pay attention to or extract different information about the same issue (Martins et al. 2012). Alternative perspectives can also lead to the stimulation of creativity and originality (Boos 2007). The development of different and conflicting views in complex and ill-defined problem solving can create a better awareness of a variety of ideas and perspectives, that may be synthesised to create effective decisions (Fiol 1994, Parayitam et al. 2010, Olson et al. 2007, Talke et al. 2010).

A balance is required as with completely diverse groups, members may not be working towards the same purpose and interactions could involve miscommunication. The main aim is not to get immediate convergence but to first facilitate discussion amongst group members (Giordano et al. 2007). Through this process the problem can be broadened to foster possible creative ideas and future courses of action, enriching both individual and collective knowledge. Rather than discouraging disagreement good decision making allows participants to identify where members thinking diverges to allow them to gather more information or ideas on how to resolve disagreements (Raiffa and Metcalfe 2002). As shown in the previous section for diversity to be effective there must be elaboration of task relevant information through information exchange which involves processing, discussing and integrating the relevant information within the team (Van Knippenberg et al. 2004, Baker 2009).

The process of consolidating a number of alternatives ideas and perspectives is likely to create conflict (Olson et al. 2007, De Dreu and Weingart 2003). It is only when diverse perspectives and opinions are expressed amongst a group that disagreements my result causing conflict. Conflict is a process in which one party perceives that its interests are being opposed or negatively affected by another party (Wall & Callister, 1995). It has been defined as:
“a process that begins when an individual or group perceives differences and opposition between itself and another individual or team about interests and resources, beliefs, values or practices that matter to them (De Dreu and Gelfland, 2008).”

A key distinction between disagreement and conflict is that a disagreement doesn't necessarily lead to a conflict, but does when there is a dispute of needs, values, interests and intentions between two or more parties (Heitler 1990). Conflict does not always result in destructive consequences. The traditional view assumes that conflict is bad, with a negative impact, and leads to declines in performance as the level of conflict increases. Conflict in this view is closely associated with such terms as violence, destruction, and irrationality. More recent views of conflict view it as natural and inevitable in organizations, and that it can have either a positive or a negative effect, depending on how the conflict is handled (Verma 1998). Where conflict can be beneficial its manifestation is not violent and extremely aggressive as more traditional depictions would imply. In a work place setting the term ‘moderate' has been used to describe conflict with a positive impact (Jehn and Mannix 2001, De Dreu 2006).

There are different types of conflicts that can affect team performance: cognitive (task), affective (relationship) and process. Cognitive conflict concerns disagreements related to the task involved including choices of alternatives or differences in judgements, opinions or ideas (De Dreu 2006, Jehn et al. 1999). Affective conflicts relate to differences regarding inter-relationship and emotional issues. It exists because of interpersonal incompatibilities between team members (De Dreu 2006, Amason 1996). It refers to personal and social issues not related to the task (De Dreu and Van Vianen 2001). Process conflicts relates to disagreements about how to execute the task such as the procedures by which the task should be accomplished including, planning and scheduling (Jehn et al. 1999). It also refers to the distribution of responsibilities and the structure of delegation within the team (Jehn 1997).

While the research has been mixed with regard to whether cognitive conflicts can have a positive effect on team performance affective and process conflict generally have a negative impact on team performance (Greer et al. 2008, Jehn et al. 1999). A negative effect of cognitive conflict is, that if left unresolved can lead to affective conflict (De Dreu and Weingart 2003). Table 2.4 outlines the consequences of different types of conflicts as devised by Badke-Schaub et al (2010).
Table 2.3 Consequences of different types of conflict (Badke-Schaub et al. 2010)

<table>
<thead>
<tr>
<th>Affective conflicts (relationship conflict)</th>
<th>Process conflicts</th>
<th>Cognitive conflicts (Task conflict)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative</td>
<td>Reduced motivation Reduced openness and communication</td>
<td>Decreased productivity Low content quality</td>
</tr>
<tr>
<td>Positive</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tasks with a high degree of uncertainty like design and innovation problems are likely to create a high degree of cognitive conflict (Chen 2006, Badke-Schaub et al. 2010). Much of the research has found cognitive conflict to be counterproductive to team success, notably De Dreu & Weingart (2003) in a meta-analysis. However other literature has shown that, moderate levels of cognitive conflict can be beneficial in non-routine tasks like design and innovation (De Dreu 2006, Song et al. 2006, Badke Schaub et al. 2010). DeDreu (2006) found a positive relationship between cognitive conflict and innovation and even a stronger correlation between the two variables when the task was uncertain and complex. Cognitive conflict can have a contributory effect in more complex decision making such as innovation as through the negotiation of conflict a number of perspectives must be synthesised to aid decision making (De Dreu 2006, Jehn et al. 1999). Managed well, cognitive conflict can allow for the discussion of a larger number of ideas and perspectives bringing about more flexible thinking and creative solutions (Carnevale and Probst 1998). This can lead to increased decision understanding, decision commitment and quality (Olson et al. 2007). As team members engage in cognitive conflict they gain more knowledge of the task at hand, in terms of complexity enabling more balanced decision making (Pelled et al. 1999). This increased understanding is due to the exchange and sharing of ideas and information and the shifting of individual perspectives as individuals examine their original positions in light of new information and perspectives (Olson et al. 2007). In addition divergent viewpoints may stimulate team reflexivity in the consideration of their performance and in turn team learning. (Van Knippenberg and Schippers 2007).

While cognitive conflict has been shown to have a role in decision making, the degree to which cognitive conflict can stimulate information exchange and decision making remains in doubt (Van Knippenberg and Schippers 2007). Van Knippenberg et al.(2004) argue that while cognitive conflict might stimulate the elaboration of task relevant information and improve collaboration it is not a prerequisite for the sharing of task relevant information. They state that it may also be the elaboration of task relevant
information and not the cognitive conflict that produces the beneficial effects of diversity. They propose that studies addressing team information processing and the role of conflict are required. Santos et al. (2015) also dispute the benefit of task conflict and suggest that it is through shared understanding that creativity and team performance is fostered. They found that team performance and creativity did not improve via team conflict but through shared cognition.

With regard to innovation tasks benefiting from task conflict, in a recent meta-analysis de Wit et al. (2012) did not find task type to moderate the association between task conflict and team performance. While they found that task conflict could benefit team performance they found no difference in performance between: (a) creativity tasks requiring idea generation and innovation, (b) decision making tasks which involve tasks requiring consensus about a solution where there is no one right answer, (c) production tasks involving routine tasks and (d) project tasks concerning problem solving and generating plans. They found that the association between conflict and performance depended on a broader array of moderators on the impact of conflict such as levels of association to affective conflict and seniority of team members in an organization. These findings also suggest that the definition of innovation in the conflict literature is restricted with a view that it only involves creative tasks such as idea generation whereas design and innovation projects could encompass all of the tasks described above. Therefore conflict may or may not be of benefit during design and innovation and other factors may determine this.

In addition a project conducted by Badke Schaub et al. (2010) on conflict amongst design and innovation students which found conflict to be of benefit was a very short project at 50 minutes where different phases of the design process were not a focus of the research. It would also be of interest is to understand how conflict materialises over the different phases of design projects and if it is always beneficial at each phase. The mixed findings from the literature would suggest that it is possible that cognitive conflict may be of benefit at certain times but could also have a negative effect at other times or at different phases of a project. This is also supported with findings that show that conflict varies throughout the stages in a project’s life cycle (Jehn and Mannix 2001). Cognitive conflict is more likely to occur in the early phase of task clarification and concept generation where diversity of knowledge and abilities and experience are required which can trigger cognitive conflict (Badke-Schaub et al. 2010). What is not known also is if conflict is beneficial at all stages of the process. Therefore where and when conflict is of benefit during design projects is a focus for this research. In addition the processes adopted during conflict are also a focus.
In a meta-analysis DeChurch et al. (2013) have theoretically reorganised the literature on team conflict to distinguish conflict states from conflict processes. Conflict states refer to the shared perceptions among members of the team about the intensity of the disagreement. They highlight that conflict processes, how teams interact regarding their differences and manage conflict are at least as important as conflict states. They argue that the literature has disproportionately addressed conflict states over conflict processes such as task and relationship conflict which has culminated in two meta-analyses (De Dreu and Weingart 2003, de Wit et al. 2012).

There have been limited studies that have looked at conflict processes. Many of the constructs identified refer to team behaviour that either support the individual or the team (Jackson et al. 2006, DeChurch et al. 2013). These behaviours have been categorised by various authors as: team collaboration, team competition, team avoiding and team openness (Deutsch 2002, Thomas 1974, De Dreu and Van Vianen 2001, Blake et al. 1962). Openness and collaboration are deemed to be collective behaviours that support the individual and the team objective while competing and avoiding are considered to be individualistic behaviours that do not support the team goals. However what the literature is lacking are studies of how teams negotiate conflict. If task conflict has been identified as having a positive role when solving complex tasks, the next step is to discover the cognitive processes and conversation activities that are used to both instigate, manage and in turn diffuse the conflict.

2.6.1 Conclusion

This section shows that the findings are mixed and inconclusive as to whether conflict benefits tasks such as design and innovation. It appears that conflict may be of benefit at certain times but could also have a negative effect at other times or at different phases of a project and may delay progress. Recent literature has shown that task type is not necessarily a moderator of the impact of conflict on performance and other factors such as levels of association to affective conflict and seniority of team members may influence the impact. The literature has also disproportionately addressed conflict states over conflict processes. More research in the area is needed to understand the how conflict is managed. Solving design problems demands a considerable level of skill and expert’s approaches to addressing design problems is strongly associated with successful practice (Lawson and Dorst 2013, Cross 2004, Paton and Dorst 2011, Björklund 2013). These differences may also have a bearing on how consensus is reached between
teams made up of experts and novices. Therefore the next section looks at the differences between experts and novices.

2.7 EXPERT VERSUS NOVICES

In order to make recommendations to support novice team’s in design it is necessary to understand the differences between how experts and novices approach design problems, collaborate, reach consensus and respond to conflict. This can better support novices in learning from expert behaviour. The differences between the two may be even more marked when designing in teams as the activities involved include both the solving of the design task and the engagement in the collaboration process and managing conflict. Much of the empirical research on design has not addressed team expertise sufficiently and has addressed either design students (Defazio 2008, Goldschmidt and Rodgers 2013, Seidel and Fixson 2013) or individual professional designers (Cross 2004, Lawson 2004).

2.7.1 Expert versus novices cognitive processes and methods

It is recognized that there is a difference in how experts and novices solve design problems (Cross 2004). Experts tend to form more abstract conceptualizations of a problem and are able to recognize underlying principles, rather than focusing on the surface features. Experts tend to have a top down and breath first approach to problems while novice behaviour is regarded as a depth first approach, sequentially identifying and exploring sub solutions (Cross 2001). Studies across a variety of domains have found that experts spend more time than novices qualitatively analysing and defining a problem and gathering information (Jain and Sobek II 2006, Atman et al. 2007) and demonstrate a more proactive stance towards the problem solving process (Björklund 2013). Christiaans (1992) found that the more time a designer spent on defining and understanding a problem the better able they were to achieve a creative solution. Experts tend to view problems as more difficult in that they will process more information to tackle the problem (Cross 2004, Björklund 2013). In a study Bjorklund (2013) found that experts perceived a wider range of requirements and drew from a wider range of outside information. This is supported by Atman et al. (2007) who found that experts spend almost double the time as novices in problem scoping, problem definition, and the gathering of information. The nature of the information gathered by the experts was also more diverse.
Experts will spend more time in defining the problem by activating prior knowledge, elaborating on the information presented, and regulating their process (Brand-Gruwel et al. 2005). Novices tend to expect ready answers whereas experts see themselves as having an active role in seeking information, have a better understanding of the information required for the project and have a better understanding of how and where to source these requirements (Björklund 2013). Experts are also more research focused (Goldschmidt and Rodgers 2013). Experts are inclined to use outside resources and consult and collaborate more with other experts. Experts are also better at judging the relevancy of information and the relationship between chunks of information (Björklund 2013, Goldschmidt and Rodgers 2013). Experts engage in analysis more showing better critical thinking ability and are able to represent problems in multiple ways whereas novices are often restricted to a single form of problem representation (Jonassen 2003). Experts have superior mental representations or frames which have a bi-directional relationship with knowledge (Alibali et al. 2009). This in turn increases pro-active behaviour and a better performance through better options and opportunities (Björklund 2013). Pro-active behaviour involves challenging the status quo rather than passively adapting to present conditions (Crant 2000).

Novice designers also tend to have a pattern of trial and error where experts plan several moves in advance, have a better capability of evaluating proposed solutions reducing the time to arrive at a final solution (Ahmed et al. 2003, Goldschmidt and Rodgers 2013). Experts therefore are better at applying metacognition and reflective practices which are essential in the design process and reflective designers are more likely to produce higher quality design solutions (Hong and Choi 2011). Lloyd and Scott (1994) observed that expert designer’s reflection involves constantly monitoring evaluating and modifying their understanding of a problem and potential solutions. Reflection in design is also associated with an increased frequency of iteration between problem definition and solution generation to show that experts are better at iteration which is associated with a better performance (Hong and Choi 2011).

Though theorists and educationists tend to recommend a wide range of solutions this appears not to be normal practice for expert designers who tend to become attached to single early solution concepts (Cross 2004). It may be that experienced designers produce good early concepts that require less iteration or that good designers are better able to modify their concepts as difficulties arise. Goldschmidt and Rodgers (2013) also found in their study that novices tended to move to solution generation earlier in the process while the experts delayed solution generation but fixed more quickly on a final
solution. However in a study Lloyd and Scott (1994) concluded that more experienced designers used more generative reasoning in contrast to the deductive reasoning employed by novices. Designers with related experience to a problem also approach the problem through solution conjectures to further understand the problem through co-evolution (Maher and Tang 2003) which reflects good design practice (Cross 2011). This shows that experts are more efficient in their thinking approach, have superior strategies to manage the process and a better understanding of where and when to use them.

Experts can also integrate knowledge from previous projects (Ahmed et al. 2003) referring more to analogous projects. In their study Ball and Christensen (2009) found that experts used significantly more analogies than novices and that the type of analogy used was also different. Novices used more case-driven analogies (concrete examples) to develop solutions. Experts on the other hand used schema-driven analogies (drawn from a variety of sources). Reasons given for this are that experts are better at identifying the more relevant information which novices find difficult to do. Experts are better able to question data and are better able to differentiate between important and less important issues (Ahmed et al. 2003).

What this section indicates is that experts will approach consensus differently. Experts carry out a greater depth of analysis indicating higher levels of critical thinking and draw on a wider pool of information and use reflection more. Experts compared to novices treat problems as more complex and spend more time at the problem definition phase to show that early consensus may not necessarily be desirable in design. The next section looks at the differences between novice and expert teams.

2.7.2 Expert versus novice collaboration

There is limited empirical research that compares expert and novice team’s cognitive engagement and even less in the area of design. This section draws together what has been addressed. For teams to be effective it is advisable for them to be heterogeneous with a degree of distributed knowledge (Hung 2013). Thus inexperienced designers lacking diverse knowledge are less likely to be able to respond to complex problems that are inherently multi-dimensional and necessitate different expertise. To succeed teams must be able to communicate and coordinate their activities (Ward and Eccles 2006). Experienced teams out preform novice teams due to better communication and coordination, a better process, better team situation awareness and decision making (Cooke et al. 2007). In a study of multidisciplinary novice design teams Seidel and
Fixson (2013) found that higher performing teams agreed better on the problem definition and had better clarity on the user needs. In addition these teams continued to structure the problem throughout the project reflecting a co-evolution method associated with good design practice (Maher and Tang 2003). Like individual design practice the higher performance teams spent less time on brainstorming but achieved better results. They also displayed better team reflection debating more over ideas, over the process to follow and over changes to the concept. This reflects good practice as teams that debate ideas tend to come up with more novel innovations due to further exploration (Pelled et al. 1999).

Fiore et al. (2002) found that meta-cognition was related to increased team performance. As teams reason meta-cognitively, they adjust their own cognitive processing, improving collective problem solving ability, advancing team knowledge. A team’s meta-cognitive ability is also critical to adapt to the changes of the problem environment as well as in accumulating experience from solving similar problems (Hung 2015). By solving different problems, teams become experts in the field. Debate has been shown to have a positive effect on team performance.

This section has shown that experts out preform novices with better communication and coordination, a better process with more debate and reflective practice. This indicates that experts are more likely to be better able to manage and benefit from conflict which is discussed in the next section.

2.7.3 Expert versus novice approach to conflict

Constructive conflict has a positive role in a team’s development of common ground or a shared mental model because individual cognitions need to be thoroughly examined, internalised, questioned, clarified, refined, and integrated into a shared mental model to guide the team towards a common goal (Van den Bossche et al. 2011). de Wit et al. (2012) found that the positive link between task conflict and performance was more strongly related to top management teams rather than teams at lower levels in the organisation. This suggests differences between how expert and novice teams cope with conflict. It is thought that top management teams are able to prevent task conflict from turning into relationship conflict and thus are able to benefit from task conflict (de Wit et al. 2012).
Trust (Olson et al. 2007, Chiocchio et al. 2011) and behavioural integration (De Dreu 2006, Mooney et al. 2007) are factors that can mediate against the negative effects of conflict and the development of relationship conflict. When individuals do not feel safe expressing different opinions it results in a loss of co-ordination, process losses and poorer performance (Martins et al. 2012). High levels of intra-group trust relate to a weaker link to cognitive and affective conflict as interpretation processes influences the transformation of one form of conflict to the other (Simons and Peterson). Olson et al. (2007) use the term competence based trust which is the level of trust that team members have in each other and in each other’s competencies. It is made up of: dependability, competence and reliability. Teams with higher competence based trust can openly challenge others without fear of ridicule. Team members will also trust the competence and expertise of others encouraging the sharing of information and diverse views. Teams with higher competence based trust will push one another towards conflict knowing that the exchange and debate of knowledge and diverse views is valuable in making strategic decisions (Olson et al. 2007). This suggests that novices may be less competent in negotiating conflict as competence based trust is less likely to be established within the team.

Mooney et al (2007) found that behavioural integration which refers to the extent to which team members engage in mutual and collective interaction can also better support a team’s ability to manage conflict effectively. These interactions have three elements: quantity and quality of information exchange, collaborative behaviour and joint decision making. Their findings show that teams with more behavioural integration had a weaker positive association between cognitive and affective conflict as misinterpretations of the motives behind disagreements were avoided. Again novices have been shown to be weaker in these three elements showing why they may be less likely to benefit from conflict. Therefore factors that can shape team members perceptions such as trust and behavioural integration can play an important role in how teams react to conflict. Experienced teams due to higher competence based trust and behavioural integration may be better able to negotiate conflict and benefit from it. The difference between expert and novice teams in the management of conflict has not been a focus of the literature yet this variable may play an important role in establishing whether task conflict benefits all teams. Therefore understanding the role of conflict in consensus reaching in design can reveal how teams negotiate design problems.
2.7.4 Conclusion

Experts have been shown to outperform novices in the design and collaboration process. The literature has been very limited in comparing experts and novices with regard to how they manage conflict and this is an area that could reveal more about the benefits or barriers to conflict. By understanding the differences between how experts and novices manage all aspects of designing in teams it is a means of guiding novice teams towards expert team practices.

2.8 LITERATURE REVIEW SUMMARY

Because of the complexity and unstructured nature of design problems, multi-disciplinary teams are better able to solve them than individuals with the pooling of diverse expertise and knowledge to handle their vast scope. (Steiner and Posch 2006, Stempfle and Badke-Schaub 2002). The initial stage of the design process involves a series of phases that involve different objectives and methods which may have a bearing on how teams engage and reach consensus at each stage. The problem definition phase requires iterative problem framing to structure and define the problem. The ideation phase requires exploration and the generation of multiple ideas while the concept development phase requires a narrowing of focus to select and refine a fewer number of solutions. Designers methods of working are different to those of other fields and designers have been shown to follow a co-evolution approach where the problem and solution are developed together, as ideas are generated this in turn informs the problem state (Cross 2001, Dorst 2011). These distinct phases and mode of operation call for the switching between a variety of thinking and reasoning styles that range from divergent to convergent reasoning involving critical thinking, creative thinking and meta-cognition. The use of linkography can reveal how designers engage in the design process and the use of analogies and mental simulations (Ball and Christensen 2009) were found to support the design process. The different objectives in design will also have a bearing on how consensus is reached and what must be agreed on. While much of this literature comes from studying individual professional designers (Cross 2004, Lawson 2004). The requirement to work in teams means that along with managing the design process teams also need to manage the collaboration process.

Some studies in design have addressed the social aspects of design (Bucciarelli 1994) where designers create their own common language to communicate about the product being designed (Dong et al. 2005). Strategies such as storytelling can enable this
common language (Lloyd 2000). Design can also be seen as negotiation where this common language is used to negotiate and progress the design process (McDonnell 2009, Stumpf and McDonnell 2002). While design teams have been shown to develop a distinct common language this does not mean that the knowledge and perspective of each team member will be brought to bear and aligned in creating a shared perspective amongst the team. In addition recent studies have shown that design teams use tentativeness and deferral strategies to avoid confronting disagreement.

As designers are increasingly working in interdisciplinary teams and in order to pool their collective resources, they must be able to work effectively together. The diversity of the disciplines and perspectives of the team can add complication to the interactions and performance of the team. Designing in teams will not just be about applying the cognitive processing to solve the design task but also about knowledge exchange and construction between team members.

To collaborate teams must develop a shared understanding and common ground to make decisions collaboratively (Klimoski and Mohammed 1994, Cannon-Bowers et al. 1993, Dong et al. 2013). Therefore the literature suggests that much of the activity used by teams will go towards not just solving the task at hand but also towards collaborating with others to align knowledge and beliefs to reach consensus and move forward in the process. Collaboration in problem solving relies on the co-construction of knowledge through the process of co-elaboration (Baker 2009). A number of models have outlined the collaboration or consensus process. While they have focused on the process they don’t reveal how these processes are achieved. The framework devised by Beers et al (2006) has shown that in order for teams to co-construct knowledge they must reach common ground. This is achieved through the process of externalization, internalization, negotiation and integration. While the model proposes that this process is supported by clarifications and verifications of team members to either accept or reject contributions, it does not highlight the cognitive processes that support this activity. By including consensus as a factor within this process it would be possible to show the effectiveness of any verbal cognitive exchange between participants that was contributing to the common ground.

Design problems have been shown to have multiple problem representations solution options which can make consensus difficult. The design process is also highly iterative making consensus also iterative as new information is processed. It has also been shown that arriving at consensus can be challenging for multi-disciplinary teams due to a
difficulty in sharing interests, views, goals and values which can cause conflict. Some studies have shown that cognitive conflict has a detrimental impact on team performance while other studies have shown that in complex problems like design and innovation that some levels of cognitive conflict can have a positive effect to stimulate the co-elaboration of knowledge and in turn performance. The findings in this area are inconclusive however. The literature has also disproportionately addressed conflict states over conflict processes (DeChurch and Mesmer-Magnus 2010). It is possible that conflict may be of benefit at only certain times or phases in a project which is an area that has not been addressed in the literature. Other factors such association to affective conflict and seniority of team members are other moderators of the impact of conflict de Wit et al. (2012). Further studies are needed to understand the interactions in design teams during conflict (Détienne et al. 2012, Badke Schaub et al. 2010).

Much of the empirical research on design has not significantly focused on team expertise but has addressed either design students (Defazio 2008, Goldschmidt and Rodgers 2013, Seidel and Fixson 2013) or individual professional designers (Cross 2004, Lawson 2004). Experts have been shown to outperform novices in the design process by carrying out a greater depth of analysis drawing on a wider pool of information and using more reflective practices (Björklund 2013, Goldschmidt and Rodgers 2013). During the collaboration process experts also outperform novice teams with better communication and coordination, thorough debate and reflective practices (Seidel and Fixson 2013). The literature has not extensively compared experts and novices with regard to how they manage conflict and this is an area that could also reveal more about different responses to conflict. By understanding the differences between how experts and novices manage all aspects of designing in teams it is a means of guiding novice teams towards expert team practices.

In building on the literature in recognising the social aspect of design and the importance of shared team cognition, this thesis seeks to further build an understanding on how teams negotiate consensus to maintain progress during the design process. It seeks to understand the cognitive processes and conversation activities that enable this. By building consensus within this process it would be possible to show the effectiveness of the verbal exchange between participants to build common ground in design. The literature has shown that conflict may be a barrier to reaching consensus and how this is managed during team interactions is part of this research. Experts have been shown to have superior design problem solving processes and collaboration process. By comparing both it will be possible to guide novices towards more expert behaviour. This research is significant as it will provide a better understanding of how teams collaborate
to reach consensus and move through the problem solving process in design. The next section outlines the preliminary conceptual model that forms the focus of the research area.

2.9 CONCEPTUAL MODEL

A concept is a mental configuration or idea about a phenomenon. Eisenhardt (1989) suggests the identification of relevant theoretical constructs prior to conducting case study research in order to accurately understand the phenomenon under study. A number of constructs have been selected and defined based on the literature, which form the basis of a preliminary conceptual model as illustrated in Figure 2.3. This model is a guideline to create a boundary for the scope of the research and forms a basis for guiding the empirical research. Following the analysis of the research data a new model may emerge based on the research findings. In the final model existing constructs will be reinforced and their relationships, additional constructs and new relationships may also emerge. As the literature review has shown, many of the constructs have been investigated by other researchers. What the existing literature has overlooked is the relationship between the constructs and how design teams reach common ground and consensus. This research proposes to further explore the constructs and their relationship to one another and build new ones to understand team cognition and collaboration in unstructured problem solving.
2.9.1 The conceptual model constructs

This section discusses the constructs or themes selected for the study as shown in Figure 2.3. Qualitative research suggests that theoretical and empirical inquiries should not be addressed sequentially, but through an iterative process where the empirical data is compared to existing theories (Yin 1994). The themes chosen for this study are derived from the literature. The first set of constructs relating to the team process are taken from Beers et al (2006) framework. This highlights the route of unshared individual’s knowledge to a team’s constructed knowledge through three forms: external knowledge, shared knowledge and common ground. In the construction of knowledge teams will never have absolute levels of mutual knowledge. As the focus of this thesis is to determine how consensus is reached the proposed model has replaced Beers et al. (2006) constructed knowledge with consensus. Consensus can indicate that a degree of
common ground has been established. Consensus for the purpose of this thesis has been defined as:

**Consensus is where members of the team externalise and publicly agree on a meaning or position which allows the team to move forward in a process.**

Evaluating internal acceptance is difficult to do but a public acceptance and agreement suggests some level of internal acceptance and cognitive consensus of the group’s interpretations and decisions. In order to reach consensus teams must negotiate common ground. Common ground has been defined as:

**Common ground is a level of sharing of assumptions and beliefs and knowledge amongst team members with some degree of internal acceptance by individuals to the group’s interpretations.**

The model in Figure 2.4 is not unlike Schön’s reflective practice framework in that naming could reflect shared knowledge and framing could reflect common ground and consensus. However this model was deemed more appropriate for this study as it is more specific to team interaction unlike the reflective practice framework which originated as an individual activity between a designer and a designed object. This model emphasises the communication process that teams must go through to reach common ground. It shows that teams must externalise unshared knowledge to other team members and that this shared knowledge must then be internalised by other participants. The model also shows that the process of going from shared knowledge to common ground is not automatic and that information must be negotiated.

This process is enabled by cognitive processes defined as:

**Cognitive processes are the thinking and reasoning that teams go through to discover, analyse and solve problems collaboratively.**

Four cognitive processes have been selected that can impact on reaching common ground in design teams; *knowledge processing, creative thinking, critical thinking* and *metacognition*. These are defined as follows:
Knowledge processing is made up of the externalizing and internalising of knowledge. This involves the exchange of knowledge between team members through clarifications, verifications, explanations and elaborations.

Critical thinking entails actively questioning, provoking, estimating and acting upon information. It involves analysis, and the judging of others contributions, making inferences, interpretations and negotiations.

Creative thinking involves being generative and solution orientated with an ability to imaginatively create something new. It involves divergent and lateral thinking to create ideas.

Meta-cognition is about reflective thinking on the team's own performance and thinking. It is made up of three skills; planning, monitoring, and evaluating.

A number of moderators are expected to impact on the process. The phases in the design process are expected to impact on consensus reaching. The problem definition phase, the ideation phase and the concept development phase are the focus of this research. In addition expertise and conflict are also factors.

2.9.2 The conceptual propositions

The conceptual model highlights some of the relationships between the constructs selected which can be described as propositions. Propositions are causal relationships between two constructs where certain conditions lead to other conditions (Yin 1994). Cognitive diversity of knowledge within a team can lead to a broader access to information, better insights towards problem solving and can foster creative problem solving (Jehn et al. 1999, Badke Schaub et al. 2010). The model shows that teams will start out with diversity in that each member may hold a different set of knowledge and belief structures towards the task. To develop common ground teams must take this knowledge through three forms from unshared individual's knowledge to external knowledge to shared knowledge. Shared knowledge is the knowledge externalised to the team and must be further negotiated on to reach common ground. This process involves the negotiation of both the meaning and the interpretation of contributions and the position that the team will take on those contributions. This involves all members understanding what another means by a contribution and on whether the team agrees on that understanding. This is an interactive and iterative process of negotiation. To support this process the model proposes that teams will need to engage collectively in knowledge processing.
What this research seeks to address is how the team process maps to the design process which has three distinct phases that will engage in further cognitive processing; critical thinking, creative thinking and metacognition. A number of moderators have been defined which may also impact on a team’s ability to reach consensus during design projects. In reconciling multiple perspectives and beliefs to reach consensus this may extend to negotiating conflict which may have a positive or negative effect on team performance. Another moderator is expertise. As experts have been shown to perform better than novices across the collaboration and design process it is proposed that experts in teams will engage differently to novices in reaching consensus. The different phases which have separate objectives that either emphasise divergent or convergent thinking is also likely to impact on how teams reach consensus.

2.9.3 Conclusion

This section has presented a preliminary conceptual model to act as a guide and a boundary for the empirical research. A number of constructs have been selected based on the literature and the model has proposed a number of relationships between these constructs. Following the analysis of the research data a revised model may emerge.

2.10 CHAPTER CONCLUSIONS

This chapter has presented a literature review that has discussed the themes that relate to consensus reaching in design. It has shown that

- Design problems are unstructured and ill-defined with no one correct problem representation or solution but several that may be apt. The design process has different phases which alternate between divergent and convergent thinking. This makes consensus reaching in design potentially more difficult.
- Team problem solving requires additional strategizing over individual problem solving. Along with the cognitive processes required to solve unstructured problems in design, teams must devise processes that will allow them to co-ordinate and pool the distributed knowledge skills, beliefs and assumptions of its team members to reach common ground and consensus.
- Beers et al (2006) model of unshared to constructed knowledge is an appropriate model to use to outline the consensus process as it shows how teams reach common ground. While knowledge processing is required the model
does not highlight the other cognitive process and conversation activities used to support this process.

- Conflict has been identified as potentially having either a positive or negative effect on reaching consensus.
- Expertise is thought to be a factor in a team’s ability to navigate the design process and reach consensus.

A number of these themes important to the research area have been selected to form the constructs and propositions that built a preliminary conceptual model.
3 Methodology

3.1 RESEARCH METHOD

This chapter presents the research approach taken to meet the objectives of the thesis as outlined in Chapter 1. A comprehensive, literature review was undertaken in Chapter 2 to understand consensus reaching in design teams. This led to a preliminary conceptual model which highlights the factors involved in consensus reaching in design. This chapter outlines the aim and research questions. This is followed by an explanation of the methodology chosen, and why a case study approach was used. The data collection and analysis methods used are then outlined. The measures taken to ensure validity and reliability are also addressed.

3.1.1 Research aim and questions

As outlined in Chapter 1;

The aim of this research is **to understand how consensus is reached during the initial phases of design and how it is negotiated within design teams.**

This can be broken down into the following research questions as stated in Chapter 1:

1. What are the cognitive processes and conversation activities used by teams during the initial phases of design?
2. How do the cognitive processes and conversation activities used by teams enable consensus during the initial phases of design?
3. What is the impact of different design phases on reaching consensus?
4. What are the differences between how experts and novices reach consensus?
5. How does conflict impact on consensus reaching in design teams?

3.2 RESEARCH DESIGN

This section gives a justification for the research approach taken describing the methodology chosen and the data collection methods used. The research takes a mainly inductive approach using case studies to integrate and extend existent theory to build on the literature as outlined in Chapter 1. An inductive approach can lead to the building of theory (Cohen et al. 2007) and is primarily concerned with the way events take place to better understand the nature of a situation or problem (Yin 1994).
3.2.1 Case study research

This research uses case studies to study design teams working on real projects in their normal environment and focuses on the dialogue of the participants to understand the cognitive activity of the teams. A cumulative or multiple case study approach was taken to explore similarities and differences within and between the cases. The goal was to replicate findings across cases (Yin 1994).

“In general, case studies are the preferred strategy when “how” or “why” questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context. (Yin 1994).

Case studies are particularly suited when the contextual conditions are believed to be relevant to the phenomenon under study (Yin 1994). As the research focus is on how teams interact in design it is necessary to study the participants within context to get an in depth insight into the activities used. The purpose of using a case study is to probe deeply and analyse intensively the make-up of a particular unit to draw generalizations about the wider population to which it belongs (Cohen et al. 2007). Case studies are often used to indicate best practice (Blaxter et al. 2006) and are a connection to real life experiences that sharpen thinking and inform decision making (Breslin and Buchanan 2008). They have been widely used where there is a constant need to learn new techniques and align theory and practice. (Breslin and Buchanan 2008). Case studies focus on exploring, in as much detail as possible, smaller numbers of instances or examples which are seen as being interesting or illuminating, and aim to achieve ‘depth’ rather than ‘breadth’ (Blaxter et al. 2006). The research is concerned with understanding behaviour from the researcher’s own frame of reference, it allows the researcher to get close to the data and carry out deep research using small case study samples (Robson 2002). Case studies are apt to understand design cognition and have been used by other researchers such as (Yilmaz and Seifert 2011) to understand the cognition of expert designers during sketching, (Bowen et al. 2016) to understand design cognition in creative practices and (Ferreira and Lacerda dos Santos 2009) who used a case study and discourse analysis to understand the cognitive processes of students to develop an online scaffolding support for knowledge advancement. Case studies are an appropriate strategy for enriching or extending theory while accommodating existing theory (Yin 1994). Eisenhardt (1989) recommends the researcher to have a prior specification to gain more accurate insights of the phenomenon under study. Burawoy (1991) describes a similar approach of prior specification, the ‘extended case methodology’ This approach
builds on prior literature to integrate and extend existing theory. The literature review has provided a conceptual model as a basis for the case study research which is intended to uncover other relevant concepts and theories to extend and integrate existing theory.

An important component of case study research is defining the unit of analysis. For this research the overarching unit of analysis is the design team. There are further units of analysis which are outlined in Section 3.4. The analysis involves looking at themes and patterns within the data and comparing and contrasting this to existing theory to create new theories. This approach is described by Yin (1994) as ‘pattern matching’ where empirical patterns are compared with predicted construct relationships.

There are a number of reasons therefore why a case study approach was appropriate for this research. The case study method is suited to identify the in-depth contextual factors that may influence team interaction. It allows for the explanation of reasoning in a situation in which all of the relevant behaviours cannot be manipulated through experimental research. Designing in teams is a social activity that is impacted by the relationships and circumstances of the situation. By studying a variety of cases in different settings there is the potential to generate new theory and gather insights on design teams that may not be picked up through other research methods. The next section looks at the selection of cases.

3.2.2 Case selection

The selection of cases is an important aspect of case study research and the generalizing of case studies can be increased by the strategic selection of cases. Minimizing the variation between cases allows for the contribution to theory, while maximizing the variation helps to identify the factors that influence the phenomenon under study (Flyvbjerg 2006). For the purpose of this study, ‘maximum variation cases’ was chosen where it is desirable to obtain information about the significance of various circumstances. The “logic” underlying the use of multiple-case studies is: each case must be selected so that it either predicts similar results or produces contrasting results (Yin 1994). No two design projects are the same and differences include: the nature and focus of the project, the complexity of the project, the experience of the team, the variety of the disciplines on the team, to whether the team members are co-located. The research looks at different design and innovation settings and different project types. The focus was not just to draw out the effect of these differences but to also draw together the similarities that occurred across different cases. It was also important to select cases
that involved unstructured problems. Four cases were selected for the study. Two of these cases had 2 teams within each case. A case was bounded by the context, the project and the experience levels of the teams. Therefore if two teams worked on the same project within the same context and from similar experience levels they were part of that one case. The first case involved a bio-medical fellowship program, the second an undergraduate project, the third a professional practice case and the fourth an additional bio-medical case. All cases addressed the initial phases of the design process. Table 3.1 summarizes the four cases selected which are then discussed in more detail.

Table 3.1 Case study profile

<table>
<thead>
<tr>
<th>Case</th>
<th>Type of project</th>
<th>Stage in design process</th>
<th>Expertise</th>
<th>Team type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bio-innovate 1</strong></td>
<td>Medical device innovation.</td>
<td>Problem definition</td>
<td>Fellows, Experienced /post-doctoral level in own discipline</td>
<td>Trans-disciplinary team from Engineering, medicine, business and law</td>
</tr>
<tr>
<td>No of participants: 8</td>
<td>The Project focus was on uncovering opportunities for innovation.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2 teams of 4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Undergraduate case</strong></td>
<td>An airline crew rest</td>
<td>Problem definition, Ideation, Concept development</td>
<td>Undergraduate design students, Novice</td>
<td>Interdisciplinary team from design</td>
</tr>
<tr>
<td>No of participants: 14</td>
<td>The Project focus was on designing a user-centred crew rest for flight attendants.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2 teams of 7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Professional Practice case</strong></td>
<td>User experience software interface design. An industry project</td>
<td>Problem definition Ideation, (combined)</td>
<td>Experienced</td>
<td>Interdisciplinary team from design, engineering and business</td>
</tr>
<tr>
<td>No of participants: 4</td>
<td>The Project focus was on the redevelopment of a software program with a user-centred approach,</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1 team)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Bio-innovate 2</strong></td>
<td>Medical device innovation.</td>
<td>Problem definition, Ideation, Concept development</td>
<td>Fellows, Experienced /post-doctoral level</td>
<td>Trans-disciplinary team from Engineering, medicine and design</td>
</tr>
<tr>
<td>No of participants: 4</td>
<td>The Project focus was on uncovering opportunities for innovation.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1 team)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Bio-innovate case:
Bio-innovate Ireland is a fellowship program where trans-disciplinary teams follow an integrated design process to identify opportunities for innovations in the area of medical
devices that reflect the needs of the users and stakeholders involved. The program is modelled on the internationally-recognized Bio-design program at Stanford University. This case was selected as the program has the mission to create leaders in the area of medical device innovation and involved complex unstructured problem solving. For the project the teams were not given a predefined problem to solve or a brief outlining a specific design task but instead had to uncover several problems themselves within a particular domain and determine the ones with the most potential for an innovative and commercially viable product. The expertise on the teams came from medicine, engineering, business and law. The program is made up of three phases: identify (Problem definition), invent (Idea generation, Concept development) and implement.

The program begins with a five-week intensive boot camp on the process of innovation. The purpose of the boot-camp is to prepare the team for the full program and includes a mini project to replicate the process that the teams follow in the year ahead. This is followed by the 10 month program which starts with eight weeks clinical immersion in hospital settings. This is the ‘identify’ or problem definition phase of the process which involves observing patients and healthcare professionals in a range of clinical settings including: specialist diagnostic clinics, surgical and interventional procedures. During this phase, the inter-disciplinary teams of fellows use ethnographic methods to study the health-care professionals and their interactions with patients within that clinical environment. The fellows identify and document the problems and challenges that are encountered by all of the stakeholders. Following on from the problem definition phase the ideation and concept development phase sees the fellows process the unmet clinical needs uncovered during the problem definition phase and filter them down to a few to develop a range of solutions. Once the clinical needs have progressed through the concept development phase, the teams then consider their implementation strategy which involves commercialization of the final solution.

This research primarily presents the cognitive processes and conversation activities employed by two teams at the problem definition phase of a two week mini project during the boot-camp which was a condensed version of the full program. During the mini project the team spent one day at a Cardiovascular Disease Prevention centre (Croí) to carry out research to uncover unspoken and unmet needs amongst patients, their families and the staff at the centre.

All of the fellows studied in this research could be described as experts in their field as all had between three and fourteen years professional experience with six of the eight
fellows holding a postgraduate qualification. There were two teams of four fellows on the program and Table 3.2 summarizes the experience and qualifications of the participants.

Table 3.2: The experience and qualifications of the participants

<table>
<thead>
<tr>
<th>participants</th>
<th>Qualification</th>
<th>Years of experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team A</td>
<td>Maria: Bio-medical engineering</td>
<td>BE</td>
</tr>
<tr>
<td></td>
<td>Vakar: Medicine</td>
<td>MB, BCh, BAO</td>
</tr>
<tr>
<td></td>
<td>Wesley: Bio-medical engineering</td>
<td>MBA, + BE</td>
</tr>
<tr>
<td></td>
<td>Colm: Engineering</td>
<td>MSc + BE</td>
</tr>
<tr>
<td>Team B</td>
<td>Will: Bio-medical engineering</td>
<td>PhD + BE</td>
</tr>
<tr>
<td></td>
<td>Jack: Medicine / Bio-medical</td>
<td>PhD and MB, BCh, BAO</td>
</tr>
<tr>
<td></td>
<td>engineering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kieran: Law</td>
<td>LLB</td>
</tr>
<tr>
<td></td>
<td>Valerie: Business</td>
<td>MSc and MBA</td>
</tr>
</tbody>
</table>

The Undergraduate case:

This case was selected as it involved distributed novice student teams from different universities and countries across different design disciplines. The students involved were from Hogeschool Utrecht [HU] in the Netherlands and the University of Limerick [UL], Ireland. The teams could be described as novices. The project gave the students the opportunity to collaborate on an industry sponsored project. Real world problems, when sponsored by real stakeholders, can engage students in ways that ‘artificial’ projects do not (Mulder et al. 2012). The company sponsor “Driessen” a world market leader specializing in products and services for Cabin Interiors and Aircraft Systems. The emphasis on this project was on blue sky innovative solutions as opposed to incremental design changes.

The design brief entailed the redesign of the Crew Rest to create an improved resting experience for long haul flight crew by understanding their unmet needs. As the teams were not co-located it created an extra challenge, typical of many practice based projects. The teams had to overcome not having access to an existing crew rest.

This research primarily focused on two out of the six teams that conducted the project. Table 3.3 provides an overview of the makeup of each team.
Table 3.3 Overview of team members

<table>
<thead>
<tr>
<th>Name</th>
<th>Course</th>
<th>School</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bob</td>
<td>Product design &amp; Technology</td>
<td>UL</td>
</tr>
<tr>
<td>Rachel</td>
<td>Product design &amp; Technology</td>
<td>UL</td>
</tr>
<tr>
<td>Kevin</td>
<td>Product design &amp; Technology</td>
<td>UL</td>
</tr>
<tr>
<td>James</td>
<td>Product design &amp; Technology</td>
<td>HU</td>
</tr>
<tr>
<td>Tom</td>
<td>Industrial Engineering Management</td>
<td>HU</td>
</tr>
<tr>
<td>Matthijs</td>
<td>Communication and Media Design</td>
<td>HU</td>
</tr>
<tr>
<td>Jukka</td>
<td>Product Design &amp; Engineering</td>
<td>HU</td>
</tr>
<tr>
<td>Team B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brian</td>
<td>Product design &amp; Technology</td>
<td>UL</td>
</tr>
<tr>
<td>Lauren</td>
<td>Product design &amp; Technology</td>
<td>UL</td>
</tr>
<tr>
<td>Lisa</td>
<td>Product design &amp; Technology</td>
<td>UL</td>
</tr>
<tr>
<td>Marcus</td>
<td>Product design &amp; Technology</td>
<td>UL</td>
</tr>
<tr>
<td>Sam</td>
<td>Communication and Media Design</td>
<td>HU</td>
</tr>
<tr>
<td>Takeo</td>
<td>Digital communication</td>
<td>HU</td>
</tr>
<tr>
<td>Janus</td>
<td>Product design &amp; engineering</td>
<td>HU</td>
</tr>
</tbody>
</table>

The Professional Practice case: The third case explores a ‘real world’ industry project. The company used in the study is a user experience (UX) and user interface (UI) design consultancy that provides a range of user centred design services for websites, web applications, software, digital devices and mobile applications. The company emphasizes ethnographic research methods, cognitive psychology, behavioural analysis and task analysis to gain deep insights to the needs of users and stakeholders. This is used to drive the development of software programs with effective navigation systems and streamlined information architecture. This case was selected as the team members were also experts but the approach used was more a traditional design one in that the goals of the project were clearer and the outputs more determinable than the Bio-innovate cases. All the participants used in the study could be described as experts with several years’ experience in their field.

The company is well established and recognized and has won several awards. Their portfolio includes websites for hotels, online banking, security software for computing and other specialized applications for more targeted users. For software applications the company begin with an application that has been developed by a client’s software development team, review the navigation methods and information architecture and redesign it with the intended user in mind. The focus is on the user and supporting them to navigate through a program, understand certain terminology and iconography. The
application at the centre of the project used in this research supports sales and marketing processes to guide users on how to analyse sales prospects. It is embedded within another customer relationship management (CRM) application which is a well-established application in the CRM field. The company employs eight people and three of them took part in the research. Table 3.4 summarises the qualifications, role and experience of the participants.

Table 3.4 The experience and qualifications of the participants

<table>
<thead>
<tr>
<th>Participants</th>
<th>Qualification</th>
<th>Company role</th>
<th>Years’ experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harry</td>
<td>Industrial design (BDes)</td>
<td>Director, Interaction designer/User experience designer, software developer</td>
<td>10+</td>
</tr>
<tr>
<td>Faye</td>
<td>Industrial design (BDes)</td>
<td>Director, business requirements, Interaction designer/User experience designer</td>
<td>10+</td>
</tr>
<tr>
<td>Annette</td>
<td>Psychology (BSc)</td>
<td>Interaction designer/User experience designer</td>
<td>5-10 years</td>
</tr>
</tbody>
</table>

The Bio-innovate case 2: The fourth case explores a team at the post clinical immersion stage after the team spent 8 weeks carrying out ethnographic research to uncover needs in the area of gastroenterology. While the first three cases involved an in-depth study of the dialogue of the participants at specific stages in a project and over relatively short periods of time, this study was carried out over a five months period. All of the fellows studied in this research could be described as experts as all had between three and over ten years professional experience with three of the four fellows holding a postgraduate qualification. Table 3.5 summarizes the team’s experience and qualifications.

Table 3.5 The experience and qualifications of the participants

<table>
<thead>
<tr>
<th>Participants</th>
<th>Qualification</th>
<th>Years of experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liam</td>
<td>Bio-medical/ Electronic engineering</td>
<td>BEng, PhD</td>
</tr>
<tr>
<td>Christy</td>
<td>Medicine</td>
<td>MB BCh BAO BSc DRCOG MRCP(UK) MRCPI</td>
</tr>
<tr>
<td>Kieran</td>
<td>Bio-medical engineering</td>
<td>BEng MSc PhD</td>
</tr>
<tr>
<td>Riona</td>
<td>Industrial Design</td>
<td>BA</td>
</tr>
</tbody>
</table>
The next section addresses the analysis of the data.

3.3 DATA COLLECTION

During the four case studies the teams were studied while they worked on real projects in their natural setting to avoid the deformations that may be caused by setting a prescribed project. The raw data was audio recorded and transcribed and field notes were written during and shortly after sessions to accurately document the events. The objective in the sampling was to capture full meetings from the problem definition phase, the ideation phase and the concept development phase. This was possible only in two of the cases, the Undergraduate case and the Bio-innovate 2 case.

In the Bio-innovate 1 case there were two teams on the program and both were recorded to see if there was variation between them. It was only possible to record four hours of the team’s conversations during the problem definition phase as one participant stated a preference not to be recorded after the first day of recordings, limiting the extent of that study. Therefore all of the data for these two meetings was transcribed and analysed.

In the undergraduate case, data was recorded from six teams. Based on the project results two teams were selected for analysis: Team A, who received marks at the lower end of the marking scale and Team B who received marks at the higher end of the marking scale. The objective in the Undergraduate case was also to record the teams when they were collaborating with their distributed team members. Each of these recorded meeting was transcribed and analysed and the meetings between the two teams spanned the three phases of the process.

In the Professional practice case the process followed was slightly different. The team did not conduct separate problem definition, ideation and concept development meetings. The meeting recorded was predominantly a problem definition meeting, where during the course of an evaluation of the client’s application the team also developed ideas. Once decisions were made on the design directions individuals worked independently on different aspects of the project. All of this meeting was transcribed and analysed.

The first three cases collected brief but detailed accounts of the team interaction so the objective in the Bio-innovate 2 project was to capture a more prolonged period of time across the three phases of the process. As the team spent a considerable amount of
time at the problem definition phase defining needs, approximately fifteen hours of data was recorded. All of the recordings were reviewed and from that review three hours were transcribed and analysed. This meeting was selected as it was representational of the other meetings and all team members were present. One team member had been absent from many of the other meetings. Over three hours of data was recorded during ideation. One brainstorming meeting was selected where only the team members were present as the other meetings had additional people which could have impacted on the team engagement. Fifty minutes were recorded of the concept development phase and all of this meeting was transcribed and analysed. Table 3.6 gives a breakdown of the time spent in the field and amount of data recorded for each project. The field notes allowed the researcher to reflect on the data and draw out insights, hunches and feelings (Cohen et al. 2007).

As theories about the data emerged, evidence was considered that both supported and didn’t support those theories. Exemplars for each code and category were extracted from the data. Examples showing contrasting behaviour were also selected. At times the teams showed collaborative behaviour while at other times they faced instances of conflict. Samples of both of these instances were shown.

Focus was also given to sections of the data where team members elaborated on information and negotiated an understanding. This was also contrasted with examples that showed where consensus was reached without much elaboration or negotiation. Examples were also selected to show the full breadth of the cognitive processes and conversation activity used. Finally, examples were also selected which showed where there was limited cognitive processes and conversation activity used.
Table 3.6 Research methods by project

<table>
<thead>
<tr>
<th></th>
<th>Bio-innovate 1</th>
<th>Undergraduate</th>
<th>Professional Practice</th>
<th>Bio-innovate 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data collection</strong></td>
<td>Data collected over 4 days</td>
<td>Data collected over 4 weeks</td>
<td>Data collected over 2 days</td>
<td>Data collected over 5 months</td>
</tr>
<tr>
<td></td>
<td>Approx. 4 hrs of conversation was recorded and analysed of 2 teams</td>
<td>Approx. 5 hrs of conversation was recorded and analysed of 6 teams</td>
<td>Approx. 1.5 hrs of conversation was recorded and analysed of 1 team</td>
<td>Approx. 20 hrs of conversation was recorded and of that 5.5 hrs were transcribed and analysed of 1 team</td>
</tr>
<tr>
<td><strong>Meetings Analysed by topic segments</strong></td>
<td><strong>Problem definition:</strong> Team A: 1Hr 40min 54 topic segments</td>
<td><strong>Problem definition:</strong> Team A: 40 min 13 topic segments Team B: 46 min. 11 topic segments</td>
<td><strong>Problem definition/ Ideation:</strong> Team 1: 1.5hrs 40 topic segments</td>
<td><strong>Problem definition:</strong> Team 1: 3hrs 48 topic segments</td>
</tr>
<tr>
<td></td>
<td><strong>Problem definition:</strong> Team B: 1hr 52min 40 topic segments</td>
<td><strong>Ideation:</strong> Team B: 1Hr 34 topic segments</td>
<td><strong>Concept development:</strong> Team A: 30min 15 topic segments</td>
<td><strong>Concept development:</strong> Team 1: 50min 35 topic segments</td>
</tr>
</tbody>
</table>

Total topic segments 1 in all cases: 330

The next section addresses the analysis of the data.

**3.4 ANALYSIS METHOD**

The first step in the data analysis process was the organization of the data (Gray 2009). The data was arranged in order of the timeline of the project process. Team conversations were audio recorded, transcribed and imported to NVIVO and arranged per case study.

**3.4.1 Content analysis**

Content analysis (CA) was the method used to analyse the data. Content analysis describes a number of analytical approaches ranging from impressionistic, intuitive, interpretive to systematic, strict textual analyses, to analyse text data (Rosengren 1981). The method focuses on the characteristics of language as communication, with attention to the content or contextual meaning of the text (Budd et al. 1967, McTavish and Pirro

---

1 A topic segment is the unit of analysis for the research as defined in section 3.4.3
Content analysis can go beyond merely counting words for the purpose of classifying large amounts of text into an efficient number of categories that represent similar meanings (Weber 1990). The goal of content analysis is “to provide knowledge and understanding of the phenomenon under study” (Hsieh and Shannon 2005). In this study, content analysis is defined as a research method for both the subjective and the deductive interpretation of the content of text data from conversations, through the systematic classification process of coding and identifying themes or patterns.

Therefore two approaches to content analyses were used in the study, conventional (inductive), and directed (deductive) and both interpret text data from a predominately naturalistic paradigm (Hsieh and Shannon 2005). In the conventional approach, using preconceived categories is avoided and the categories and labels for categories emerge from the data (Kondracki et al. 2002). Data analysis starts with reading the data repeatedly to achieve immersion and an overall sense of what is happening. The data is then read word by word to derive codes by first highlighting the words that appear to capture key thoughts or concepts (Patton 2002, Miles and Huberman 1994). Notes of first impressions, thoughts, and initial analyses are then made. As this process continues, labels for codes emerge that become the initial coding scheme. Codes are then sorted into categories based on how different codes are related and linked (Robson 2002, Patton 2002). This was the approach taken to understand the conversation activity used by the teams to progress through the design process.

While the research was predominantly inductive the literature review and conceptual model provided four overarching cognitive processes to expect within the data; knowledge processing, critical thinking, creative thinking and meta-cognition. These provided higher order categories to then inductively explore the conversation activities that make up these four process types. A directed approach was also applied to the data. The goal of a directed approach to content analysis is to validate or extend conceptually a theoretical framework or theory. Content analysis using a directed approach is guided by a more structured process than in a conventional approach (Hickey and Kipping 1996). Using existing theory or prior research, key concepts or variables are identified as initial coding categories (Potter and Levine-Donnerstein 1999). Definitions for each category are determined using the theory. Coding with this approach can begin immediately with these predetermined codes (Hsieh and Shannon 2005). The use of rank order comparisons of frequency can also be applied to categories defined by this approach (ibid).
The flexibility of CA is therefore suited to this study which aims to interpret the cognitive processes and conversation activity that enable teams to reach consensus in design. By analysing team member’s turns of talk (Hutchby and Wooffitt 2008) this can show how teams share diverse information, negotiate shared understanding and agree. CA can also show how conflict is responded to and managed within teams.

The first step in the analysis was to divide the data into units for analysis.

3.4.2 Identifying topic segments

Yule and Brown (Yule and Brown 1983) suggest that a topic may be defined or characterised in what they describe as a topic framework. This includes what the conversation is about, including the aspects of the context that are included in the text. In order to divide up a lengthy recording of conversational data into topic segments which can be investigated in detail, the analyst must make intuitive decisions about where one part of a conversation begins and ends (Yule and Brown 1983). Conversations usually cover a number of topics and involve shifts from one topic to the next. The identification of these topic shifts was the means of dividing up data into segments for analysis (Yule and Brown 1983). This is the point at which the shift from one topic to the next is marked. Ochs, Keenan and Schieffelin (1976) differentiate between continuous and discontinuous discourse. A speaker may either:

- retain and continue a previous topic,
- shift a topic by retaining an aspect of the topic in the shifted topic or
- change the topic by introducing a new subject

There is not always a clear dividing line between topic shift and topic change and this depends on the level of connectedness between the topic segments. A high degree of connectivity between segments indicates a topic shift while a low level indicates a topic change. In a topic shift the previous topic is not recognizably closed by mutual consent. Before a topic is changed participants will normally aim to reach mutual agreement (Bublitz 1988). Agreement however is not necessarily a requirement for a topic shift as it is a much more subtle transition. There are indications of topic changes in that by closing one topic a speaker may summarise what has been said, they may paraphrase it or make a concluding evaluation. Topic changes may also be indicated by a question, request or a proposal. Examples of phrases that suggest a topic change are: that’s that; now then, what about, or dropping that, how is (Yule and Brown 1983). The occurrence
of fillers such as: *well, mmm, you know, er*, can also indicate topic change (ibid). Topic shifts are more difficult to define as usually the participants move from the previous topic by sequences of digressions that occur naturally (Bublitz 1988).

Topic shift and topic change were considered to be appropriate means of marking topic segments and analysing consensus in teams as topical changes or shifts tend to come about through cooperation, maintaining common ground and agreement (Bublitz 1988). Therefore participants must explicitly endorse or permit a change by a speaker. The purpose of this study is to understand the turns of talk within topic segments and the activities used to reach consensus as discussed in the next section.

### 3.4.3 Analysis of topic segments

In this study the inter-personal communication during naturally occurring design meetings and informal interaction e.g. (Luck 2013, Deken et al. 2012) was analysed. The analysis was based on a verbatim transcript of the team interactions, where the reasoning of the participants was displayed through the turns of talk (Koschmann 2011, Matthews and Heinemann 2012). The data was first divided into units of analysis; episodes of topical cohesion which formed the topic segments. Breaks between topic segments were decided upon inductively by ascertaining topic shifts or topic changes. In conversation people require positive evidence of having been understood. Acknowledgements are the most obvious sign of positive evidence and often marked by utterances such as: *uh, yeah, yes, mm, and Ok* (Bublitz 1988). Acknowledgements can involve a participant repeating another’s utterance as a confirmation (Clark and Brennan 1991). The conversational means by which a topic shift or topic change occurred was identified and assessed with regard to whether the topic was concluded and if the participants reached a verbal mutual agreement before the topic was shifted or changed. When this occurred at the transition from one topic to the next, it can be assumed that the team members had achieved sufficient agreement to progress to the next topic. As the focus of the analysis is to determine the activities teams use to progress through the design process, evidence of mutual agreement would indicate that the conversation activities are effective in negotiating shared understanding and agreement amongst the participants. The following are examples of topic changes and shifts that were identified:

In the first example the team from the Bio-innovate 2 case were scoring their research findings to identify priority needs. The topic concludes with an agreement on the score. Kieran closes the topic with “we can move on” Christy then introduces the next topic
Kieran: that's fine it's a 4.
Liam: yeah a 4 is a good score.
Kieran: we can move on.

*Topic change*

Christy: There is a need for a more comfortable way for a child to be tested for Coeliac disease.

Likewise in the following example from the Undergraduate case, a topic is concluded with agreement on an aspect of the project and how to proceed. The topic is then changed by asking other team members if they want to bring up anything else.

Lauren: Exactly
Brian: it's something we can explore. We won't set it in stone yet, yeah definitely.

*Topic change*

Brian: Did you want to bring anything else up lads?

The following example from the Professional practice case is less explicit in terms of the change in topic and can be described as a topic shift. The word OK is the indicator that Harry has shifted the topic to discuss the political map.

Faye: maybe they restrict through their methodology?
Harry: Maybe I don’t know, it's just a question for them.

*Topic shift*

Harry: Ok, political map, there’s a major restriction with these tool bars here. It’s kind of floaty and I know it’s often a way of doing that kind of stuff. It doesn’t work here.

The next section addresses how the data was analysed to uncover the cognitive processes and conversation activities used.

### 3.4.4 Coding of cognitive processes and conversation activities

Each utterance within each topic segment was analysed to identify the cognitive processes as defined in the literature and conversation activities used. An inductive approach was used first where utterances were coded to themes allowing for the discovery of patterns and broad areas to emerge (Cohen et al. 2007). Segments of the transcript were often coded to more than one category. Themes found in the first study were used as a framework to guide subsequent studies which looked for both those themes and new themes. As new themes were found in subsequent cases earlier cases
were again revised to check for omissions. The four steps of the coding steps are described as follows and examples are taken from the Bio-innovate 1 case:

**Step 1 open coding.** This involved inductive open coding of the data (Robson 2002) to allow categories to emerge. The data was first read several times and initial sense was made of what was going on in the team meetings. Initial comments and themes were assigned to the data inductively. Key words and sentences that led to important topics, variables or factors that were relevant to the research questions were identified to form the initial codes. Examples of themes were where the team may have been planning what they were going to do or where the team were explaining information. New codes and categories were created until all the data was coded. In the following segment in Table 3.7 Team A are establishing the information needed from the Croí organisation, the focus of their project. The open codes are shown with initial comments that describe what was happening in the text.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Colm:</strong> Did they stick to the program, what did they find tough about the program? You were told to give up smoking, or you were told to run two miles.</td>
<td>Scenario, building on, planning</td>
</tr>
<tr>
<td><strong>Waquar:</strong> Exactly, I was told to run two miles even though I have a bad hip, that kind of thing.</td>
<td>Scenario, building on, planning</td>
</tr>
<tr>
<td><strong>Colm:</strong> So what we have looked at is general information about them, the program... What about the specific tests they have done? Were they painful, were they tough?</td>
<td>Building on, evaluating, planning</td>
</tr>
<tr>
<td><strong>Wesley:</strong> I wouldn’t say painful, word it about their experience of the test.</td>
<td>Arguing, perspective of others, evaluating</td>
</tr>
<tr>
<td><strong>Colm:</strong> Yeah perfect.</td>
<td></td>
</tr>
<tr>
<td><strong>Wesley:</strong> Look at this now, go broad, probe deeper. We’re probing deeper now.</td>
<td>Evaluating, monitoring</td>
</tr>
<tr>
<td><strong>Colm:</strong> We’re only going to get three or four minutes. I think these are enough questions. We can only push so far.</td>
<td>Evaluating, monitoring, planning</td>
</tr>
<tr>
<td><strong>Wesley:</strong> Remember these patients have been screened so they have said yes and in all likelihood they will be responsive.</td>
<td>Elaborating, explaining, arguing</td>
</tr>
<tr>
<td><strong>Colm:</strong> Yeah.</td>
<td></td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

All of the data was coded in this way and in summary there were 20 different codes identified across cases as listed in Table 3.8.
### Table 3.8 Summary of open coding

<table>
<thead>
<tr>
<th>Open codes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Elaborating/explaining</td>
<td>To make something clear to someone by describing it in detail.</td>
</tr>
<tr>
<td>2. Clarifying</td>
<td>To make clear or easier to understand. To clear confusion or uncertainty</td>
</tr>
<tr>
<td>3. Domain knowledge</td>
<td>Specialist and expert knowledge of a particular domain,</td>
</tr>
<tr>
<td>4. Reference to prior experience</td>
<td>Using prior experience, from life experience or a particular case</td>
</tr>
<tr>
<td>5. Stories</td>
<td>Relating prior experience or knowledge through a narrative.</td>
</tr>
</tbody>
</table>
| 6. Analogies                           | Transferring information or meaning from a particular subject (the analogue or source) to another subject (the target).  
 e.g.: Comparing the shape of a car to a fish. |
| 7. Informed opinions                   | Statements based on their prior experience, expertise or knowledge.  
 Statements beginning with I think or I believe etc. |
| 8. Assumptions                         | Speculate, make a conjecture.                                                                  |
| 9. Analysing                           | To study or examine something in detail, in order to discover more about it. Inference, judging, interpreting. |
| 10. Questioning                        | Where a practice or information is not taken for granted but considered and questioned.         |
| 11. Arguing                            | Give reasons for or against an idea, action, or theory, typically with the aim of persuading others to share one's view. |
| 12. Mental simulation                  | Where a sequence of interdependent events is consciously enacted or run through mentally to determine cause and affect relationships. |
| 13. Scenarios                          | Creating a mental picture of how someone would behave or feel in a certain situation. Imagining and predicting a situation. |
| 14. Perspective of others              | Showing empathy for others or understanding how another might experience a situation.           |
| 15. Idea generating                    | Putting forward ideas or proposed solutions. divergent and lateral thinking                    |
| 16. Building on                        | Building on another’s thoughts and ideas.                                                      |
| 17. Humour                             | Banter, joking and the use of lateral thinking that enabled the teams to create wild ideas that challenged conventional thinking. |
| 18. Planning                           | Where someone makes a reference to forming a plan or approach to carrying out the project. Identifying the requirements, dividing the problem into sub-problems and strategizing how to conduct the project e.g. Gathering data, prioritising the requirements. |
| 19. Monitoring                         | Engaging in periodic review of the progress of the project. Supervising activities to ensure they are on course. |
| 20. Evaluating                         | Sum up. Appraising or judging aspects of the problem and whether the work carried out meets the requirements of the project, judging what progress has been made. |

**Step 2 Consolidated coding.** The next step was to consolidate codes. To ensure reliability and validity the codes were subjected to the constant comparison method of
Corbin and Strauss (2008) to assess if the categories were distinct from each other. Categories were then merged and consolidated where appropriate. In constant comparison, the researcher generates theory inductively by coding and making categories. As new data is analysed a cycle is created where a comparison and reflection on ‘old’ and ‘new’ material is repeated several times. It is only when new material does not create a new category is the analysis saturated. Any new material can be assigned to existing categories.

On examining the open codes it became apparent that many of the open codes could be categorised as the primitives that make up the four cognitive processing types of; knowledge processing, critical thinking, creative thinking and meta-cognition or categorised as the conversation activities that supported these cognitive processes. As defined by the literature elaborating/ explaining and clarifying are components of knowledge processing (Beers et al. 2006) and were consolidated into this category. During knowledge processing to communicate with others information must be elaborated on, explained and clarified. These codes were consolidated into knowledge processing. As defined by the literature analysing, questioning, (Choi and Lee 2009, Hung et al. 2008), informed opinions and assumptions with regard to the task (Facione 1998) are components of critical thinking and therefore merged into critical thinking. Where these activities were directed at the team performance they were defined as meta-cognition. The literature has also defined planning, monitoring and evaluating as components of meta-cognition (Flavell 1979, Schraw et al. 1995) and were therefore consolidated in to that category. Idea generating is about the creation of a solution and specific to creativity and was therefore merged to creative thinking. The remaining codes were not specific to a cognitive process and were distinct in their own right and defined as conversation activities that could support any of the four main cognitive processes. Some of these remaining codes were also merged due to similarities and when they were repeatedly coded to the same data; reference to prior experience was merged with domain knowledge. Both of these codes related to expertise and knowledge and were therefore merged. The use of stories was found to reflect domain knowledge or used to convey analogies. Stories were therefore merged either into domain knowledge or analogies. Scenarios by their nature are human centred and used to convey the perspective of others. On examination of the codes perspective of others was found to be embedded in scenarios and was therefore merged to scenarios. Humour was dropped as a category due to infrequent use. Table 3.9 lists a summary of the codes that were primitives of the four higher order codes and the consolidated codes that could be described as the conversation activities that support the cognitive processes.
Table 3.9 categorising of open codes into cognitive processing and conversation activities

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Primitives</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td>It involves elaborating/explaining, clarifying and exchanging information.</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td>It is made up of analysing, judging, evaluating, inferring, interpreting and convergent thinking. It involves, logical reasoning, comparing, questioning, inferring, hypothesising and appraising. It includes making Informed opinions/assumptions with statements beginning with I think or I believe etc.</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td>It is made up of idea generating, lateral thinking, imaginative and divergent thinking. Creative thinking means thinking about new things or thinking in new ways. It involves seeing existing situations in a new way, and making new links that generate a positive outcome. This includes: sifting and refining ideas or combining unrelated ideas to discover possibilities.</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td>It involves Planning, monitoring and evaluating oneself or the team.</td>
</tr>
</tbody>
</table>

Table 3.10 Example of top level codes Bio-innovate 1 Team A

<table>
<thead>
<tr>
<th>Domain knowledge</th>
<th>Specialist and expert knowledge of a particular domain including: Stories or reference to prior experience, or a particular case.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analogies</td>
<td>Transferring information or meaning from a particular subject (the analogue or source) to another subject (the target). e.g.: Comparing the shape of a car to a fish.</td>
</tr>
<tr>
<td>Arguing</td>
<td>Give reasons for or against an idea, action, or theory, usually with the aim of persuading others to share one's view. Includes: Questioning practices, not taking information for granted.</td>
</tr>
<tr>
<td>Mental simulation</td>
<td>Where a sequence of interdependent events is consciously enacted or run through mentally to determine cause and affect relationships.</td>
</tr>
<tr>
<td>Scenarios</td>
<td>Creating a mental picture of how someone would behave or feel in a certain situation. Imagining and predicting a situation. Scenarios enable empathy and understanding the perspective of others by understanding how another might experience a situation.</td>
</tr>
<tr>
<td>Building on</td>
<td>Building on another’s thoughts and ideas.</td>
</tr>
</tbody>
</table>

The next step involved deductively coding the utterances to the four cognitive processing types of: knowledge processing, critical thinking, creative thinking and meta-cognition. While each utterance generally defaulted to only one of the categories there was some overlap for example where an utterance could include both knowledge processing and critical thinking. Table 3.10 provides an example.
Colm: Did they stick to the program, what did they find tough about the program? You were told to give up smoking, or you were told to run two miles.

CT, MC

Waquar: Exactly, I was told to run two miles even though I have a bad hip, that kind of thing.

CT,

Colm: So what we have looked at is general information about them, the program, what about the specific tests they have done? Were they painful, were they tough?

CT, MC

Wesley: I wouldn’t say painful, word it about their experience of the test.

CT, MC

Colm: Yeah perfect

Wesley: look at this now, go broad, probe deeper. We’re probing deeper now.

MC

Colm: We’re only going to get three or four minutes. I think these are enough questions. We can only push so far.

MC

Wesley: Remember these patients have been screened so they have said yes and in all likelihood they will be responsive.

CT

Colm: Yeah

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

Step 3 Axial coding. This involved coding on and linking the conversation activities to the cognitive processes within each utterance. The data was examined to see if a conversation activity was used as, knowledge processing, critical thinking, creative thinking or meta-cognition in the particular instance of use. Table 3.11 provides an example. While the conversation activities may have been used frequently in one category they were also used across all of the four categories. See Appendix A for examples of data analysis.

Table 3.11 Linking the conversation activities to the cognitive processes Bio-innovate 1 Team A

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colm: Did they stick to the program, what did they find tough about the program? You were told to give up smoking, or you were told to run two miles.</td>
<td>CT, MC</td>
<td>Scenario, Building on,</td>
</tr>
<tr>
<td>Waquar: Exactly, I was told to run two miles even though I have a bad hip, that kind of thing.</td>
<td>CT,</td>
<td>Scenario, Building on,</td>
</tr>
<tr>
<td>Colm: So what we have looked at is general information about them, the program, what about the specific tests they have done? Were they painful, were they tough?</td>
<td>CT, MC</td>
<td>Building on,</td>
</tr>
<tr>
<td>Wesley: I wouldn’t say painful, word it about their experience of the test.</td>
<td>CT, MC</td>
<td>Arguing</td>
</tr>
<tr>
<td>Colm: Yeah perfect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wesley: look at this now, go broad, probe deeper. We’re probing deeper now.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colm: We’re only going to get three or four minutes. I</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

83
think these are enough questions. We can only push so far.

**Wesley:** Remember these patients have been screened so they have said yes and in all likelihood they will be responsive.

**Colm:** Yeah

*KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition*

The next part of the analysis involved analysing how the cognitive processes and conversation activities enabled the teams to reach common ground and consensus to move forward in the process.

### 3.4.5 Identification of how the activities enabled consensus

This involved re-examining the cognitive processes and conversation activities to discover intentions, functions and consequences of their use and how they mapped to the conceptual model to enable consensus. This involved examining the turns of talk within each topic segment to understand how each utterance contributed to subsequent utterances.

Consensus was analysed on a number of levels during topic segments:

- Consensus on meaning where agreement was reached on the intended meaning of a contribution. This is the point of shared knowledge in Figure 2.4.
- Consensus on position where agreement was reached on the position and opinion about a contribution. This is the point of common ground in Figure 2.4.
- Consensus to make a decision. This follows common ground in Figure 2.4.

Also of interest was to examine incidences where there was conflict, disagreement or a lack of consensus. Conflict was defined as a disagreement between one or more participants that was disputed over a number of utterances within topic segments.

Figure 3.1 outlines a summary of the data analysis.
The next section addresses the validity and reliability of the research approach to ensure that the methods adopted were appropriate and effective.

3.5 RELIABILITY & VALIDITY

Qualitative validity can be addressed through;

“The honesty, depth, richness and scope of the data achieved, the participants used and the extent of objectivity (Gray 2009).”

3.5.1 Reliability

Reliability refers to the degree to which the findings can be replicated if further studies are to be carried out. CA was the main mode of analysis and language is not like a scientific instrument and can have many interpretations and meaning. Coding practices often rely on inter-coder reliability which can conceal rather than reveal the specific criteria that coders employ in order to categorise a segment of data to a particular code (Garfinkel 1967). Inter-coder reliability is better applied to deductive analysis where a positivistic approach is adopted. Deductive studies are concerned with being objective, systematic and quantitative to the point that analytical categories are defined so precisely that different coders may apply them and obtain the same results (Kassarjian 1977). Part of the coding relied on deductive analysis in that the researcher looked for four specific themes in the data; knowledge processing, critical thinking, creative thinking and meta-cognition. An inter-rater reliability study was conducted where another coder, coded a section of the data independently to descriptions of those themes as provided by the researcher. The results show a Kappa coefficient of: 0.718, See Appendix B for results.

The remainder of the analysis involved the inductive generation of themes. DA is both inductive and subjective and depends on not just the transcribed text but on the researchers understanding of the context and the meanings intended when the utterances were made. Instead of coding data to rigid predefined codes, new categories may emerge to generate new theory (Patton 2002). Researchers who employ reliability assessments defer to positivist research standards, which are at odds with the purpose of qualitative inquiry (Cook 2012). Rather than relying on reliability assessments, detailed findings give credibility to results and theoretical constructs reported can be traced back to their original sources through extracts from transcripts and examples of analytical procedures (Guba and Lincoln 1994).
However quality in qualitative research can be assessed using similar concepts of validity used for quantitative research, but these need to be adapted to take into account the distinctive goals of qualitative research (Mays and Pope 2000). Inter-coder reliability is an attempt to reduce the error and bias generated when with processing large amounts of text-based data. However, the high degree of inference required to categorize inductive qualitative data can lead to low agreement between coders (Hagelin 1999). To strengthen the reliability of the coding of the conversation activities, peer debriefing was carried out. Two colleagues were given sections of pre-coded transcripts to examine how each segment of the data was coded. Prior to categorising the transcript, both colleagues were provided with a description of each category. They were asked to either agree or disagree with the coding and to mark any changes they would make where disagreements occurred. The transcripts of each of the coders were compared to that of the researcher’s. The agreement between the researcher and each coder was 0.88 respectively. Some adjustments and modifications were made to the coding based on discussion and feedback with the checkers. Refer to Appendix C.

The effect of being observed may have altered the behaviour of participants and they may try to produce the data they think is required (Rosenthal 1966a). It was made clear to all participants during the studies that the data would not be used to evaluate them. Prior to beginning the studies consent was gained from the participants to record and use their conversations, presentations and design work from the projects, see Appendix D.

3.5.2 Construct validity

Construct validity refers to the extent to which a study investigates what it claims to investigate, that is the extent to which a procedure leads to an accurate representation of the study (Morse et al. 1994). This research studies design teams working on real projects in their normal working environment. Real situated practice allows for the natural dynamics of real events where external factors and emerging issues and constraints play a bearing on a project situation. How individuals behave in a lab setting may be very different to how they behave in a real context where there are consequences for the outputs of their efforts. Practice based approaches offer a holistic understanding of knowing and learning as dynamic, emergent and social, that are situated in specific contexts (Suchman 2000, Marshall 2007).
The capturing of team verbal interactions has been gathered by a number of researchers such as (Valkenburg and Dorst 1998, Stempfle and Badke-Schaub 2002, McDonnell 2009, Deken et al. 2012, Dong et al. 2013) and considered to be an accurate means of understanding team cognition. Oak (2011) argues that the analyses of conversation in design offers an effective approach to understand the communications and negotiations central to design. It is through conversation that information is shared and negotiated. It is also through conversation that team members can indicate to others whether they are in agreement or not. By understanding team member’s communication acts it is possible to identify the conversation activities that have led to a degree of common ground.

To understand the contextual environment which would influence the interpretation of the data the researcher was present during all data gathering.

3.5.3 Internal validity

Qualitative research is at risk of being subjective as researchers may interpret events differently and it may be difficult to prove that the data gathered is sufficiently objective to represent a true reflection of events. In order to increase internal validity a number of steps were taken. The data was recorded and transcribed for transparency to be reviewed and if necessary re-interpreted (Gray 2009).

Peer auditing helped to ensure the instance of reflexivity was minimised. The principle of negative cases was applied. This involved understanding why some processes or activities were not used or used infrequently. It also involved looking at situations where consensus was difficult to achieve. The data was also subjected to the constant comparison method of Corbin and Strauss (2008). As each of the four case studies were analysed, comparisons were made between the different sets of data and to previous cases conducted to check for patterns and ensure consistency between the findings. For example conversation activities that may have been discovered in later cases prompted a re-examination of earlier analysed cases to check for possible omissions. In addition comparisons were made to the literature.

3.5.4 External validity

External validity refers to the degree to which results can be generalised to the wider population. Generalisability in naturalistic research is interpreted as comparability and transferability (Eisenhardt 1989). Eisenhardt (1989) states that case studies can be used to develop theory and proposes that a cross case analysis involving 4 or more cases can
provide the basis for analytical generalization. It is possible to identify possible comparison groups and to indicate how data might translate into different settings and cultures. In an effort to increase generalization, four studies were carried out and comparisons were made between them to see if the findings were transferable across different settings within design.

3.6 CHAPTER SUMMARY
This chapter began with the listing of the research aims, objectives and research questions. This was followed by a discussion on the justification for the research approach taken and why a case study approach was adopted. A description of the cases used for the study was also given with reasons for their selection. The data collection and the analysis methods used were then presented. This was followed by a discussion on the measures taken to ensure reliability and validity. The next four chapters present the findings of the research carried out for each case study.
4 The Bio-innovate Case

This chapter is an in-depth study of a project undertaken during a Bio-innovate fellowship program. Following a description of the program and project undertaken in Section 4.1, the findings are presented and are divided into the following sections:

Section 4.2 presents the cognitive processes and conversation activities used during team interactions to reach consensus.

Section 4.3 describes the role of the cognitive processes and conversation activities in relation to diversity and conflict.

Section 4.4 presents the frequency of the cognitive processes and conversation activities.

4.1 CASE DESCRIPTION

As outlined in Section 3.2.3 this case involves two interdisciplinary teams of four expert fellows in the area of medical device innovation. The project began with the teams developing a mission statement for the project. They then identified known and unknown information about the project and planned the research methods for the field trip. This was followed by a day immersion at the cardio vascular centre; Croí where the teams used ethnographic methods including interviews and observations, to uncover problems experienced by the staff, patients and other stakeholders. The teams then went through a process of converting the observations and research findings to problem and then needs statements. As the fellows identified in the region of three hundred needs, filtering of the needs was conducted where each need was scored against weighted criteria.

4.1.1 Data overview

The project was carried out over 4 days for both Team A and Team B. Approximately 4 hours of conversation was recorded and analysed of both teams. The primary data to analyse the team’s cognitive processes and conversation activities their role in consensus reaching and conflict consisted of two work sessions, one with Team A and one with Team B. These meetings took place at the beginning of the project and the purpose at this stage was to define the requirements for the project, the objectives of the Croí organization and plan for the field trip to Croí. The teams were guided through four stages in the meeting as follows:
1. The development of a strategic focus statement to create a shared focus for the objectives of the project.
2. The identification of known and unknown information about Croí
3. The identification of a stakeholder list.
4. The development of interview and research questions for the field trip.

Table 4.1 describes the data.

<table>
<thead>
<tr>
<th>Description of data</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Team A</strong></td>
</tr>
<tr>
<td>Content: Audio and transcript of meeting between members of team A</td>
</tr>
<tr>
<td>Present: team A, 1 facilitator and 1 researcher</td>
</tr>
<tr>
<td>Duration: 1Hr 40min</td>
</tr>
<tr>
<td>Units of Analysis: Topic segments: 40.</td>
</tr>
<tr>
<td>Utterances of Participants: 431</td>
</tr>
<tr>
<td>Stage in process: Problem definition phase</td>
</tr>
<tr>
<td><strong>Team B</strong></td>
</tr>
<tr>
<td>Content: Audio and transcript of meeting between members of team B</td>
</tr>
<tr>
<td>Present: team B, 1 facilitator and 1 researcher</td>
</tr>
<tr>
<td>Duration: 1hr 52min</td>
</tr>
<tr>
<td>Units of Analysis: Topic segments: 56</td>
</tr>
<tr>
<td>Utterances of Participants: 503</td>
</tr>
<tr>
<td>Stage in process: Problem definition phase</td>
</tr>
</tbody>
</table>

4.2 DATA ANALYSIS

As outlined in detail in Chapter 3 the data was first divided into topic segments and instances of verbal consensus were noted within topic segments and at the end of topics. Three steps in the coding process then followed this as outlined in Chapter 3. At times there were topics that shifted without a verbal consensus and when this happened it can be assumed that there was some level of consensus to allow the discussion to progress when there were no objections to proceeding. Also of interest was to examine incidences where there was conflict, disagreement or a lack of consensus. The next section discusses these findings further and provides examples. Both teams are presented separately.
4.2.1 Team A how the activities enabled consensus

40 topic shifts were identified during team A’s meetings. Of the 40 topic shifts identified in team A’s interactions, 27 were preceded by verbal consensus. Of the remaining 13 topic shifts there was no evidence of a disagreement and the topic naturally moved with assumed agreement to address new points in the discussion. Two of the 40 topic shifts included instances where a team member returned to a previous topic which in both cases was a shift to an earlier topic that wasn’t fully expanded upon or concluded.

Table 4.2 outlines a section of the transcript as Team A were developing a strategic focus statement which was seen as “critical for everyone to buy-in to what the team was attempting to achieve”. In line with Beers (2006) model negotiation of common ground began with a contribution by Vakar who asks if stakeholders should be included in the team’s strategic focus statement. Through the externalisation of his view he is applying critical thinking by making explicit to the team that he believes they should be included. This is also coded as metacognition as he is planning ahead also. This is then internalised by the other team members causing them to consider their position and recall their own internal knowledge and respond. The topic continues with what is known as pair sequences where contributions are responded to with assessments, justifications, confirmations and elaborations (Oak 2010). Through these negotiations and elaborations, beliefs and knowledge are updated, expanded upon and revised until the team have established the variety of stakeholders involved and that ‘low cost’ is an important consideration.

In the course of the conversation the team engage in a number of cognitive processes that support the process as outlined in the conceptual model. Knowledge processing enabled them to exchange knowledge, explain, elaborate, clarify and verify. In applying critical thinking the team members’ show their analyses and negotiation of information and meta-cognition engaged them in planning and monitoring their approach. Creative thinking did not occur in this topic. A number of conversation activities also helped the team to reach common ground. Arguing allowed team members to justify their reasoning to others to expand and negotiate on the knowledge shared. Maria for example argues that the government must be considered a stakeholder “as they provide funding.” This is accepted in the following responses by Wesley and Colm who are then prompted to expand the discussion to the needs of the government. The use of domain knowledge was an important activity to verify shared knowledge, ensuring accuracy of the information. By applying his domain knowledge, Vakar was able to convey how the
‘Croi’ service operates and how it can impact on the various stakeholders. Negotiating of common ground can be afforded by making individual team members’ perspectives explicit to others (Kirschner et al. 2008). Scenarios provided explicit depictions and justification of beliefs and knowledge. By using a scenario Vakar was able to show how ‘Croi’ “helps the hospital to reduce its load of patients.” The scenario in this instance was better enabled by domain knowledge and had the effect of increasing a shared understanding. This is expressed in the proceeding statement as Wesley uses building on to support this.

The activities used in this segment were effective at reaching a degree of common ground allowing for explicit consensus within the team. The team began with unshared knowledge and beliefs. Through the use of the cognitive processes and conversation activities the members externalised their respective knowledge and beliefs, elaborated and negotiated on this to reach common ground. This is reflected in utterances of consensus marked by terms such as; exactly and fair point. This is further emphasised when Vakar repeats the utterance; “and enhance cost,” in the final line. In summary the cognitive processes used were: knowledge processing, critical thinking and meta-cognition. The activities that supported this were: arguing, domain knowledge, scenarios and building on. The activities were at times used in combination.

Table 4.2 Team A developing a strategic focus statement

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vakar: Are we going to mention any stakeholders in that sentence?</td>
<td>CT, MC</td>
<td></td>
</tr>
<tr>
<td>Colm: Stakeholders; employees.</td>
<td>KP, CT</td>
<td>Arguing</td>
</tr>
<tr>
<td>Wesley: They will enjoy low cost and low stress.</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td>Maria: The government is a stakeholder because they give funding.</td>
<td>KP, CT</td>
<td>Arguing</td>
</tr>
<tr>
<td>Wesley: they want low cost</td>
<td>CT</td>
<td>Domain knowledge</td>
</tr>
<tr>
<td>Colm: Because if the service is effective the government also win as they don’t automatically go into the hospital through re-education and change of lifestyles.</td>
<td>CT</td>
<td>Arguing, scenario,</td>
</tr>
<tr>
<td>Wesley, Vakar, Maria: Exactly CONSENSUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wesley: Yeah I like the benefits and reduced cost, that’s down the road. CONSENSUS</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td>Maria: What about the extreme stakeholders we discussed this morning?</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Colm: Fair point. CONSENSUS Well we mentioned one of them in the family? They’re indirectly influenced because they come here for the patient.</td>
<td>CT, MC</td>
<td></td>
</tr>
<tr>
<td>Vakar: Family and hospital would they be the two</td>
<td>KP</td>
<td></td>
</tr>
</tbody>
</table>
Meta-cognition played an important role in ensuring common ground by routine checks to confirm agreed positions. Table 4.3 is an example of this. The topic shifts as Wesley reflects on the team’s progress with “so where are we at now?” By using metacognition the team were ensuring a shared understanding had been reached by reviewing the strategic focus statement. The topic concludes with explicit agreement on the statement showing that common ground had been reached. Meta-cognition was the main cognitive processes used as the team members monitored and evaluated their process followed by critical thinking and knowledge processing to judge the proposed statement. Supporting conversation activities did not occur in this topic segment.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wesley: So where are we at now?</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Colm: So we still have the same mission statement.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Wesley: Can you read it? I have to hear it.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Vakar: A minute and a half left.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Colm: Observe proceedings to provide a low stress effective service at a reduced cost.</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td>Vakar: Succinct, That sound good CONSENSUS</td>
<td>CT, MC</td>
<td></td>
</tr>
<tr>
<td>Wesley: That’s nice CONSENSUS</td>
<td>CT, MC</td>
<td></td>
</tr>
</tbody>
</table>

The construction of knowledge via common ground involves a mutual process of building meaning, refining, or modifying a contribution (Baker 1994). This is reflected in Table 4.4 which shows how the team built information collectively with the activities of building on
through turns of talk to plan the interview questions for the physiotherapist at Croí. This extract begins with the team members developing questions for her which are built on by others. Building on is where one person internalises a contribution of another and either refines or develops that contribution. Through building on the team also expands the discussion to bring in new information. This is reflected in the agreement shown between the team members that they are making good progress as Wesley states “so now we are drilling down.” Vakar’s domain knowledge is again reflected in a scenario he uses to further expand on other contributions and communicate this effectively. This is in turn prompts further building on from others. The topic is concluded as Vakar agrees with the phrasing of the question. The activities used in his segment reflect collaborative behaviour as the team built a shared representation. Consensus is marked by terms used, such as; “so now we are drilling down”, “exactly” and; “yeah you could ask that exactly.” Meta-cognition was mainly used as the team planned the research questions for the field trip, followed by critical thinking as the team formed judgements about the stakeholders. In summary the activities that supported this were: building on, scenarios and domain knowledge.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maria</strong>: How long has this been the standard of care?</td>
<td>MC</td>
<td>Building on</td>
</tr>
<tr>
<td><strong>Colm</strong>: What is the exercise program?</td>
<td>MC</td>
<td>Building on</td>
</tr>
<tr>
<td><strong>Wesley</strong>: What is the regime and where are they getting it from?</td>
<td>MC</td>
<td>Building on</td>
</tr>
<tr>
<td><strong>Maria</strong>: With some patients it might be more complicated</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Colm</strong>: And they might need something else.</td>
<td>CT</td>
<td>Building on, arguing</td>
</tr>
<tr>
<td><strong>Wesley</strong>: So now we’re drilling down.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td><strong>Maria</strong>: Some issues might be very straight forward and some might be very complicated</td>
<td>MC, CT</td>
<td></td>
</tr>
<tr>
<td><strong>Vakar</strong>: Have you come across patients who use various medical devices that have an effect on your physiotherapy? If they are on long term oxygen or if they have a pace maker in there is a special kind of a bi-ventricular pace maker that patients can get provided they fit certain criteria. That kind of pacing for the heart can really improve their lifestyle, and improve their exercise program.</td>
<td>MC, CT</td>
<td>Building on, Scenario, Domain knowledge,</td>
</tr>
<tr>
<td><strong>Wesley</strong>: Have they interacted with this kind of treatment?</td>
<td>MC</td>
<td>Building on,</td>
</tr>
<tr>
<td><strong>Vakar</strong>: Exactly CONSENSUS Have they any views on that. Also adherence to treatment, adherence to whatever they suggest to patients?</td>
<td>MC</td>
<td>Building on,</td>
</tr>
<tr>
<td><strong>Wesley</strong>: How do they know they are doing it? They ask the patient is that it? Or can they visibly see it in the</td>
<td>MC</td>
<td>Building on,</td>
</tr>
</tbody>
</table>
In summary the examples shown in Tables 4.2 to 4.4 show how the cognitive processes and conversation activities facilitated the process of externalising unshared knowledge, the creation of shared knowledge to build common ground and facilitate consensus based on the establishment of common ground. The focus on this meeting was on forming a strategic focus statement for the project and planning the research questions for the field trip. A number of cognitive processes and conversation activities were used to support the process of going from unshared knowledge to shared knowledge and common ground.

4.2.2 Team B how the activities enabled consensus

56 topic shifts were identified during team B’s meetings. 32 of these were preceded by verbal consensus. Of the remaining 24 topic shifts there was no indication that topics were left completely unresolved and the topic naturally moved with assumed agreement to address new points in the discussion. Team B used similar cognitive processes and conversation activities to Team A. There were some differences between the teams in that while Team A spent more time planning Team B spent more time analysing the activities of Croí and associated medical practices. Table 4.5 outlines a segment where team B are planning the field trip to Croí. The team are trying to establish the practices and situations with regard to the patient.

In gathering the distributed knowledge Jack uses critical thinking to expand the topic. He uses a series of scenarios based on his domain knowledge to throw out a number of possibilities with regard to the patient. This is in turn prompts the other team members to externalise their own thoughts and bring new points into the discussion through building on to expand the knowledge on the patient experience. The proceeding utterance by Jack shows that shared understanding has been achieved as he concludes based on previous utterances that they now need to find out about the patient’s “lifestyle” and “risk factors.” Turns can display an analysis of prior turns and show how utterances are interpreted (Sacks 1995, Wooffitt and Hutchby 2008) and in applying critical thinking to the preceding utterance Valerie shows how she has internalised the preceding utterances to then argue that patients may be “uncomfortable about being asked about their risk factors.” A negotiation ensues. By using his domain knowledge of interacting
with patients, an analogy to a hospital environment and scenarios to provide clear examples, Jack applies critical thinking to persuade Valerie to his view. She puts forward counter arguments but concedes to some degree to Jack’s view when she concludes his argument with “yeah if they’re willing to sit there and have us ask them the questions certainly.” A level of common ground is finally achieved when Kieran builds on the previous discussions to propose a way forward with; “what program they’re on is a way of leading them into how often they have to attend.” This alleviates Valerie’s concerns and all the team members agree to this proposal. It can be concluded that the activities used were effective at sharing knowledge and beliefs to negotiate common ground and consensus. The building on activities showed that meaning was co-elaborated through turns of talk. Some of the conversation activities were combined for example scenarios were embedded with analogies. In summary the cognitive processes used were: knowledge processing, critical thinking and meta-cognition. The conversation activities that supported this were: domain knowledge, scenarios, building on, analogies, and arguing.

Table 4.5 Team B developing interview questions for the Croí field trip

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jack: what are their symptoms? Maybe there are no symptoms, so maybe there’s a family history. What are their concerns? What is bringing them there today?</td>
<td>MC, CT</td>
<td>Domain Knowledge, Scenario</td>
</tr>
<tr>
<td>All: yeah CONSENSUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valerie: What do they like or dislike?</td>
<td>MC, CT</td>
<td>Building on,</td>
</tr>
<tr>
<td>Jack: About the service</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td>Valerie: And what they have to do because most of these are probably going to be repeat patients</td>
<td>MC, CT</td>
<td>Building on,</td>
</tr>
<tr>
<td>Jack: So we need to find out about their lifestyle maybe and what their risk factors are.</td>
<td>MC, CT</td>
<td>Building on</td>
</tr>
<tr>
<td>Valerie: Yeah CONSENSUS and I’m guessing some of them might be uncomfortable about being asked about their risk factors. I don’t know.</td>
<td>MC, CT</td>
<td>Arguing</td>
</tr>
<tr>
<td>Jack: they’ll be used to it, they’re used to having these things talked about.</td>
<td>KP</td>
<td>Arguing, Domain Knowledge,</td>
</tr>
<tr>
<td>Valerie: If they look like their clamming up let’s not push the issue.</td>
<td>MC, CT</td>
<td></td>
</tr>
<tr>
<td>All: yeah, yeah. CONSENSUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jack: This is par for the course that patients get plagued by medical students, night and day in medical hospitals asking them intimate details.</td>
<td>KP</td>
<td>Domain knowledge, Analogy, Scenario</td>
</tr>
<tr>
<td>Valerie: Yeah that’s in teaching hospitals.</td>
<td>CT</td>
<td>Arguing,</td>
</tr>
<tr>
<td>Jack: These patients I imagine are well familiar with the system if they’re..</td>
<td>CT</td>
<td>Arguing,</td>
</tr>
<tr>
<td>Valerie: Yeah if their willing to sit there and have us ask</td>
<td>CT</td>
<td>Arguing, Building</td>
</tr>
</tbody>
</table>
In the segment in Table 4.6 the team are trying to establish the role of Orla the Cardiac technician at Croí in order to prepare research questions. The team uses knowledge processing to externalise and share information, critical thinking to analyse and make sense of the information and metacognition to then make a plan based on the information discussed. It is through Jack’s domain knowledge and his ability to communicate this through analogies, and scenarios that he is able to elaborate on the information and build a bigger picture for the team members of the role of Orla. When Valerie says “yeah” she is acknowledging that she understands what Jack is saying. This information helps the team to plan appropriate interview questions as Will is prompted to consider a question for Orla; “what is your background?” Jack continues to build information for the team. While the topic does not conclude with explicit agreement it can be assumed that there was some level of consensus as the team shifted to another topic without opposition by any of the team members and a level of grounding had occurred.

Table 4.6: Team B understanding the role of the cardio technician

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Jack:</strong> I think Orla was mentioned as a nurse specialist.</td>
<td>KP</td>
<td>Building on, Domain knowledge, Analogy, Scenario,</td>
</tr>
<tr>
<td><strong>Valerie:</strong> She’s a cardio tech.</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td><strong>Jack:</strong> Cause there’s a whole new area of nursing now that for example cancer is big and to have a cancer nurse specialist that would be widely available to patients that would have their mobile numbers. They’d just be able to ring in if they have any concerns. They’re very good and just work in that one area.</td>
<td>KP, CT</td>
<td></td>
</tr>
<tr>
<td><strong>Valerie:</strong> Yeah CONSENSUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Will:</strong> Out or in the home?</td>
<td>KP</td>
<td>Building on, Domain knowledge, Analogy, Scenario,</td>
</tr>
<tr>
<td><strong>Jack:</strong> In the community as well. In the hospital you have tissue viability nurses. Nurses that have post graduate qualifications in just tissue, skin and wound healing and it complements the services of the plastic surgery team. They’re limited to a point but there’s a huge amount that they can do just compared to a nurse. It sound like there’s someone out there that’s a cardiac nurse specialist. So she is probably running it and when they run into problems they probably go to the cardiologist. I’d say that’s the way it’s going to be</td>
<td>KP, CT</td>
<td>Arguing</td>
</tr>
</tbody>
</table>
Will: What is your background?

Jack: There are probably a few other nurses doing blood pressure and doing routine things and ECGs

<table>
<thead>
<tr>
<th>Will:</th>
<th>MC Building on,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jack:</td>
<td>CT Building on, Domain knowledge, Scenario</td>
</tr>
</tbody>
</table>

**KP:** knowledge processing, **CT:** Critical thinking, **CRT:** Creative thinking, **MC:** meta-cognition

In summary while Team B was at the same stage in the project their focus was slightly different. This meeting was more about the analysis of the Croí organisation and medical practices. The discourse showed an emphasis on knowledge processing in sharing information about medical practices and critical thinking to analyse the information. The team also used meta-cognition to mainly plan the research questions. The activities that supported the meeting were: domain knowledge, arguing, analogies, mental simulations, scenarios and building on.

### 4.2.3 Conclusion

This section outlines the conversation activities used by the teams to support the cognitive processing of: knowledge processing, critical thinking, creative thinking and meta-cognition and revealed how they were used to externalise unshared knowledge, generate shared knowledge, negotiate common ground to enable consensus. Six conversation activities were found in this case:

- **Domain knowledge,**
- Analogies,
- Arguing,
- **Mental simulations**
- **Scenarios,**
- **Building on**

The activities allowed the team members to share their distributed knowledge, align viewpoints, create mutual understanding and build on each other’s contributions. They enabled the teams to identify known and unknown information and issues and challenge normal practice to set the goals for the project. They also helped the teams to reflect on their progress to ensure that the process and methods used by them was effective. The activities used were team dependent evident in building on where team members built on each other’s statements. The activities were often used in combination with some activities being strengthened by the input of other activities. Most of the analogies were referred to by the medics showing a strong association to domain knowledge. Scenarios
were used to support *arguing*. *Building on* was often made up of any of the other activities.

Each topic outlined showed consensus to different degrees. Team A showed clear consensus with explicit agreement. Team B were less effusive in their agreement with one another but there were indicators that the team had reached sufficient grounding to move forward in the process as there were no objections. The next section looks at the impact of conflict on the use of the cognitive processes and conversation activities.

### 4.3 COGNITIVE CONFLICT

There was limited evidence of cognitive conflict in Team A’s discussions, however at times Team B had instances of cognitive conflict. Externalising and sharing knowledge did not automatically lead to common ground and required at times considerable negotiation and *critical thinking*. Table 4.7 is an example of a topic where Team B’s discussion is concerned about whether some referrals of patients by GPs to Croí are possibly inappropriate. The cognitive conflict that occurred was due to the differing opinions of Valerie and Jack which resulted in disagreement. Valerie believes that the current process is not effective while Jack feels that it has to be done the way it currently is. Both *argue* and counter *argue* their viewpoints relying on their *domain knowledge* to support their *arguments*. *Scenarios* were instrumental in communicating this *domain knowledge* and to support arguments by giving clear examples and justifications to arguments being made. *Analogy*es to other situations also expanded the discussion to bring in wider and related contexts.

Midway through the topic segment Jack expresses some level of common ground by conceding somewhat with; “so inappropriate referrals.” As Valerie was from another discipline she had the ability to be objective and question accepted practice. Jack the expert in the domain however was more inclined to assume that the way things were done and the process followed was the correct approach. This negotiation process using the conversation activities was instrumental in shifting Jack’s viewpoint to the possibility that some referrals of patients by GPs to Croí could be inappropriate.

The conversation continues in a collaborative manner until Jack challenges Valerie by *arguing* that it would be inappropriate to ask the cardio technician if her referrals are inappropriate and *argues* why. Valerie shows some level of agreement to this argument with the contribution; “yeah, yeah, yeah.” The negotiations continue until Jack accepts
Valerie’s position with; “It would be nice if they did more in primary care, then there would be less referrals to Croí.” What this also shows is that the grounding process is iterative and dynamic, as common ground is achieved on chunks of information, the process begins again as new information and beliefs are brought to bear.

The debate is concluded with partial agreement. While the outcome from this topic was only partial agreement the conflict that occurred had the benefit of getting team members to extract different information about the same issue (Martins et al. 2012). The conversation activities were effective for Jack and Valerie to consider new perspectives and the wider implications of the topic. Arguing with strong domain knowledge communicated through scenarios and analogies was a persuasive means of bringing about conceptual change and a degree of common ground. In summary the cognitive processes used were: knowledge processing, critical thinking and meta-cognition. The conversation activities that supported this were: domain knowledge, arguing, scenarios, analogies and building on. The activities were also regularly used in combination.

Table 4.7 Team B debate over whether all referral to Croí appropriate

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valerie: Can we go back to her for a quick sec and address one other thing that came up in the conversation? I wonder if they are doing tests how do they compare to the GP’s tests? So are they getting significantly different results to the GPs?</td>
<td>KP, CT</td>
<td>Analogy, Scenario, arguing</td>
</tr>
<tr>
<td>Jack: The cardio tech would be using the equipment that’s up on the wall there.</td>
<td>KP</td>
<td>Domain knowledge</td>
</tr>
<tr>
<td>Valerie: Yeah but the G.P refers them because they got a result that says one thing and are they getting results that are significantly different that gives rise to do something different? Because I know that in A&amp;E, I have a friend that works in A&amp;E and she says that it drives them mental number one that the G.Ps aren’t doing the tests that they should be doing and secondly the results they’re getting are complete shite compared to what the hospital is getting and part of that is that the training is tough.</td>
<td>KP, CT</td>
<td>Arguing, scenario, Domain knowledge, analogy</td>
</tr>
<tr>
<td>Jack: What kind of tests was she talking about?</td>
<td>KP</td>
<td>Arguing</td>
</tr>
<tr>
<td>Valerie: I don’t know, heart rates, ECGs and stuff that they’re not doing those but they probably should be because a lot of them are referred into the hospital. They shouldn’t be coming into the hospitals. The GPs should be doing these tests themselves.</td>
<td>KP, CT</td>
<td>Arguing, Analogy</td>
</tr>
<tr>
<td>Jack: The only thing a GP will do is a blood test or an ECG. They won’t have access to anything else and they’re not really going to be able to do troponins and acute tests like that. They’re probably referred to.</td>
<td>KP, CT</td>
<td>Arguing, Domain knowledge</td>
</tr>
<tr>
<td>Valerie: Well none of these patients are going to be doing troponins hopefully one hopes.</td>
<td>CT</td>
<td>Arguing, domain</td>
</tr>
<tr>
<td><strong>Jack:</strong> The G.P will do blood tests and ECGs and that’s why they need to refer.</td>
<td>KP</td>
<td>Arguing, Domain knowledge,</td>
</tr>
<tr>
<td><strong>Valerie:</strong> Yeah but he’s made the decision right that it needs to be referred on to Croí and are they getting the same results from the blood tests and ECGs.</td>
<td>CT</td>
<td>Arguing, Scenario</td>
</tr>
<tr>
<td><strong>Jack:</strong> The referral might be on the basis of risk factors and something like that as opposed to the results of the test.</td>
<td>KP, CT</td>
<td>Arguing, Domain knowledge,</td>
</tr>
<tr>
<td><strong>Valerie:</strong> Yeah but it goes back to are they getting a lot of referrals that they should never be getting in?</td>
<td>CT</td>
<td>Arguing, Scenario</td>
</tr>
<tr>
<td><strong>Jack:</strong> So inappropriate referrals. <strong>CONSENSUS</strong></td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td><strong>Valerie:</strong> Inappropriate referrals. Yeah so how many patients?</td>
<td>MC</td>
<td>Building on,</td>
</tr>
<tr>
<td><strong>Jack:</strong> Is this the Orla girl? Yeah I suppose if she’s being asked to do an echo.</td>
<td>KP</td>
<td>Scenario</td>
</tr>
<tr>
<td><strong>Valerie:</strong> If 15% of her patients are coming in that she feels she should never see.</td>
<td>KP</td>
<td>Building on, Scenario</td>
</tr>
<tr>
<td><strong>Wesley:</strong> I think it’s good to know where people’s time is wasted because in my last job I could easily look at things where you could spend a few grand but sometimes there’s a short sightedness there where you don’t and so finding out where peoples time is wasted is important. Do you think we have enough there?</td>
<td>CT, MC</td>
<td>Analogy, Scenario, Domain knowledge,</td>
</tr>
<tr>
<td><strong>Valerie:</strong> Yeah <strong>CONSENSUS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Kieran:</strong> I think so Yeah. <strong>CONSENSUS</strong></td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td><strong>Jack:</strong> But in one sense it’s not her decision to make whether it’s inappropriate or not cause if there’s any doubt the G.P. can sometimes refer.</td>
<td>CT</td>
<td>Arguing, Domain knowledge,</td>
</tr>
<tr>
<td><strong>Valerie:</strong> Maybe it’s because the GP have been doing different types of tests. That’s inevitable.</td>
<td>CT</td>
<td>Arguing, Scenario,</td>
</tr>
<tr>
<td><strong>Jack:</strong> If there’s a good reason. It’s a bit like doing research if there’s a good reason to do the test a negative result is as important as a positive result.</td>
<td>CT</td>
<td>Arguing, Domain knowledge</td>
</tr>
<tr>
<td><strong>Valerie:</strong> Yeah, Yeah, Yeah <strong>CONSENSUS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Jack:</strong> In that sense it’s a bit of a loaded question to ask the cardiac technician, are your referrals inappropriate? It’s not fair to say. It might be valid information to the G.P. because the patient may have presented in a very cardiac standing and symptom and it’s very important to have a negative ECG if you know what I mean?</td>
<td>KP, CT</td>
<td>Arguing, Scenario, Domain knowledge,</td>
</tr>
<tr>
<td><strong>Valerie:</strong> We can argue this one to the death but I’m fully convinced that there are lots of inappropriate referrals from GPs into other health care systems and do we need to go back and retrain the GPs on state of the art equipment? She may say it would really help if the GPs did this before they referred somebody.</td>
<td>CT, MC</td>
<td>Arguing, Scenario,</td>
</tr>
<tr>
<td><strong>Jack:</strong> Yeah <strong>CONSENSUS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Valerie:</strong> Does she feel that she would be able to screen out some of the patients. It may only be 2% and in which case it’s not worth worrying about but if its 20% of the new patients coming</td>
<td>CT, MC</td>
<td>Arguing, Scenario,</td>
</tr>
</tbody>
</table>
in maybe there is something that she would say it would be great if you did that then I wouldn’t have to worry about those patients coming in at all. And it’s just purely the knowledge or whatever.

Jack: It would be nice if they did more in primary care then there would be less referrals to Croí. CONSENSUS In one sense this equipment is expensive and it needs to be done in a dedicated centre. So most GPs don’t do any more than an ECG.

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

As shown, diverse perspectives can lead to disagreement and cognitive conflict. Conflict had a positive effect where it arose in Teams B’s discussion as it facilitated the discussion of a larger number of ideas and perspectives, the challenging of conventional thinking to bring about more flexible thinking. During conflict common ground was not automatic upon the externalizing of knowledge. This knowledge was internalised by others, reviewed and often rejected. This forced the elaboration and the negotiation of beliefs and knowledge until both parties reached common ground. Through the adoption of the activities the teams were able to carry out this elaboration and negotiation process. While the outcome of the negotiations did not result always in unanimous agreement it led to some level of common ground. The next section looks at the frequency of use of the cognitive processes and conversation activities.

4.4 THE FREQUENCIES OF THE COGNITIVE PROCESSES AND CONVERSATION ACTIVITIES DURING TEAM DISCOURSE

The number of times a cognitive process and conversation activity was used in the data was counted to give the frequency of use, see Table 4.8. The top three most frequently used activities are shaded. While most of the data was coded to a cognitive processes not all utterances came under these categories. The percentages were calculated from the total number of utterances for the meeting. The total percentage often came to more than 100% as many of the utterances could be coded to more than one cognitive process or conversation activity. There was emphasis on meta-cognition particularly planning as the teams were at the beginning of the process strategizing how to proceed. The use of metacognition was also about monitoring and evaluating the team progress and was due to the very uncertain nature of this phase. The team were planning a trip to review an organisation they had no great experience of. This is typical of more complex design tasks where a team needs to become immersed in an area they have no previous experience of. The use of metacognition was evidence of good practice in adapting to this uncertain environment (Hung 2015). These routine checks allowed the team to
adjust their approach while also ensuring common ground by making sure that all were on board with the direction the project was going.

There was some variation between the teams which was accounted for in the slight variation of the focus. Team A spent a larger portion of the activity in *planning* for the field trip to Croí. In contrast Team B spent more time analysing the activities of Croí and associated medical practices. The proportion of *knowledge processing* to *critical thinking* was similar for both teams highlighting that as knowledge is shared it is then further elaborated and analysed. There was infrequent use of *creative thinking* due to the early problem definition phase that the teams were at. The focus was to uncover the problems to address and not on generating ideas. Similar conversation activities were observed across both teams. *Domain knowledge* was used more by Team B, 19% compared with 10% for team A reflecting again the focus of Team B in explaining and analysing current practices. Team B used more *analogies* reflected in their comparisons of Croí to other medical environments. However Team A used more *Scenarios* to communicate various practices within the domain. Team B used slightly more *arguing* due to the conflict that occurred in Team B.

**Table 4.8: Model of cognitive processes and conversation activities**

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Team A Frequencies</th>
<th>Team B Frequencies</th>
<th>Total Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td>85 (20%)</td>
<td>169 (34%)</td>
<td>254 (27%)</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td>132 (31%)</td>
<td>151 (30%)</td>
<td>283 (30%)</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td>1 (0.2%)</td>
<td>13 (3%)</td>
<td>14 (1%)</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td>282 (65%)</td>
<td>267 (53%)</td>
<td>549 (59%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>500 (116%)</td>
<td>600 (119%)</td>
<td>1100 (118%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversation activities</th>
<th>Team A</th>
<th>Team B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain knowledge</td>
<td>42 (10%)</td>
<td>97 (19%)</td>
<td>139 (15%)</td>
</tr>
<tr>
<td>Analogies</td>
<td>4 (1%)</td>
<td>18 (4%)</td>
<td>22 (2%)</td>
</tr>
<tr>
<td>Arguing</td>
<td>60 (14%)</td>
<td>81 (16%)</td>
<td>141 (15%)</td>
</tr>
<tr>
<td>Mental simulations</td>
<td>1 (0.2%)</td>
<td>2 (0.3%)</td>
<td>3 (0.3%)</td>
</tr>
<tr>
<td>Scenarios</td>
<td>78 (18%)</td>
<td>71 (14%)</td>
<td>149 (16%)</td>
</tr>
<tr>
<td>Building on</td>
<td>143 (33%)</td>
<td>181 (36%)</td>
<td>324 (35%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>328 (76%)</td>
<td>449 (92%)</td>
<td>777 (83%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can be coded to more than one category

The top four most frequently used activities across the case study were: *domain knowledge, arguing, scenarios* and *building on* and supported bringing about common ground which was indicated by evidence of consensus. *Mental simulations* were
infrequently used and analogies were only limitedly used particularly by Team A. This is surprising as analogies are considered to be a feature of design practice (Ball and Christensen 2009). The Reasons for their limited use were due to the focus of the meeting and the phase the team were at in the design process. Building on was used much more than any other conversation activity and reflects the requirement to co-construct knowledge at this the phase. It depended on turns of talk as team members expanded on previous utterances to expand the problem space. This expansion of the problem state relied on domain knowledge to identify relevant and critical information. While the interaction relied on elaboration it also required negotiation to reach common ground reflected in the use of arguing and scenarios to illuminate or justify a point being made.

In terms of bringing about consensus common ground came about gradually within topics and the activities used throughout the topic had a bearing on reaching consensus. This is in line with the conceptual model which shows that the development of common ground comes through the externalising of unshared knowledge which is then internalized by the team members. Through a process of negotiation the team can then develop common ground which can lead to consensus. Therefore it wasn’t necessarily the activities used in the last few utterances that brought about consensus.

4.5 CHAPTER CONCLUSION

This case has described the cognitive processes and conversation activities used by two trans-disciplinary teams to reach consensus during the problem definition phase of a design project. It also highlights the challenges that arose for the team members, including conflict and how this was managed. The following conclusions are drawn from the findings.

The findings validate the consensus model to show that distributed knowledge is first externalised within the team. This is then internalised by other team members to create shared knowledge. Team members will then either, accept or reject the information put forward, build upon it further, refine it or negotiate a change to arrive at common ground. The process was iterative as new information was processed showing that common ground was a constantly evolving state over the course of a project. The following cognitive processes were engaged with: knowledge processing, critical thinking, creative thinking and meta-cognition. In addition six conversation activities were used to support the cognitive processes. Meta-cognition and critical thinking were
predominantly used as the teams planned and structured the project. *Domain knowledge* was critical in providing much of the knowledge needed to define the problem and better supported the other conversation activities. There were patterns in the way the activities were used with some activities embedded together.

The cognitive conflict that occurred during team interactions had a contributory effect on the team’s efforts. The activities used both created and managed this conflict. They made explicit the diverse knowledge and opinions of the team. They prompted the teams to co-ordinate their efforts to challenge and negotiate important aspects of the project ensuring flexible and collaborative thinking. This enabled the teams to uncover previously hidden problems and needs which triggered opportunities for innovation. The use of the cognitive activities had a positive effect on the management of cognitive conflict which was resolved with partial agreement. Achieving consensus however when there was conflict was more difficult as team members had to persuade and convince others to gain consensus. *Domain knowledge, arguing and scenarios* featured significantly during conflict to negotiate a shift in perspectives.
5 The Undergraduate Case

This chapter is an in-depth study of an under-graduate design project. Following a description of the project in Section 5.1, the findings are then presented and divided into the following sections:

Section 5.2 presents the cognitive processes and conversation activities used during team interactions to reach consensus.

Section 5.3 describes the role of the cognitive processes and conversation activities in relation to diversity and conflict.

Section 5.4 presents the frequency of the cognitive processes and conversation activities.

5.1 CASE DESCRIPTION

As outlined in section 3.2.3 this case involved the redesign of a Crew Rest for an industry sponsor. The case involved distributed teams of novice students from two different schools from different design disciplines.

5.1.1 Data overview

The data was collected over 4 weeks for both Team A and Team B. Approximately 3 hours of conversation was recorded and analysed of both teams. The data consisted of four meetings, two with Team A and two with Team B. These meetings took place at the following phases in the project:

Problem definition phase: This involved uncovering and understanding the issues associated with the crew rest. Attention was given to exploring not just issues associated with the physical size of the crew rest but also the deeper emotional and physiological needs of flight attendants (FAs) from diverse social and cultural backgrounds.

Ideation phase: This involved developing ideas around the needs identified at the research stage. This involved brainstorming sessions.

Concept development: This involved developing a few select ideas in further detail and then finalizing on one solution. Table 5.1 describes the data.
The teams also had to work with themes for the project: Transitions (moving between work and rest), Nurturing, Look & Feel, Flexibility, Closing Off and Service. Each team was given a theme to give direction and focus to the project. As part of the brief the teams were provided with three personas, Jasmine, Braham, and Irene, fictional characters to represent the different user types. Using these personas the teams were asked to visualise and act out scenarios to explore the activities that the personas may follow in their interaction with the crew rest.

5.2 DATA ANALYSIS

As in the first case study the data was first divided into topic segments and instances of verbal consensus were noted during and at the end of topic segments. Three steps in the coding process then followed this as outlined in Chapter 3. The findings are
presented beginning with Team A and followed by Team B and are split into the phases that were captured for each team.

5.2.1 Team A: how the activities enabled consensus during problem definition

13 topic shifts were identified during this meeting of which 10 were preceded by verbal consensus. Of the remaining 3 topic shifts there was no evidence of a disagreement and the topic naturally moved with assumed agreement to address further points in the discussion. Two of the 13 topic shifts included instances where a team member returned to a previous topic which in both cases was a shift to an earlier topic that wasn’t fully expanded upon or concluded. Table 5.2 outlines a topic segment from the meeting between the UL half of Team A. The purpose of the meeting was to identify the factors associated with the project theme ‘nurturing’.

Throughout the meeting the team members externalised their beliefs about what constitutes nurturing. The team members found it difficult at times to form these views and externalise them for the team. Rachel’s use of metacognition in this case is recognition of the lack of good progress of the team. She uses this to prompt and encourage the team with comments such as “what else” and “come on guys we really need to focus on this.” These prompts help the team members to apply critical thinking to consider how someone could feel ‘fresh’ or ‘nurtured’. The prompts were effective in getting team members to build on each other’s contributions. As one team member externalises an opinion this is then internalised and contributed to further by the other team members. As team members internalised another’s contribution it helped them to recall their own knowledge. Scenarios and analogies were two conversation activities that supported the process. For example James builds on previous utterances using a scenario to form the opinion that the users would not be happy using recycled water. Rachel further builds on this statement and uses an analogy to a product in the market place. She further builds on the subject by creating the scenario of someone changing out of pyjamas into a fresh clean suit to feel fresh. The topic concludes with Kevin’s agreement on Rachel’s contribution showing that the team had developed a level of common ground with regard to ‘freshness’.

Table 5.2 Team A exploring the project theme

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rachel: So freshness, sanitation or sanitary or whatever you want to say. What have you got?</td>
<td>K P</td>
<td></td>
</tr>
<tr>
<td>Kevin: The need to wash your hands and your face to feel fresh</td>
<td>CT</td>
<td>Scenario,</td>
</tr>
</tbody>
</table>
alive and fresh.

Rachel: So if you branch out from that so what else?  

James: Also probably fresh water because you don’t want something that’s just, someone’s washing their hand and it’s going to be filtered and washed again. You don’t want that you want fresh water.

Rachel: Like the thing they have there where they empty the waste water and they open a new thing of water. So fresh water. Come on guys we really need to focus on this. So fresh water washing hands face we’ll throw it all in there. And will the water be drinkable? You could drink it too.

Kevin: Yeah CONSENSUS

Rachel: So if you add in fresh water, drinkable. Freshness it’s about changing as well, Getting out of your pyjamas into your nice fresh clean suit. Am I wrong?

Kevin: No I agree CONSENSUS

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

Later on in the meeting the team were trying to establish a shared understanding with regard to the theme ‘hospitality’. A similar process is followed of externalising unshared beliefs which are internalised by other team members and followed by further contributions. The negotiation of common ground in this meeting was less about changing another’s contribution but more about expanding the topic and refining the shared understanding. This is reflected in several prompts by James to the other team members as he seeks to expand the topic such as “Rachel when you go into a hotel what makes you like or dislike it?” This is also shown in the series of building on statements as shown in Table 5.3 as the team co-constructs a shared understanding of what would enable hospitality. Scenarios allowed team members to expand the topic and imagine how the users would feel. They also helped the team members to communicate this by creating rich examples for the team. Analogies also helped the team to draw comparisons to other environments that would create the experience of hospitality.

Table 5.3 Team A exploring the project theme

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kevin: Do you know what would help is your attitude when you go in (to the crew rest).</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td>James: Yeah I suppose hospitality as well could be an exchange of people chatting. CONSENSUS</td>
<td>CT</td>
<td>Scenario, building on</td>
</tr>
<tr>
<td>Ron: Communication?</td>
<td>CT</td>
<td>Building on</td>
</tr>
<tr>
<td>James: Yeah, good communication. Also hospitality can be good friendship between people. If you’ve good friendship</td>
<td>CT,</td>
<td>Scenario, building on</td>
</tr>
</tbody>
</table>
you’ve got that nice feeling and to be able to relate to another person as well. What else do you want? If you go into a hotel, what makes you like it when you go in there?

**Kevin:** Atmosphere

**James:** Ok that’s another one. **CONSENSUS**

**Kevin:** If it’s nice and warm and not cold.

**James:** The people as well, the people that you’re around. Yeah so you can put people in and receptionist, waiters, staff all of that stuff. What else? Rebecca when you go into a hotel what makes you like or dislike it?

**Rachel:** Space, I went into this hotel in Galway and it was so big, you’d fit a house into it.

**James:** What would you call all that? The facilities? Is it the facilities of how people have cared for you?

**Rachel:** So facilities, functional, usable. So will we try to put these together in one mind map?

**Kevin:** Building on

**James:** Building on

**Rachel:** Analogy, Building on

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

In summary knowledge processing, critical thinking and meta-cognition helped the teams to externalise their distributed knowledge and beliefs of the individual team members to co-construct a shared understanding of the theme ‘nurturing’. The acknowledgments and agreements uttered showed that the team had developed common ground on this. The conversation activities that supported this were: perspective of others, scenarios, analogies, informed opinions and building on.

### 5.2.2 Team A: how the activities enabled consensus during concept development

The next phase of the process captured was the concept development phase. 15 topic shifts were identified during this meeting of which 11 were preceded by verbal consensus. Of the remaining 4 topic shifts there was no evidence of a disagreement and the topic naturally moved with assumed agreement to address different points in the discussion. Three consecutive topics are presented and discussed one at a time to show how consensus is reached at the end of the 3rd segment. The first as outlined in Table 5.4 is from a meeting between the UL and the HU sides of Team A. The purpose of the meeting was to discuss a concept direction as proposed by the HU half of the team. The UL half of the team were not entirely happy with the solution and the following excerpt outlines how the two sides negotiate consensus in how to proceed. Unlike the previous meeting common ground required negotiation rather than the expansion of the topic to frame an understanding.
James begins by explaining to the HU team members his rational for an alternative concept. He questions an earlier proposal by the HU half of the team which involved bunks of different sizes. He applies critical thinking and the scenario that “there will be no fighting” if all the bunks are the same in an attempt to sway the HU half of the team. A series of arguments and counter arguments are put forward between the two sides of the team to justify each stance. However in the course of the debate knowledge processing occurs as clarifications and verification are made between the team members externalising information and creating shared knowledge. Armed with this shared information James using a scenario continues to argue that there is a risk with the other half of the team’s concept, of stepping on someone’s head when getting into the top bunk. This prompts the HU team to consider this issue and a discussion takes place between them in Dutch. The topic segment until this point has shown intense negotiation upon the externalising of differing viewpoints between the sides of the team. This negotiation brings about a change in the line of utterances with the HU half of the team showing consideration for the UL position. Matthijs uses knowledge processing to request further information from the UL half of the team. A series of exchanges follows to provide this information. The topic is not concluded with agreement as James needs to suspend the meeting to confirm some calculations. While agreement has not yet been made on a concept direction the UL half of the team have managed to persuade the other half of the team to consider their position.

As the team were trying to come to a consensus on the final concept the topic involved strong negotiation to ensure that important considerations were made with regard to the concept. In summary the cognitive processes used were: knowledge processing, critical thinking and meta-cognition. The conversation activities that supported this were: scenarios, arguing, and building on.

**Table 5.4 Team A negotiate agreement on a concept direction segment 1**

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>James</strong>: We were looking at the way the bunks are laid out and the idea is that every person has the same size bunk that is at the standard size that it is at now so there will be no fighting to see who gets the best bunks and who doesn’t want to get that smaller bunk than everyone else.</td>
<td>KP, CT</td>
<td>Scenario</td>
</tr>
<tr>
<td><strong>Matthijs</strong>: There are not smaller bunks, all the bunks are equal.</td>
<td>KP</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>James</strong>: In your idea as well?</td>
<td>KP,</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Matthijs</strong>: Yeah, They are all equal. They have all the same components, the same height, the same width.</td>
<td>KP</td>
<td>Arguing</td>
</tr>
<tr>
<td>Speaker</td>
<td>Statement</td>
<td>Type</td>
</tr>
<tr>
<td>---------</td>
<td>-----------</td>
<td>------</td>
</tr>
<tr>
<td>Kevin</td>
<td>Aren’t you tapering in on the bunks at the sides?</td>
<td>KP, CT</td>
</tr>
<tr>
<td>Matthijs</td>
<td>Yeah only where your feet are.</td>
<td>KP, CT</td>
</tr>
<tr>
<td>Kevin</td>
<td>And aren’t you making the side bunks slightly smaller at one end?</td>
<td>KP, CT</td>
</tr>
<tr>
<td>Matthijs</td>
<td>Yeah at one end, that’s only where your feet go.</td>
<td>KP</td>
</tr>
<tr>
<td>James</td>
<td>So when you are climbing in to the bunk on top the person is going to be stepping where your head is going to be.</td>
<td>KP, CT</td>
</tr>
<tr>
<td>Matthijs</td>
<td>Just give us a second ok (separate conversation between HU participants in Dutch). .. Guys I just want to know how much space you can use for the sedentary zone in the crew den?</td>
<td>KP</td>
</tr>
<tr>
<td>James</td>
<td>How much space it’s going to need?</td>
<td>KP</td>
</tr>
<tr>
<td>Matthijs</td>
<td>Yes.</td>
<td>KP</td>
</tr>
<tr>
<td>Kevin</td>
<td>Its 70cm high.</td>
<td>KP</td>
</tr>
<tr>
<td>Matthijs</td>
<td>Yeah how much space you can free for the sedentary zone?</td>
<td>KP</td>
</tr>
<tr>
<td>James</td>
<td>Just give me one second. (Separate conversation between UL participants). Which sanitary, which one are we going with? Or can we do it with the other side?</td>
<td>KP, MC</td>
</tr>
<tr>
<td>Kevin</td>
<td>Its 140</td>
<td>KP</td>
</tr>
<tr>
<td>James</td>
<td>Its 140 and 160 and 120 so that’s 27m. Right for the sanitary area we are going to require a floor space of 120 cm by 50cm.</td>
<td>KP</td>
</tr>
<tr>
<td>Tom</td>
<td>Do you know how wide your shoulders are, that’s very small?</td>
<td>CT</td>
</tr>
<tr>
<td>James</td>
<td>Sorry?</td>
<td>KP</td>
</tr>
<tr>
<td>Matthijs</td>
<td>He says that 50cms is not big and if you have broad shoulders you can’t move in there.</td>
<td>CT</td>
</tr>
<tr>
<td>James</td>
<td>No I could be wrong with that, I can get back to that in the next 10 minutes or so.</td>
<td>KP, MC</td>
</tr>
<tr>
<td>Matthijs</td>
<td>Ok CONSENSUS</td>
<td></td>
</tr>
</tbody>
</table>

**KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition**

The conversation continues for a time with separate discussions between each half of the team. When the conversation resumes, see Table 5.5. James tries to persuade the HU half of the team of the benefits of the UL proposed concept. He argues to justify the proposal and Matthijs applies critical thinking to counter argue that he can’t really see that the added space benefit of the UL proposal. He then breaks off the main discussion to discuss this further with his HU team members. Through the use of a scenario Kevin is able to provide a further critical analysis of the concept and argue why it should be a certain way. Matthijs begins to show a shift towards accepting James’s argument when he requests James to show the amount of space between the bunks and the door. While the team have externalised and shared knowledge, the negotiations to reach common
ground have not yet been successful at this point as there is no agreement on a concept. In summary the cognitive processes used to reach this stage were: knowledge processing, critical thinking and meta-cognition. The conversation activities that supported this were: scenarios, and arguing.

Table 5.5 Team A negotiate agreement on a concept direction segment 2

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>James</strong>: Just what we were saying was we were just coming up with a few ideas of layout there a minute ago. We were just coming back to our concept of the crews den. We just feel it gives us the right amount of space. A good layout for the bunk it gives us good space for the sanitary area and it also gives us space for the crew themselves if they want to walk around and for movement down below in the crew rest. So if we turn on our camera we will give you a walk around of the model. Is that ok with ye.</td>
<td>KP, CT, MC</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Matthijs</strong>: Ok CONSENSUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>James</strong>: So can you see the camera now guys. The main thing is, it’s not a big change what we are doing inside it’s just the movement of the bed from over here to here Ok?</td>
<td>KP,</td>
<td></td>
</tr>
<tr>
<td><strong>Matthijs</strong>: Yes, you say you have much more space to enter the bunks, but I can’t really see that but, (separate conversation between HU participants in Dutch). ..</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Kevin</strong>: If you have it here your limiting the space to get into the lower bunks down in here, you can only get in through this material and the same for above and if you have both leg room at the bottom so the persons head is going to be here so you’re going to be stepping on their head getting into the top bunk. And if you move it to this side you’ll have the whole bottom bunk to get into, all that area and the same for the top. And with the person’s head here and the step for the person to get up here. So their head is up here and it’s the same on the opposite side and then you have all the area too on this side too to get into both bunks.</td>
<td>KP, CT</td>
<td>Scenario Arguing,</td>
</tr>
<tr>
<td><strong>Matthijs</strong>: OK just go through the door. How much space is between those two bunks if you need to go through the door.</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td><strong>James</strong>: There you go that’s the space</td>
<td>KP</td>
<td></td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The topic shifts then to bring in further elements to the discussion, see Table 5.6. Rachel begins the topic using an analogy of being “rounded like pods” to explain a drawing. Both James and Kevin build on this to further explain and argue for the solution. The
discussion concludes with a clear consensus between the team members which is expressed when Matthijs says: “The idea is great because it is just a slight change from our idea.” This is in contrast to the beginning of the meeting which started with the UL half of the team expressing concerns about the HU half of the team’s proposed solution. It was again evident that at times the distributed nature of the teams and the language barrier meant that the communication was reduced simply to relaying information and thus knowledge processing. It was difficult for the distributed team members to design together and much of the communication involved repeated explanations. However through the use of the cognitive processing and activities the team was able to finally reach common ground and get a consensus on a final concept direction. Consensus was only reached following a thorough elaboration and negotiation of the relevant information. In summary the cognitive processes used were: knowledge processing, critical thinking and meta-cognition. The activities that supported this were: analogies arguing and building on. Tables 5.4, 5.5 and 5.6 have provided three topic segments which show how the activities over the three topic segments supported the teams in a process of externalising unshared knowledge, to the creation of shared knowledge and in turn the negotiation of common ground to enable consensus on a final concept.

Table 5.6 Team A negotiate agreement on a concept direction segment 3

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rachel: If you take into consideration the drawing you sent us. You know the way they are all kind of rounded like pods?</td>
<td>KP</td>
<td>Analogy</td>
</tr>
<tr>
<td>Tom: Sorry?</td>
<td>KP,</td>
<td></td>
</tr>
<tr>
<td>Rachel: You know the way they are all rounded?</td>
<td>KP,</td>
<td></td>
</tr>
<tr>
<td>James: They are rounded at the edge, they are circular at the edge. We are doing that with these bunks here.</td>
<td>KP,</td>
<td>Building on</td>
</tr>
<tr>
<td>Kevin: it will be easier to go through the bunks then.</td>
<td>KP, CT</td>
<td>Arguing, Building on</td>
</tr>
</tbody>
</table>

| Tom, Matthijs: Yeah ok CONSENSUS | |
| James: Ok so this bunk here will have a radius on it and so will this one, so we are leaving space to go through here. | KP |
| Rachel: We really like your idea of having them all rounded. They look really kind of new. | CT |
| James: Your idea for the bunks is really nice. We are going to keep the idea for it but just incorporate this kind of layout. That’s what we mean. Is that ok? | KP, CT |
| Matthijs: Ok. CONSENSUS Give us a second. We want to try it, but you need to go in a few minutes but when are you back this afternoon? | MC |
| James: We are back this afternoon at 2 o’clock our time. | MC |
| Tom: Ok, one hour that’s ok. CONSENSUS I want to try to | MC |
figure it out in solid works for myself so we can measure how much space we have.

James: What do you think of this? Are you happy with this or are we changing too much?

Tom: I just want to know the exact measurements between the spaces we have. We can’t judge it now.

James: I know yes, yes. CONSENSUS

Matthijs: The idea is great because it is just a slight change from our idea. We are going to put it into solid-works and look at how it measures and we will speak to you in about an hour or so.

James: Ok that’s fine. CONSENSUS

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

5.2.3 Team B: how the activities enabled consensus during problem definition

Nine topic shifts were identified during this meeting of which seven were preceded by verbal consensus. Of the remaining four topic shifts there was no evidence of a disagreement and the topic naturally moved with assumed agreement. Table 5.7 is a topic segment from a meeting between the UL half of team B. As the team members had no access to a crew rest and users the purpose of the meeting was to draw upon their own related experiences of being in confined spaces to understand the issues. In externalising the distributed information the team start to build a shared picture of what this might involve. As in the problem definition phase for Team A the team members primarily build on one another’s contributions to broaden the scope of this. Brian begins by suggesting that sleeping in a crew rest includes “sleeping in an upright position.” This prompts a series of building on statements to consider what this might entail. Lisa makes an analogy to relay a story of a personal experience on a long haul flight. This prompts Lauren to internalise the previous contributions and indicates a level of common ground to conclude that kindness and empathy were factors that needed to be considered in the design of the crew rest. While there is no verbal consensus to conclude the topic, common ground came about from the turns of talk as individuals expanded on the preceding utterances to expand and refine the shared knowledge on the topic. In summary the cognitive processes used were: knowledge processing and critical thinking. The conversation activities were: building on and an analogy.

Table 5.7 Team B exploring the project theme

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian: So personal experiences, like sleeping in an upright position</td>
<td>KP</td>
<td></td>
</tr>
</tbody>
</table>
Lisa: Yeah like experiences in the plane itself.
Brian: Yeah any long haul travel experience
Lauren: So sleeping
Brian: Sleeping, smells
Lisa: Yeah I was on a long haul flight once and there was this guy behind me and when I put my chair back at an angle he kept catching it and pushing it forward.
Brian: I’d have done that as well!
Lisa: 14 hours of a flight, no thank you. And he kept pushing it and I said it to the air hostess and I complained. He was complaining that he didn’t have enough leg room because he was so tall and that I should be sitting somewhere else and that you’re not allowed put your chair back so I had to sit straight up for fourteen hours.
Lauren: So Kindness no, relationship empathy?
KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

In Table 5.8 the topic shifts to consider further issues within the crew rest. Again through turns of talk the team members externalise the distributed knowledge of the team. The building on statements reflect how the contributions are internalised by others and further expanded upon as team members are reminded of their own knowledge and experiences. Scenarios also provided vivid examples of potential worst case situations. Lisa uses scenarios to consider the perspective of the passengers when someone asleep leans on another person. This prompts Brian to consider the hygiene implication. Lisa continues to build shared knowledge by depicting the scenario of sharing arm rests and having to get past seated people to go to the toilet. This also prompts Lauren to consider temperature and lighting. Much of the discussion involved making analogies to the passenger experience on an aircraft. By using their own frame of reference analogies allowed the team to predict the crew rest experience by comparing it to similar environments. While there was no explicit consensus at the end of the topic it is clear that the discussion led to the development of a shared understanding of the issues found amongst passengers sharing a confined space on a long haul flight. In summary the cognitive processes used were: knowledge processing, critical thinking and creative thinking. The conversation activities that supported this were: reference to prior experience, stories, perspective of others, scenarios, and building on.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lisa: Someone leaning on your shoulder when they are sound asleep.</td>
<td>CT</td>
<td>scenario, Analogy</td>
</tr>
<tr>
<td>Brian: Hygiene</td>
<td>CT</td>
<td>Building on</td>
</tr>
</tbody>
</table>

Table 5.8 Team B exploring the project theme 3
Lisa: Somebody invading your space because your seat is quite tiny, because if you put your arm on the arm rest your putting your arm on their arm rest because there is only one arm rest between two people. So if you get your arm on it first you are lucky, so you better keep your arm there for fourteen hours... Or the nuisance of three seats, if your in the middle one or in the inside you have to get out past two people to go to the toilet.

Lauren: Temperature

Brian: Yeah **CONSSENSUS**

Lauren: Lighting

**Brian:** I was coming back from a flight once and they weren’t offering any entertainment. I mean all you need to do is pay two euro for entertainment and you could play games or whatever. I mean that would be good for entertainment. Well I know Ryanair are never going to offer that.

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The two examples shown in Tables 5.7 and 5.8 show how the team used the activities to draw out their own understanding of the issues and conflicting needs relating to people sharing space on long haul flights. The activities over the topic segments facilitated the gradual process of externalising unshared knowledge, the creation of shared knowledge, to build common ground. Consensus was less of a requirement as the focus was on forming a shared representation of the problem. This was reflected later in the team’s final solution where different zones were created in the crew rest to allow for the different activities and needs of the flight attendants, see Figure 5.1.

**Figure 5.1:** A rendering of a final solution and a scaled model
Following the problem definition phase the team moved to the ideation phase.

5.2.4 Team B: how the activities enabled consensus during ideation

34 topic shifts were identified during Team B’s ideation meeting of which 24 were preceded by verbal consensus. Of the remaining 10 topic shifts there was no evidence of a disagreement and the topic naturally moved with assumed agreement to address different points in the discussion. Four of the 34 topic shifts included instances where a team member returned to a previous topic which in all cases was a shift to an earlier topic that wasn’t fully expanded upon or concluded. In Table 5.9 the team are considering how to get around the issue of changing clothes in the crew rest which is shared by both genders. While the focus of the meeting is to come up with design solutions the team are at odds about whether a separate changing area is required for the FAs or whether the passenger toilets are acceptable alternatives. This topic reflects a process of externalising distributed knowledge which is then negotiated. A series of arguments are put forward by individuals. Arguing was supported by scenarios to depict the cause and effect of worst case situations and how people might behave to convince others to that view. Arguing was also supported by analogies. For example Lauren argues that the crew rest area is too small to change in by drawing on an analogy to a tent to describe her own experiences of trying to change in a restricted space. The topic began with different views about the matter but concludes with consensus that the team need to provide a separate area other than the toilets for women to change. Therefore the arguments brought about conceptual change where others views were shifted to accommodate new perspectives (Jonassen and Kim 2010). Despite being at the ideation phase this topic shows that the analysis of the problem also continues at this phase. While there was one reference to creative thinking and the proposal of an idea this topic was more focused on negotiating an agreement on the scope of the design brief. In summary the cognitive processes used were: knowledge processing, critical thinking and creative thinking. The activities that supported this were: scenarios, analogies and arguing.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lisa: Yeah as I had seen from the thing I put up last week from your one on the foreign flight. She got dressed upstairs. Can you say you’re not allowed get dressed downstairs? It is impractical, but it is flexible.</td>
<td>KP CT</td>
<td>scenario, arguing,</td>
</tr>
<tr>
<td>Tutor: The only thing about dressing in the toilets is you are taking over the bathroom or toilets for a long period</td>
<td>CT</td>
<td>scenario, arguing,</td>
</tr>
</tbody>
</table>
of time. If you took the time to change your clothes wash your teeth take out your contact lenses etc. go to the loo it would be too long.

**Lauren**: But for example I think because the space is so small you cannot even change there. Any time we go to the coast I bring a tent which is 1 metre and I tried to change inside and even my daughters couldn’t because of the space you can’t change. What’s your height? 185?

**Brian**: 180 or something

**Lauren**: If the person has 180 how are you going to change properly? So I think that’s why they don’t have this (changing room in rest).

**Lisa**: What about under the stairs is there space there? You need to allow the women have somewhere to change. The woman won’t be six foot tall and they are the ones that possibly want that bit more privacy and take more time, so you could say that maybe the men don’t need to use that space and let them use the toilet.

**Marcus**: The fact is the women are changing in the toilet.

**Brian**: That’s the particular study you saw where the lady changed in the toilet. I think it’s very easy to say that look they can get changed in the toilet but you know we should be able to design something for them.

**Tutor**: What if there are 3 or 4 passengers queuing for the toilet?

**Brian**: That’s it, that’s it exactly. Plus there’s nothing to say that when you go into the toilets that the toilets are going to be clean. **CONSENSUS**

**Tutor**: Yeah someone’s just puked in the toilet **CONSENSUS**

**Marcus**: It’s the same toilet as the passengers use right? **CONSENSUS**

**Lauren**: Yeah **CONSENSUS**

**KP**: knowledge processing, **CT**: Critical thinking, **CRT**: Creative thinking, **MC**: meta-cognition

The conversation continues to explore the stairs and how more space could be created by changing or moving the stairs. Table 5.10 outlines the conversation at this point. There is an emphasis on *creative thinking* as the team start to generate ideas. However this is also combined with *critical thinking* to further analyse the problem and ideas created. Lauren begins the segment using *critical thinking* to question the need for a stairs and *creative thinking* to propose using an elevator.” Her idea triggers a series of responses from the other team members. As the idea is considered it is further built upon by other team members. Common ground comes about through the co-construction of ideas as individuals build on previous utterances. **Scenarios** and *mental simulations* were effective in communicating how an idea could function for others. The clear
communication of ideas was essential for others to understand them in order to develop them further. While the topic doesn’t conclude with a verbal consensus to support the idea there is evidence of common ground throughout the discussion as the team built on each other’s ideas. In summary the cognitive processes used were: knowledge processing, critical thinking and creative thinking. The activities that supported this were: scenarios, analogies, mental simulations, arguing and building on.

<table>
<thead>
<tr>
<th>Table 5.10 Team B ideation 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examples</strong></td>
</tr>
<tr>
<td>Lauren: But the other option is if you don’t need a stairs maybe you need an elevator, like a platform where you just press a button and go up.</td>
</tr>
<tr>
<td>Tutor: That could be the changing room as well. There you’ve got an idea. <strong>CONSensus</strong></td>
</tr>
<tr>
<td>Marcus: I think that’s a good idea. <strong>CONSensus</strong></td>
</tr>
<tr>
<td>Lisa: It’s an elevator but you can keep it closed while you are changing your clothes. <strong>CONSensus</strong></td>
</tr>
<tr>
<td>Lauren: Exactly you can even change while you are getting down. <strong>CONSensus</strong></td>
</tr>
<tr>
<td>Tutor: Very good idea <strong>CONSensus</strong></td>
</tr>
<tr>
<td>Lauren: You like it?</td>
</tr>
<tr>
<td>Brian: I think you could probably steal a little bit more room as well so you could stand up in it.</td>
</tr>
<tr>
<td>Lisa: Yeah because your height is 1.6 because when you open the door to go down you have the height of the door</td>
</tr>
<tr>
<td>Brian: You are standing in the actual plane at that stage.</td>
</tr>
<tr>
<td>Tutor: The only thing for health and safety you might have an issue as in a building where you have a lift you also have a stairs in case of a power cut. You may need to offer mechanical option a rope ladder or some such alternative.</td>
</tr>
<tr>
<td>Lauren: Yeah a ladder, like an emergency ladder. <strong>CONSensus</strong></td>
</tr>
<tr>
<td>Brian: Even in those old big hotels where they also have those service lifts where you have to pull them with a handle or those windows on ropes. You know a hand crank or something.</td>
</tr>
<tr>
<td>Lauren: You know the fire man what they do.</td>
</tr>
<tr>
<td>Brian, Lauren: The pole.</td>
</tr>
<tr>
<td>Brian: How do you get back up though?</td>
</tr>
<tr>
<td>Lauren: No the elevator.</td>
</tr>
<tr>
<td>Brian: Alright so. <strong>CONSensus</strong></td>
</tr>
</tbody>
</table>

**KP**: knowledge processing, **CT**: Critical thinking, **CRT**: Creative thinking, **MC**: meta-cognition
While the team had co-created the idea of a combined elevator and changing room further on in the discussion the team turn their attention to the critique of the idea, see Table 5.11. This highlights the evolving and shifting nature of common ground as further negotiation is required to reach agreement on the solution. Marcus applies critical thinking to question the logic of using an elevator as a changing room. He uses a scenario to argue that it may not be a practical solution. Both Brian and Lisa show agreement with one another and support for the idea. They put forward counter arguments to Marcus’s claims. They do this successfully by building on each other’s arguments and using scenarios and an analogy to justify their idea. The negotiation that occurred had the benefit of ensuring that the idea was rigorously evaluated and that there was a sufficient amount of shared knowledge generated to form conclusions. At one point in the discussion Lisa reconsiders the proposal with the scenario of someone waiting to use the elevator while someone else is spending “a half hour on hair and makeup”. This is again evaluated and resolved as Brian argues that you’ll always have that and in building on that, Lisa, using a scenario to argue that “they can still just step out for a second, leave the person down and go back in again.” While Marcus instigated the concerns, he expresses no further reservations with regard to the proposed solution. It can be therefore concluded that some degree of consensus had been reached where he was either convinced by the arguments made, or not convinced, but in agreement to progress. He does not verbally state his position at this point but the topic shifts to another subject without his objection. In summary the only cognitive process used throughout was critical thinking. The activities that supported this were: scenarios, analogies, arguing and building on.

Tables 5.9, 5.10 and 5.11 have provided three topic segments which show how the activities over the three topic segments supported the teams in a process of externalising unshared knowledge, to the creation of shared knowledge and the negotiation of common ground to enable consensus. This facilitated the further structuring of the problem, the generation of an idea and the evaluation of the solution. However by focusing on the thorough evaluation of this proposal the team had stopped generating further ideas resulting possibly in the early consensus on a solution.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marcus: It’s very hard for it to be an elevator at the same time. If someone is changing (because there are seven in the cabin) and someone else wants to go up or down,</td>
<td>CT</td>
<td>Scenario, arguing</td>
</tr>
</tbody>
</table>
that’s not possible because someone is changing.

| Lisa: Yes yeah, well you’ll have your engaged button on. | CT          | Arguing                  |
| Brian: Occupied yeah. I mean you’re going to run into that. **CONSENSUS** | CT          | Arguing                  |
| Lisa: Whether it’s the toilet or the stairs. | CT          | Arguing, analogy Building on |
| Brian: Whether someone is coming down the stairs or going up the stairs you just can do that. | CT          | Scenario, arguing, building on |
| Lisa: Yeah but then you’ll have the person who spends a half an hour on their hair and makeup, when you have your man who wants to come down the stairs. | CT          | Scenario, arguing       |
| Brian: You’ll always have that. | CT          | arguing                  |
| Lisa: But they can still just step out for a second, leave the person down and go back in again. | CT          | Scenario, arguing, Building on |
| Brian: Yeah, no definitely I think it’s a nice idea. I like the way we can put reflective material on it so it adds another element to it. **CONSENSUS** | CT          | Arguing, building on     |
| Lisa: Yeah, the mirror will actually make the space look bigger. **CONSENSUS** | CT          | Arguing, building on     |

**KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition**

### 5.2.5 Conclusion

This section provides a detailed picture of the activities used by the teams to support the cognitive processing of: knowledge processing, critical thinking, creative thinking and meta-cognition and reveals how they were used to navigate the consensus process from unshared knowledge to common ground and consensus. The conversation activities used were:

- **Analogies**, 
- **Arguing**, 
- **Scenarios**, 
- **Mental simulation** 
- **Building on**

*Domain knowledge* was not used and was evident in the team’s limited knowledge of the subject area. This also limited the effective use of the other conversation activities. The next section shows how the activities were used to manage conflict.
5.3 COGNITIVE CONFLICT

Conflict was evident at times between the distributed sides of Team B which may have been exacerbated by the distributed location of the team which appeared to negatively impact on the teams’ process of developing common ground. The topic segment in Table 5.12 towards the end of the ideation meeting highlights this. The team were deciding on the work that needed to be carried out for the next stage of the project but there was disagreement between the two halves of the team with regard to this. Brian begins the segment by applying metacognition by asking the HU half of the team “Did that make sense to ye?” Janus replies with “no” and questions the need to do story boards. Through **arguing** and the support of a **scenario** the team negotiate a broader understanding of what a story board can be. This is reflected in the comments by Lauren and Lisa: “But in your drawings you have a story board already.” “That’s still telling a story” and “They don’t necessarily all have to be drawn by hand.” This is accepted by Janus when he utters “yeah.” While the two sides of the team take a slightly different approach to executing the proposed solutions they agree that they can present the work in different ways. A degree of common ground has been achieved that is sufficient to allow the team to progress. Therefore it is not always essential that full common ground is achieved on all aspects of the project. Metacognition played a role also in reflecting on the team’s methods. Had Brian not asked the HU part of the team if it made sense to them the issue may not have been addressed and potentially escalated into a more serious conflict later on. While the outcome of the negotiations resulted in a both halves developing a different approach to the presentation there was agreement that this was not an issue for the project. In summary what started with a moderate level of conflict was resolved with the use of critical thinking and metacognition and the conversation activities of: arguing and a scenario.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brian: Did that make sense to ye?</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Janus: No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brian: No? ok</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lisa: If we just spend maybe ten minutes writing it down.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Janus: Why would we make storyboards?</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td>Lauren: Because she says that is the best way to present the ideas.</td>
<td>KP</td>
<td>Arguing</td>
</tr>
<tr>
<td>Marcus: No she said we can choose ourselves</td>
<td>KP</td>
<td>Arguing</td>
</tr>
<tr>
<td>Lauren: She says there are a few ways to present ideas, one is a storyboard, one is a plan view, so a client will understand the concept better from a story board.</td>
<td></td>
<td>Arguing</td>
</tr>
</tbody>
</table>

Table 5.12 Team B example of cognitive diversity
Team A also had instances of conflict which were generally resolved, however at times the conflict bordered on relationship conflict as highlighted in Table 5.13. The text in bold shows that the language is much more confrontational and emotive bordering on a personal attack. While the issue was eventually resolved it is possibly to see how task and relationship conflict can be difficult to separate and that the benefits of task conflict...
could be quickly outweighed by the negative effect of relationship conflict. A lack of communication was the main reason for the relationship conflict which prevented consensus. When the two sides of Team B failed to make contact at times during the project assumptions were made about the intentions of the distributed partners which escalated the risk of relationship conflict. Observations showed that it was through open dialogue that relationship conflict was limited. Therefore behavioural integration and trust appeared to be missing between these two sides.

Table 5.13 Team A exploring the project theme

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matthijs: remember at the earlier Skype meeting we told our ideas and you were Ok with that, now all of a sudden you are not.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>James: No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matthijs: I’m a bit confused.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>James: No what we mean was, when we really looked at the ideas you had we were kind of thinking. You know the way with the bunks in the centre that ye have? Ye said that ye had to shorten them a bit. We don’t want to create this sort of feeling where if someone is going down, oh I don’t want those bunks because they are smaller, you know that kind of way?</td>
<td>KP, CT</td>
<td>Scenario, arguing</td>
</tr>
<tr>
<td>Matthijs: But size of the product is not as big a pressure.</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td>James: we wanted to accommodate for all people so you wouldn’t create this scenario.</td>
<td>KP CT</td>
<td>arguing</td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The next section looks at the frequency of use of the cognitive processes and conversation activities.

5.4 THE FREQUENCIES OF THE COGNITIVE PROCESSES AND CONVERSATION ACTIVITIES DURING TEAM DISCOURSE

This section addresses the frequency of the cognitive processes and the conversation activities used, see Table 5.14. The top three most frequently used conversation activities are shaded. While most of the data was coded to a cognitive process not all of the utterances could be assigned to these categories. The percentages were calculated from the total number of utterances for the meeting. The total percentage often came to more than 100% as many of the utterances could be coded to more than one cognitive process or conversation activity.
There were differences in the emphasis of the cognitive process used overall, across the phases and between the two teams. Overall knowledge processing was most frequently used reflecting the high proportion of knowledge exchange to reach common ground. This was followed by critical thinking and metacognition, reflecting the requirement to analyse and negotiate on shared information. Overall creative thinking was used least.

However creative thinking increased significantly at the ideation phase for team B. This was due to the differences in the purpose of the meetings. Team A’s meeting was focused on getting both sides of the team to agree between different concepts whereas Team B’s meeting was about coming up with ideas.

Critical thinking fell for both teams at the ideation and concept development phases. This indicates that it was the problem definition phase that required most of the analytical thinking. However both teams still used more critical thinking than creative thinking even at the generative phases of the project. The findings indicate that critical thinking was used at these phases to not just analyse proposed solutions but analyse the problem further as ideas created posed new questions about the problem state. Overall team B used more critical thinking than team A showing a deeper level of analysis to the project. They demonstrated a more superior performance throughout the project which was assessed by four tutors and awarded higher marks. While both teams were undergraduate students team B had a number of mature students which suggests that their increased life experience may have contributed to their higher frequency of critical and creative thinking. One possible negative observation of team B was an overuse of critical thinking during ideation in the critique of ideas possibly at the expense of generating a range of ideas.

Meta-cognition was varied in use between the teams and used mostly by Team A at the problem definition phase. While metacognition is a positive aspect of team behaviour, in Team A’s meeting it reflected a level of uns sureness as the team regularly turned their attentions to co-ordinating themselves rather than applying the other cognitive process to process the project information.

Team A also used a significant amount of knowledge processing at the concept development phase which involved explaining a concept to their distributed members. Their difficulty in interacting with their distributed partners at times meant their conversation was often simply reduced to explaining and clarifying.
Table 5.14: Model of cognitive activities

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Team A problem definition 102 utterances</th>
<th>Team A Concept development 161 utterances</th>
<th>Team B problem definition 134 utterances</th>
<th>Team B ideation 345 utterances</th>
<th>Total 742 utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td>22 (22%)</td>
<td>98 (61%)</td>
<td>64 (48%)</td>
<td>110 (32%)</td>
<td>294 (40%)</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td>30 (29%)</td>
<td>24 (15%)</td>
<td>55 (41%)</td>
<td>98 (28%)</td>
<td>207 (28%)</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td>4 (4%)</td>
<td>3 (2%)</td>
<td>4 (3%)</td>
<td>54 (16%)</td>
<td>65 (9%)</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td>43 (42%)</td>
<td>31 (19%)</td>
<td>18 (13%)</td>
<td>64 (19%)</td>
<td>156 (21%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>99 (97%)</td>
<td>156 (97%)</td>
<td>141 (105%)</td>
<td>326 (94%)</td>
<td>722 (97%)</td>
</tr>
</tbody>
</table>

The conversation activities used were made up of: *Domain knowledge, analogies, arguing, mental simulations, scenarios and building on.*

*Domain knowledge* was not used by Team A and used infrequently by Team B. This is not surprising considering the teams consisted of undergraduate students with limited knowledge of the subject area. Reflection on prior knowledge is a necessary part of problem solving (Kolodner et al. 2003) and while the teams lacked *domain knowledge* they made references to related experiences through the use of analogies. As they did not have direct experience of a crew rest, *analogies* to related experiences compensated to some degree for a lack of *domain knowledge*. The teams did not however, refer to other projects or other cases previously solved due to a lack of experience of having solved similar problems.

*Arguing* was used significantly particularly at the ideation and concept development phases highlighting the persuasive nature of team interaction to reach common ground. *Mental simulations* were not frequently used by either team. This may have been due to the novice nature of the team in their limited knowledge of how products function and
operate. In contrast *scenarios* were frequently used across all phases of the project. *Scenarios* were mainly used to develop empathy for users and understand their needs during the problem definition phase and to predict new possibilities and how users would interact with proposed solutions during the ideation phase. *Scenarios* were particularly versatile as they were also used to justify arguments by giving vivid examples to justify claims being made. *Building on* was the most frequently used activity and reflected collaborative behaviour as the team members took each other’s contributions and built on them to develop shared knowledge.

There were some differences in the conversation activities used between the phases of the design process. At the problem definition phase the focus was on sharing knowledge and understanding the factors associated with the crew rest. *Building on* was high in frequency at this phase indicating its divergent nature in gathering information and the team’s collaborative approach to constructing knowledge and building common ground. *Building on* was barely used however by team A at the concept development phase. This meeting was more convergent in the analysis and selection of concepts and more confrontational between the distributed partners.

At the ideation and concept development phases there was an increase in *arguing* showing that these phases required increased negotiations to justify solution directions. At these phases the teams were critiquing proposed solutions and coming to decisions on directions. Achieving consensus when there was a difference of opinion was more difficult as team members had to persuade and convince others. Other differences in the use of the activities were due to differences between the teams. Team B used significantly more conversation activities than Team A, particularly *analogies*, *scenarios* and *arguing*. This again indicates that the increased use of the conversation activities was associated with a higher performance.

To conclude, common ground and consensus came about gradually within topics and the activities used throughout had a bearing on reaching that consensus. Some of the activities could be described as collaborative, where members built on other’s contributions but when combined with activities such as arguing were also a powerful tool to persuade and convince. There were some differences in the emphases of the cognitive processes and conversation activities across the phases of the design process and between the teams.
5.5 CHAPTER CONCLUSIONS

This case provides an understanding of the cognitive processes and conversation activities used in an undergraduate design project and their role in creating consensus. The challenges to reaching consensus such as conflict have also been addressed. The following conclusions are drawn from the findings:

The findings validate the conceptual model to show that the teams followed the consensus process as outlined in the conceptual model in the externalising, internalising, elaboration and negotiation of knowledge to reach common ground and in turn consensus. The process in this case was again shown to be iterative, as new information was introduced the process was repeated.

The cognitive processes identified can be defined under the headings of: knowledge processing, critical thinking, creative thinking and meta-cognition. The findings have mainly replicated what was discovered in the Bio-innovate case but there were further differences in the frequency of the activities used. Creative thinking increased but was still at low levels at the ideation and concept development phases. Critical thinking was at high levels at this phase to critique ideas and explore the problem further. Domain knowledge was used infrequently which can be accounted for the lack of experience of the team members. However analogies were used frequently and compensated to some degree for the lack of domain knowledge by enabling them to draw comparisons from related areas.

At times there was cognitive conflict particularly between the UL and HU sides of the teams. Cognitive conflict however was not necessarily negative and had a positive effect on the team’s performance. It facilitated the discussion of a larger number of ideas and perspectives, the challenging of conventional thinking, to bring about more creative solutions through the use of the activities. However within Team A at times the conflict bordered on relationship conflict due to poor communication and a lack of integration. While this was managed with the conversation activities, unresolved it could have been unconstructive. Achieving consensus when there was conflict involved persuasive behaviour and arguing. While scenarios, analogies and building on, were also collaborative and generative activities they also supported arguing. Conflict was heightened at the ideation and concept development phase of the project as decisions were required.
6 Professional Practice Case

This chapter is an in-depth study of a user experience design consultancy. Following a description of the company in section 6.1, the findings are then presented and are divided into the following sections:

Section 6.2 presents the cognitive processes and conversation activities used during team interactions to reach consensus.

Section 6.3 describes the role of the cognitive processes and conversation activities in relation to diversity and conflict.

Section 6.4 presents the frequency of the cognitive processes and conversation activities.

6.1 CASE DESCRIPTION

This case follows an interdisciplinary team of experts from a user experience (UX) and user interface (UI) design consultancy in the evaluation and design development of a software interface.

6.1.1 Data overview

The data was collected over 2 days. Approximately 1.5 hours of conversation was recorded and analysed. Content analysis was then carried out of the team’s dialogue as they carried out an evaluation of a client’s application. All three team members had reviewed the application separately and the purpose of the meeting was to bring the team members together to establish the short comings of the application and propose possible solutions in order to prepare the scope of the design brief for the client. Harry was the lead in the project and as he was liaising with the client and the most informed about the application. Both Harry and Faye hold senior positions as partners in the company so dominated the meeting with Annette contributing to a lesser degree. In carrying out an evaluation, the company conduct a cognitive walkthrough of the application to examine the sequence of steps or actions required by a user to accomplish a task. The evaluators question each step in terms of the usability of the application, whether it makes sense to the user and whether there is an easier way of doing the task. Table 6.1 describes the data.
Table 6.1 Description of dataset

<table>
<thead>
<tr>
<th>Description of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content: Audio and transcript of meeting between members of the team</td>
</tr>
<tr>
<td>Present: team and 1 researcher</td>
</tr>
<tr>
<td>Duration: 1Hr 30min</td>
</tr>
<tr>
<td>Units of Analysis: Topic segments: 44.</td>
</tr>
<tr>
<td>Utterances of Participants: 401</td>
</tr>
<tr>
<td>Stage in process: problem definition and ideation phase (combined)</td>
</tr>
</tbody>
</table>

6.2 DATA ANALYSIS

This case study followed a similar approach to the first two cases. The data was first divided into topic segments and instances of verbal consensus were noted within and at the end of topic segments. Three steps in the coding process followed as outlined in Chapter 3. 42 topic shifts were identified during the team’s meeting of which 33 were preceded by verbal consensus. Of the remaining nine topic shifts there was no evidence of a disagreement and the topic naturally moved with assumed agreement to address different points in the discussion. Two of the 42 topic shifts included instances where a team member returned to a previous topic which in all cases was a shift to an earlier topic that wasn’t fully concluded. In comparison to the Bio-innovate and Undergraduate cases there was a difference in the frequency of use of the cognitive processing and conversation activities. The findings are as follows:

6.2.1 How the activities enabled consensus

During the team’s review of their client’s application it became apparent that there were usability issues which was not intuitive for the user and caused difficult navigation. Throughout the meeting the team members informed one another about their individual evaluations of the program. Table 6.2 is an example of a topic segment that outlines an example and shows the cognitive processes and conversation activities used. The early part of the topic involves Harry externalising his knowledge of the application for the team. He begins with a mental simulation to explain the step by step process of how the user adds and deletes competitors on the application. His explanation also externalises his belief that this is not an effective means. Faye responds with support and the evaluation that this “was weird”. Her evaluation indicates to Harry that she agrees with him. Harry continues to share further information which prompts Faye to request elaborations with “how do you fill in those main competitors?” Harry explains this and within this explanation he again expresses his assessment of the feature which is not
positive; “you dump them in, but it’s just text.” At this point the team have established shared knowledge about the feature and the subsequent utterances by Faye and Harry shows that common ground has been reached as they both concur that the feature is not effective with; “That’s crap,” and “It’s not even a look up”. Grounding continues as Faye makes further evaluations. She uses arguing to explain and justify both her own and Harry’s line of reasoning. Arguing supported the development of common ground in that it helped the team to confirm that they were correct in their judgement. Henry’s response “you’ve gone past it yeah”, shows that Henry agrees with Faye. The conversation continues with further elaborations and clarifications as grounding continues. The topic is concluded with consensus and the team have reached common ground on their analysis and assessment of this feature of the application.

The team alternated between knowledge processing to provide the information for the team and critical thinking to then analyse this information. The domain knowledge of the team in the area of user experience was essential in not just providing information but in also forming the critical thinking necessary to form evaluations. Mental simulations were frequently used to evaluate the step by step logical flow of interactions with the program features, make evaluations and communicate this to others. Building on reflected how common ground was co-constructed through the turns of talk of Harry and Faye as they built an understanding and scenarios justified arguments being made.

The topic has followed the consensus process in the sharing of distributed knowledge, the elaboration of this information to establish common ground. In summary the cognitive processing styles used were knowledge processing and critical thinking. The activities that supported this were: domain knowledge, scenarios, mental simulations, and building on.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harry:</strong> See the competitors here now this screen shot hasn’t got one. Basically those competitors here are not the same as those competitors here so you know how you add competitors you asked them how do you delete and add competitors? It’s down here.</td>
<td>KP</td>
<td>Mental simulation,</td>
</tr>
<tr>
<td><strong>Faye:</strong> Yeah this actually, I noticed and I thought it was weird.</td>
<td>KP, CT</td>
<td></td>
</tr>
<tr>
<td><strong>Harry:</strong> So it’s down there that’s them there, you put them in down there. It’s in the standard opportunity but then they have this field called competitors or main</td>
<td>KP, CT</td>
<td>Mental simulation,</td>
</tr>
</tbody>
</table>
competitors here and it’s not them.

<table>
<thead>
<tr>
<th><strong>Faye:</strong> And how do you fill in those main competitors? That’s the question I was asking.</th>
<th>KP,</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harry:</strong> You double click on the little pencil and you dump them in but it’s just text.</td>
<td>KP, CT</td>
</tr>
<tr>
<td><strong>Faye:</strong> That’s crap.</td>
<td></td>
</tr>
<tr>
<td><strong>Harry:</strong> It’s not even a look up. CONSENSUS</td>
<td>KP, CT</td>
</tr>
<tr>
<td><strong>Faye:</strong> But that doesn’t look like it’s editable. I never noticed that little pencil. And the other thing as well do you see on that panel that’s sitting in the smart force app? You have no idea, you don’t really look at the date underneath, you kind of disregard it. You end up pressing on the icons and going in to the app so it means if that is where you are putting in the competitors, because I couldn’t find it anywhere in.</td>
<td></td>
</tr>
<tr>
<td><strong>Harry:</strong> you’ve gone past it yeah. CONSENSUS</td>
<td>KP</td>
</tr>
<tr>
<td><strong>Faye:</strong> But those competitors on that field are they the ones that come up in the assessment?</td>
<td>KP</td>
</tr>
<tr>
<td><strong>Harry:</strong> No it’s the other ones. It’s these ones that come up in the assessment.</td>
<td>KP</td>
</tr>
<tr>
<td><strong>Faye:</strong> Ok CONSENSUS</td>
<td></td>
</tr>
<tr>
<td><strong>Harry:</strong> I know it’s very counter intuitive. They’re basically sucking up a standard sales force object for those competitors.</td>
<td>KP, CT</td>
</tr>
<tr>
<td><strong>Faye:</strong> Yeah CONSENSUS</td>
<td></td>
</tr>
<tr>
<td><strong>Harry:</strong> And then they’ve got their own one and the question is it’s a question.</td>
<td>KP, CT</td>
</tr>
<tr>
<td><strong>Faye:</strong> Yeah but you definitely disregard a lot of this information down here because you’re more inclined to interact with those elements there.</td>
<td>CT</td>
</tr>
<tr>
<td><strong>Harry:</strong> Yeah CONSENSUS</td>
<td></td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The topic then shifts to address the design of the application’s icons, see Table 6.3. Harry begins with the analysis that the icons are very colourful. Faye agrees and uses an analogy to “Noddy” to build on this analysis. Harry provides further information and uses an analogy to compare the icons to Windows XP. His domain knowledge allows him to not just question the icons but to also apply creative thinking to recommend better alternatives. He uses a scenario to consider the perspective of the user with “there is no way that you are going to remember that the chess board is x” and a mental simulation to suggest how this could work better. At this point the team has shared information about the icons and have established common ground that they need to be redesigned. Faye uses creative thinking to build on Harry’s proposed solution and Harry in turn builds on Faye’s contribution. Faye agrees with this and Harry continues to build on the solution. With the combination of critical thinking to analyse the requirements and creative
thinking to propose a solution he draws on his domain knowledge and a mental simulation. The topic is concluded with consensus. This topic shows the iterative natures of building common ground and consensus as new issues are addressed. Harry and Faye contribute chunks of information that are internalised, analysed and in turn elaborated on or refined by the other. In summary the cognitive processes used in the topic were: knowledge processing, critical thinking and creative thinking. The activities that supported this were: domain knowledge, scenarios, analogies, mental simulations, questioning and building on.

Table 6.3 Discussion on application no.2

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Harry</strong>: I guess with the icons the key things as well as just being very over colourful.</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td><strong>Faye</strong>: Yeah, very Noddy.</td>
<td>CT</td>
<td>Analogy, building on</td>
</tr>
<tr>
<td><strong>Harry</strong>: It just looks like windows XP. Great we’ve got full colour icons now. And I’d say they’re stock but they do have new ones that they showed us which looked slightly better. But the other thing is there is no way that you are going to remember that the chess board is x so you have to hover every time you use it for the first good while. So it doesn’t make any sense. On the subsequent pages they are reinforced by text which I think is better. They need to look more clickable. I think it would be a good opportunity to hold the space with the icon somehow, so you use the full width of the thing to create something.</td>
<td>KP, CT, CRT</td>
<td>Domain knowledge, analogy, scenario, arguing, mental simulation,</td>
</tr>
<tr>
<td><strong>Faye</strong>: That distinguishes it from the rest of the page.</td>
<td>CRT</td>
<td>Building on</td>
</tr>
<tr>
<td><strong>Harry</strong>: And wraps around the presentation underneath.</td>
<td>CRT</td>
<td>Building on</td>
</tr>
<tr>
<td><strong>Faye</strong>: Yeah CONSENSUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Harry</strong>: It needs to have a hover state so you know that it’s clickable, so maybe the link text underneath, so if you have it supported by text it should have an underline for the link as well.</td>
<td>CT, CRT</td>
<td>Domain knowledge, Mental simulation, arguing, building on</td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The topic again shifts to take in further aspects of the program, see Table 6.4. In the first utterance Harry combines knowledge processing to explain a feature of the program, critical thinking to analyse it and creative thinking to propose a solution. He draws on his domain knowledge, a scenario and a mental simulation. Faye does not instantly accept Harry’s solution and responds using a scenario to argue that the user would not have the information that they need on the screen on the initial use. Harry provides clarification for Faye and Faye further builds on the solution in an attempt to establish a common
understanding of the solution being proposed. Harry continues to build on the solution further and argues to justify it with a mental simulation to explain how it would work. He is also supported by his domain knowledge in considering what is intuitive to the user and to justify his solution. His contribution is accepted by Faye and common ground is reached as she responds with: “Yeah, ok that makes sense.” This topic reflects how the team co-evolved both the problem and solution. As the issues were defined this prompted the proposal of ideas to resolve them. Negotiation to reach common ground was a key feature of this topic and it did not happen automatically upon the externalising of knowledge and views. Clarifications, elaborations and refinements were required throughout the topic until consensus at the end of the topic indicated that common ground was achieved. In summary the cognitive processes used were: knowledge processing, critical thinking and creative thinking. The conversation activities used were: domain knowledge, scenarios, analogies, mental simulations, and building on.

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harry: This stuff here again it’s all very rough. This is a classic example of unbelievably inefficient space use. You’d get all of this in here and it would still read properly if you designed it properly. You could have all of this in here and the rolled up stuff and not have this presentation at all. Because this is an amalgamated part of this. So when you click on this; it pops out that. It asks all the questions and rolls up the figure and you can have all of these states in there as well. It’s no problem there’s not that much information there.</td>
<td>KP, CT, CRT</td>
<td>Domain knowledge, scenario, mental simulation, arguing</td>
</tr>
<tr>
<td>Faye: The only problem we have there is if you look at initial use right. What does the user see on the screen when they haven’t filled in the questions?</td>
<td>CT</td>
<td>scenario, arguing.</td>
</tr>
<tr>
<td>Harry: The questions? You fill them out and then you roll them up.</td>
<td>KP</td>
<td>Mental simulation,</td>
</tr>
<tr>
<td>Faye: Each one of these would be almost like headers.</td>
<td>CRT</td>
<td>Analogy, building on</td>
</tr>
<tr>
<td>Harry: Yeah CONSENSUS</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td>Faye: Expand and contract questions.</td>
<td>CRT</td>
<td>Building on</td>
</tr>
<tr>
<td>Harry: Yeah and you do the questions and it roll ups and when you close it, it reconfigures the header and that gets them away from having to do this save thing which is counter intuitive because you do the questions down and the save up. So it gets rid of the whole thing.</td>
<td>KP, CT CRT</td>
<td>Domain Knowledge, mental simulation, arguing, building on,</td>
</tr>
<tr>
<td>Faye: Yeah, ok that makes sense. CONSENSUS</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td>Harry: you would have to design it obviously.</td>
<td>KP, CT</td>
<td></td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition
6.2.2 Conclusion

This section provides a detailed picture of the conversation activities used by the teams to support the cognitive processes of: knowledge processing, critical thinking, creative thinking and meta-cognition and revealed how they were used to externalise unshared knowledge, generate shared knowledge, negotiate common ground and enable consensus. By following this process and through the application of the activities the teams were able to bring about a consensus that reflected a high degree of acceptance between members. The activities used were:

- Domain knowledge
- Analogies
- Arguing
- Mental simulations
- Scenarios
- Building on

The next section discusses cognitive conflict.

6.3 COGNITIVE CONFLICT

There was no conflict evident in this meeting. This may have been due to the similarity of disciplines of the team members and the lengthy duration that the team were established. This case also involved a more structured project in that the goals of the project were more defined and there were less solution options. While consensus reaching was not difficult this does not mean that it was quickly reached and that the topics were not thoroughly explored and debated. The next section looks at the frequency of use of the cognitive processes and conversation activities.

6.4 THE FREQUENCIES OF THE COGNITIVE PROCESSES AND CONVERSATION ACTIVITIES DURING TEAM DISCOURSE

This section addresses the break down and distribution of the cognitive processing and the conversation activities used. The number of times a cognitive process and conversation activity was used was counted to give the frequency. While most of the data was coded to a cognitive processes not all of the utterance could be assigned to these categories. The percentages were calculated from the total number of utterances
for the meeting, see Table 6.5. The total percentage often came to more than 100% as many of the utterances could be coded to more than one cognitive processes or conversation activity. The top three most frequently used activities are shaded.

The team spent a significant proportion of time in knowledge processing at 31% which could be expected as a large portion of the meeting involved the team members, sharing and pooling knowledge, understanding and analysing the client’s application. Critical thinking was the most used activity at 54%. This was observed throughout the meeting as the team members analysed and evaluated the application within the meeting. The purpose of the meeting was also to come up with improvements and solutions however creative thinking only accounted for 7% of the team’s activity. This reflects the co-evolution approach to the project as the teams in generating solutions spent significantly more time in critically analysing and further defining issues.

Meta-cognition was also used infrequently at 9% of the team’s activities and much of this was spent towards the end of the meeting as the team monitored the work done and planned the key requirements for the next phase. Meta-cognition in the other cases seemed to be linked to uncertainty and complexity. This case was less unstructured and involved experts who had experience in having solved similar projects, making meta-cognition less of a requirement. However there were times during the meeting when the team members struggled to interpret aspects of the application and this was reflected periodically with self-monitoring and self-evaluating with statements such as “So we’ve misinterpreted.”

Table 6.5 Model of cognitive processes and conversation activities

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Frequency 401 utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td>125 (31%)</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td>218 (54%)</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td>27 (7%)</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td>38 (9%)</td>
</tr>
<tr>
<td>Total</td>
<td>407 (101%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversation activities</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain knowledge</td>
<td>108 (27%)</td>
</tr>
<tr>
<td>Analogies</td>
<td>19 (5%)</td>
</tr>
<tr>
<td>Arguing</td>
<td>134 (33%)</td>
</tr>
<tr>
<td>Mental simulations</td>
<td>80 (20%)</td>
</tr>
<tr>
<td>Scenarios</td>
<td>22 (5%)</td>
</tr>
<tr>
<td>Building on</td>
<td>31 (8%)</td>
</tr>
<tr>
<td>Total</td>
<td>394 (98%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can coded to more than one category
The frequency of the conversation activities is also presented in Table 6.6. This was made up of: Domain knowledge, analogies, arguing, mental simulations, scenarios, and building on.

In doing an expert evaluation the team look for standard ways of doing things because they believe standardization is important as people will understand what is familiar. This requires the application of domain knowledge. The team were highly knowledgeable in both their domain of user experience and interaction design but also in the client’s domain and business needs. They displayed high frequencies of domain knowledge which allowed the team members to question features of the application make informed opinions and judgements that were shared by all members.

Analogies accounted for 5% of the activities and were used to draw comparisons to other systems to make evaluations of the application and support claims being made. Arguing was frequently used. It was used as critical thinking to justify team members reasoning and evaluations. Arguments are often associated with disagreements, however in this case they were regularly used to support the reasoning of not just the contributor but other team members also. Scenarios accounted for 5% of conversation activity and were used to empathise with and understand how users would interact with the program. Mental simulations which are similar to scenarios were more significantly used at 20%. They were used to evaluate the step by step functionality of the application to identify usability issues. Scenarios, analogies and mental simulations were also extremely useful to support arguments, idea generation and communicate.

Building on did not occur as frequently as in the previous cases and only accounted for 8% of the teams activities. This was partially due to the nature of the meeting in that Harry was more informed than the other two members and much of the meeting was about him explaining his analysis to them. When building on did occur it reflected the close working relationship between the team members where Faye was able to finish Harry’s sentences as follows:

Harry: “Yeah it’s here in contacts. But I would expect”
Faye: “To cross link yeah.”

Many of the conversation activities were used in combination with one another. For example scenarios, mental simulations and analogies were better enabled by domain knowledge. Arguing was supported regularly by analogies, mental simulations, scenarios
and domain knowledge. Analogies were often embedded within mental simulations. To conclude in terms of developing common ground and consensus it was often not just one activity within each utterance that contributed to this but the combination of two or more together.

6.5 CHAPTER CONCLUSIONS

This case study provides insights into how professional experienced designers collaborate to solve design problems. All of the participants could be described as experts in their field so it afforded an opportunity to study the activities used by them. The following conclusions are drawn from the findings:

In terms of reaching consensus the findings supports the conceptual model and shows the process to be iterative. Consensus came about gradually during the topics as the team externalised unshared knowledge and then negotiated common ground and consensus. While the process was negotiated in this case it was less about persuading others but more about collectively building a case where each team member contributed chunks of information or beliefs which were further contributed to by others to slowly build a common frame of references. All of the activities used within a topic contributed to reaching that consensus.

Conflict did not exist in this case and may have been due to the more structured nature of the problem and the similarities of the disciplines involved with less diversity to instigate conflict. While conflict did not occur the team were united in their critique of their client’s application. Consensus only came after a thorough review and elaboration of the project information. Grounding came about through turns of talk as individuals responded to each other’s utterances with further contributions that allowed them to elaborate on the project information, frame and reframe to create common ground.

This process required clarifications, verifications and explanations and at times negotiations which were supported by the cognitive processes and conversation activities. There were some differences compared to the previous cases. Meta-cognition was used less in this case and appears to be required only infrequently amongst well established teams with experience of having solved similar more structured projects.

Arguing was the most frequently used activity in this case and was less about persuasion and negotiation and more about the justification of other’s as well as one’s own
reasoning. *Mental simulations* were used much more frequently in this case and were valuable to evaluate critique and explain complex sequence of steps in a process and support ideation. *Mental simulations* depended on strong *domain knowledge* associating them with expertise. *Mental simulations, scenarios and analogies* were particularly useful to make evaluations while also supporting ideation during the co-evolution of the problem and solution. The conversation activities were often used in combination with one activity embedded with another such as *mental simulations* and *scenarios*. 
7 The Bio-innovate Case 2

The study follows a Bio-innovate team during a year-long program. This study was carried out over a period of five months to explore the activities used over a more prolonged period of time at different phases of a project. Following a description of the program and project undertaken in Section 7.1, the findings are presented as follows:

Section 7.2 presents the cognitive processes and conversation activities used during team interactions to reach consensus.

Section 7.3 describes the role of the cognitive processes and conversation activities in relation to conflict.

Section 7.4 presents the frequency of the cognitive processes and conversation activities.

7.1 CASE DESCRIPTION

As outlined in section 3.2.3 this case involves an interdisciplinary teams of four expert fellows in the area of medical device innovation.

7.1.1 Data overview

The teams were observed over a five month period and 20 hours of the team’s dialogue was audio recorded. 5.5 hours of the recorded data from each phase of the process was transcribed. Content analysis was then carried out of the team’s interactions and dialogue as they progressed through the project. The primary data to analyse the team’s cognitive activity consisted of three meetings. These meetings took place at three different phases in the project as follows:

Problem definition phase: This involved the processing of the needs observed during clinical immersion, their scoring and filtering.

Ideation phase: This involved developing ideas around a select few needs filtered at the problem definition phase.

Concept development phase: This involved the further development of design solutions centred around one particular need. Table 7.1 outlines the data.
### Table 7.1 Description of dataset

<table>
<thead>
<tr>
<th>Description of data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meeting 1: problem definition phase</strong></td>
<td></td>
</tr>
<tr>
<td>Content: Audio and transcript of meeting between members of the team</td>
<td></td>
</tr>
<tr>
<td>Present: All 4 team members and 1 researcher</td>
<td></td>
</tr>
<tr>
<td>Duration: 3hrs</td>
<td></td>
</tr>
<tr>
<td>Units of Analysis: Topic segments: 40. Utterances of Participants: 637</td>
<td></td>
</tr>
<tr>
<td><strong>Meeting 2: Ideation phase</strong></td>
<td></td>
</tr>
<tr>
<td>Content: Audio and transcript of meeting between members of the team</td>
<td></td>
</tr>
<tr>
<td>Communication medium between distributed members: Skype</td>
<td></td>
</tr>
<tr>
<td>Present: 3 of the 4 team members (Christy was not at this meeting) and 1 researcher</td>
<td></td>
</tr>
<tr>
<td>Duration: 1hr 25min</td>
<td></td>
</tr>
<tr>
<td>Units of Analysis: Topic segments: 37 Utterances of Participants: 348</td>
<td></td>
</tr>
<tr>
<td><strong>Meeting 3: Concept development phase</strong></td>
<td></td>
</tr>
<tr>
<td>Content: Audio and transcript of meeting between members of the team</td>
<td></td>
</tr>
<tr>
<td>Present: 3 of the 4 team members (Christy was not at this meeting) and 1 researcher</td>
<td></td>
</tr>
<tr>
<td>Duration: 50min</td>
<td></td>
</tr>
<tr>
<td>Units of Analysis: Topic segments: 34 Utterances of Participants: 274</td>
<td></td>
</tr>
</tbody>
</table>

### 7.2 DATA ANALYSIS

This case study followed a similar approach to the first case in terms of the analysis. The data was first divided into topic segments and instances of verbal consensus were noted within topic segments and at the end of sentences. Three steps in the coding process then followed this as outlined in Chapter 3. The findings are split into the three phases of problem definition, Ideation and concept development.

#### 7.2.1 How the activities enabled consensus during problem definition

49 topic shifts were identified at this phase of which 44 were preceded by verbal consensus. Of the 5 instances where consensus was not reached the previous topics were returned to when a team member wanted further clarification or when the topic moved forward without their explicit agreement. Agreement was then reached quickly. During two months of clinical observation 696 ‘need’ statements were collated by the team. The purpose of this meeting was to evaluate and score the needs with a view to selecting a limited number to bring forward to the ideation phase. In scoring the needs the team were required to define and explore the scope of each need. These decisions
were critical to the project as low scoring needs were quickly eliminated. The process took the team a number of weeks and a number of filtering criteria were applied to select the needs. In this meeting the team were scoring the needs against the filtering criteria of ‘provider impact’ and how if this need was addressed it would impact on the provider. The scoring range was between 1 and 5. The topic segment as outlined in Table 7.2 gives an example of how one need was assessed against the provider impact. The need was stated as:

*Need to ensure entering lungs is avoided during nasogastric (NG) tube intubation.*

NG tube intubation involves tube feeding patients that cannot be fed orally. In this topic reaching consensus takes considerable negotiation. Riona begins by suggesting a score to rate the ‘need’. Kieran does not respond directly to this and indicates that he is not ready to score the need and wants to consider the issue further when he refers to the factors involved; “ease of use and convenience”. Liam disagrees with Riona’s score and proposes a lower one. Riona disagrees with Liam. Negotiation is required to align the different perspectives. She uses *domain knowledge* to *argue* that patients need to get an x-ray to ensure the correct placement of the feeding tube. Kieran confirms this indicating support for Riona’s position at this point. Liam expresses doubt in this assertion and uses a *scenario* to argue that it will only be a five minute delay if “he goes into the lungs”. Riona uses her *domain knowledge* to argue that the medical practitioner will not know if the tube is in the stomach and that is why there is a need for an x-ray. She uses a *scenario* to elaborate on this and show that there could also be a delay in getting an x-ray. Kieran acknowledges Riona’s point and *argues* that an x-ray takes time and has a cost. Riona adds to her *argument* with the *scenario* that if the feeding tube goes into the lungs it will kill the patient. At this point Liam is not yet convinced and while there is shared knowledge amongst the team, common ground has not yet been established. He defers to Christy the medical doctor on the team for his input. Christy concurs with Riona’s point and uses his *domain knowledge*, a *scenario* and *mental simulation* to convince Liam of this. Liam continues to *argue*; “would the patient not be coughing and wheezing?” which would indicate any risk. Christy uses his *domain knowledge* with a *mental simulation* to provide a detailed account of the entire procedure and depicts the worst case *scenario*. His explanation fully convinces Liam who then suggests a score of four. Common ground has started to emerge and is finally established after further negotiations on the final score.
The scoring of this need involved consensus by all team members. A premature scoring was suggested at the beginning of the topic but the team were not fully informed with the relevant knowledge yet to make this decision. In delaying consensus they were required to first externalise the opinions and knowledge related to the decision, elaborate and negotiate on this information. This explains why there was an emphasis on: *arguing, scenarios* and *domain knowledge* to debate the important aspects of the problem. The requirement for a concrete decision appears to have promoted stronger negotiation from the team members. *Scenarios* and *mental simulations* were critical in explaining the risks involved. Christy’s *domain knowledge* and prior experience were instrumental in creating the *mental simulations and scenarios* to convince the other team members of the importance of this ‘need’. Once the other team members were convinced of the issues, common ground was reached enabling consensus. In reaching consensus in this topic the activities used were: *mental simulations, scenarios* and *arguing.*

**Table 7.2 Discussion on scoring a need**

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Riona:</strong> This is a 3 or a 4</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td><strong>Kieran:</strong> Ease of use, convenience</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td><strong>Liam:</strong> 2 or a 3</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td><strong>Riona:</strong> No. They have to go and get an X-ray before they can feed that patient.</td>
<td>CT, KP</td>
<td>Domain knowledge, arguing</td>
</tr>
<tr>
<td><strong>Kieran:</strong> That is what Bill said.</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td><strong>Liam:</strong> Surely it’s a minor improvement. If he goes into the lungs he just takes the tube out and it will just take another 5 minutes.</td>
<td>KP, CT</td>
<td>arguing, scenario</td>
</tr>
<tr>
<td><strong>Riona:</strong> But they don’t know if they are in the lungs or the stomach so they have to go off and get an X-ray. And they can’t get an X-ray immediately and it might take two days just to prove that the tube is in the stomach. If they think that.</td>
<td>CT</td>
<td>Arguing, scenario</td>
</tr>
<tr>
<td><strong>Kieran:</strong> Having to use an X-ray to verify costs and takes time. What’s the cost of an X-ray? It’s expensive isn’t it?</td>
<td>KP, CT</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Riona:</strong> But if they feed the patient and it’s in the lung they’ll kill him. 3</td>
<td>CT</td>
<td>Arguing, scenario</td>
</tr>
<tr>
<td><strong>Liam:</strong> Have you ever seen that Christy?</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td><strong>Christy:</strong> Oh yeah every time you insert a feeding tube you send them for an X-ray. <strong>CONSENSUS</strong> You have to. There are 2 types of NGs. There’s a drainage tube if someone is nauseous, it’s just for drainage you never put anything into it. You don’t need to X-ray that, you just throw it down. A feeding tube is a really thin white or yellow one. You never put anything through a feeding tube until you have established that it is in the stomach.</td>
<td>KP</td>
<td>Domain knowledge, scenario, mental simulation</td>
</tr>
<tr>
<td><strong>Liam:</strong> Would they not be coughing and wheezing?</td>
<td>CT</td>
<td>Arguing,</td>
</tr>
<tr>
<td><strong>Christy:</strong> A lot of the time people will be coughing and wheezing anyway when you put in an NG. It might hit the vocal chords</td>
<td>KP, CT</td>
<td>Domain knowledge,</td>
</tr>
</tbody>
</table>
going down. It mightn’t go in the right way. So it’s to establish if they have coughed because it’s gone into the trachea or because they have coughed because of the tube anyway. You need to check the position every time you start a feed. So they get a syringe and blow a bubble with it and they’ll put a stethoscope over the stomach and they’ll hear a bubble basically through the gastric contents. You’ll then take some contents so you’ll use a syringe to pull back and test the contents with some litmus paper. Usually it should turn blue or red but if it was in the lungs it wouldn’t. So they are the two tests that you always do to ensure the tube is in the stomach.

Liam: That’s only a 4 so.  
Riona: We should really give it a 5  
Christy: Well it’s every single NG.  
Kieran: Every single time?  
Christy: Yeah every single time.  
Kieran: So it’s very common  
Christy: Well having to X-ray is very common.

Christy: So it’s a three or a four I don’t know. A three, it’s not a huge problem either. It’s a problem if it has to be done on a Saturday and you have someone who has a stroke on a Thursday and you NG them on Friday afternoon and you can’t get an X-ray until Monday, they can’t be fed until after the X-ray on Monday. So that is an issue.

Kieran: ok 3 CONSENSUS

The next section addresses the ideation phase.

7.2.2 How the activities enabled consensus during ideation

37 topic shifts were identified during the team’s meeting of which 27 were preceded by verbal consensus. As this was a generative and exploratory phase in the project consensus was not required to shift topics. In some instances the team members simply moved to consider new ideas. There was no evidence of disagreement or conflict during this meeting. Of the 37 topic shifts 10 of these involved returning to previous topics to build on earlier ideas. The ideation meeting captures one of the team’s brainstorming sessions as they developed ideas around one of the final eight needs selected. The need is as follows:
Need a more time-efficient way to break down adhesions in patients during abdominal surgery.

The segment in Table 7.3 is about midway through the meeting. The focus was to explore a range of ideas rather than come to a decision on one solution. The team members applied mainly creative thinking as they generated alternative ideas. Common ground came about not through negotiation but more through the elaboration of information as team members responded and contributed to one another’s utterances. This was reflected in building on statements as team members helped one another to expand and develop ideas. Some of the ideas suggested were deliberately ‘wild’ as advocated by brainstorming guidelines (Kelley 2001). This often triggered building on which resulted in others taking what may not be a practical solution but developing it towards a more realistic idea. Mental simulations and analogies were key activities to explain ideas and ensure a shared understanding of information. There was only a very minor critique of the ideas with one use of arguing. Domain knowledge was used to provide information. In summary creative thinking dominates this topic and the conversation activities used were: domain knowledge, mental simulations, analogies and building on.

Table 7.3 Ideation discussion 1

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kieran: What if you just froze them and hit them with a hammer?</td>
<td>CRT</td>
<td>Mental simulation,</td>
</tr>
<tr>
<td>Riona: Yeah <strong>CONSENSUS</strong> no seriously yeah shatter them.</td>
<td>CRT</td>
<td>Building on</td>
</tr>
<tr>
<td>Kieran: Yeah <strong>CONSENSUS</strong> like they do for verrucas, nitrogen oxide and you just freeze it. And you get a mallet of some kind.</td>
<td>CRT</td>
<td>Mental simulation, Analogy, building on</td>
</tr>
<tr>
<td>Liam: Maybe if you just froze the centre of the adhesion like if the top of the thing just froze instantly and then you just cut it.</td>
<td>CRT</td>
<td>Mental simulation, building on</td>
</tr>
<tr>
<td>Kieran: with a hammer and anvil or something.</td>
<td>CRT</td>
<td>Building on,</td>
</tr>
<tr>
<td>Liam: A mini hammer.</td>
<td>CRT</td>
<td>Building on</td>
</tr>
<tr>
<td>Researcher: What do they use for verrucas it’s a solution isn’t it?</td>
<td>CRT</td>
<td>Analogy, building on</td>
</tr>
<tr>
<td>Riona: Liquid nitrogen.</td>
<td>KP</td>
<td>Domain knowledge</td>
</tr>
<tr>
<td>Researcher: Would you be able to put that inside the body</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td>Riona: Possibly not but something along those lines.</td>
<td>KP, CT</td>
<td></td>
</tr>
<tr>
<td>Liam: you might spill it.</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td>Kieran: You could put it on a swab so it doesn’t actually come out. You inject it through a long chord and a drop lands on a tip of a swab and you hit the swab off the adhesion.</td>
<td>CRT</td>
<td>Mental simulation, building on</td>
</tr>
</tbody>
</table>
Riona: Yeah CONSENSUS

Liam: Could you inject it into the adhesion? CRT Mental simulation, building on

Kieran: Yeah CONSENSUS that’s kind of like the sclerosis one where you inject liquid nitrogen. CT

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The topic shifts in Table 7.4 as Kieran looks at the problem laterally from another perspective. He needs to get support from his team members and to get this he must thoroughly explain his idea and convincing them of the merits of his proposal. He uses his domain knowledge and a mental simulation to externalise his idea for the team. Shared knowledge is established as Riona acknowledges her understanding and builds on the idea further. Kieran in turn builds on this and uses a mental simulation to further explain the idea. Consensus is reached at the end of the topic showing that common ground had been reached on the idea. Creative thinking was the main cognitive processes used. The conversation activities used were: domain knowledge, mental simulations, scenarios and building on.

Table 7.4 Ideation discussion 3

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kieran: What about going from the other angle instead of trying to address all the adhesions and trying to find all the adhesions just spending your time separating the fascial layer of the peritoneum cavity from everything else. I’d just work off of the fascia. The fascia is at the base of the peritoneum cavity, underneath that adheres the adhesions. So if you could go in and do a big kind of a blitz to free everything underneath the Fashia.</td>
<td>KP, CT, CRT</td>
<td>Domain Knowledge, scenario, mental simulation</td>
</tr>
<tr>
<td>Riona: A big swipe yeah. CONSENSUS</td>
<td>CRT</td>
<td>Building on</td>
</tr>
<tr>
<td>Kieran: And then you can inflate the whole thing properly and see where everything is.</td>
<td>CRT</td>
<td>Building on, mental simulation</td>
</tr>
<tr>
<td>Riona: Hmm that’s nice CONSENSUS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

In summary the ideation phase displayed generative reasoning in the exploration of ideas. Common ground came about as the team members built on each other’s ideas. It was less about the negotiation of consensus and more about being open to ideas being put forward by other team members and helping to further develop those ideas by contributing additional information or perspectives. It involved the elaboration of
information as team members responded and contributed to one another’s utterances. This was reflected in the building on statements as team members helped one another to expand and develop ideas. There were many instances where topics were returned to but this was mostly to explore earlier ideas further. This was a generative phase in the project with an increased emphasis on creative thinking. However critical thinking was also used not so much to judge ideas but to expand and analyse the problem further as ideas generated uncovered gaps in information about the problem state. The conversation activities used supported the cognitive processes and the development of common ground and in turn consensus. The conversation activities were often used together. For example a mental simulation could be embedded with an analogy to support idea generation.

7.2.3 How the activities enabled consensus during concept development

33 topic shifts were identified during this meeting of which 22 were preceded by verbal consensus. Of the remaining 11 topic shifts the topic moved to bring in additional points to the discussion before consensus could be reached. Four of the 13 topic shifts included instances where a team member returned to a previous topic. In two of these instances it was to return to a previous concept that was being discussed to consider it further. The remaining two topic returns involved returning to a topic to brief a team member who returned from leaving the room briefly.

At this stage in the process the team had selected a final need to develop a solution around. The need was as follows:

A need for an easier way to manage fecal matter from an ileostomy\(^2\) in a way that reduces the risks of skin complications and improves security in its management.

The team were aiming to reach consensus in the selection of a final concept. Consensus took time to achieve as solutions needed to be thoroughly critiqued and judged before team members could come to a decision. Differences in opinion forced the elaboration of and the analysis of the proposed solutions and strong negotiations to reach common ground. There were about three or four options that the team were working with to eliminate the risks of skin complications that occur with existing ileostomy bags. The meeting was focused on discussing the suitability of the options.

\(^2\) An ileostomy is an opening in the abdominal wall that’s made during surgery. The end of the ileum (the lowest part of the small intestine) is brought through this opening to form a stoma.
In Table 7.6 there is disagreement amongst the team and while information is externalised and shared, common ground is not established. Liam begins the topic by discussing the manufacture of the product. He has concerns with a proposal that Riona has put forward. He uses a **scenario** to **argue** that it adds complication to the manufacturing process. A series of counter **arguments** follow which are supported by **domain knowledge** and **scenarios**. In summary the activities used were: **domain knowledge**, **scenarios** and **arguing**. Common ground is not yet established and the topic shifts as outlined in Table 7.5.

**Table 7.5 Concept development discussion 2**

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Liam</strong>: I’m trying to think of it from a manufacturing point of view, as soon as you put this protrusion on it you have a different mode of selection, like what size is your stoma? It’s almost like you have to buy these as customised. I’m just thinking production line.</td>
<td>CT</td>
<td>Scenario, arguing</td>
</tr>
<tr>
<td><strong>Riona</strong>: It’s three different moulds.</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Liam</strong>: If it’s three different moulds it becomes more expensive very fast</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Researcher</strong>: But if they have to cut it to size would it be accurate enough?</td>
<td>CT</td>
<td>Scenario, arguing</td>
</tr>
<tr>
<td><strong>Riona</strong>: I wouldn’t allow them cut it at all. I think if we made it flat and this gives you your accommodation that might be enough, we might need to prove that or we might prove that you need two different sizes within the range.</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Kieran</strong>: I wouldn’t be worried about manufacturing that versus a flat in terms of a mould. This stuff is very easy to mould.</td>
<td>KP, CT</td>
<td>Domain knowledge, arguing</td>
</tr>
<tr>
<td><strong>Liam</strong>: The question is, are you manufacturing ten different sizes or can you customise it?</td>
<td>CT</td>
<td></td>
</tr>
<tr>
<td><strong>Researcher</strong>: That looks like it would stretch to any size</td>
<td>CT</td>
<td>Arguing</td>
</tr>
</tbody>
</table>

**KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition**

In Table 7.6 As agreement was not established in the previous topic Kieran shifts the topic to propose an alternative solution. The reaction to this solution is more positive reflected in increased **creative thinking** and **building on** to develop the idea rather than critique it. Kieran begins with a **mental simulation** to suggest how the idea would work. This is then further built on by both Riona and Kieran. Riona also contributes to the development of the idea by using **domain knowledge** to explain that there are bags that “are cut to size and ones that are pre-cut.” which Kieran acknowledges. An **analogy** is
also made to vacuum cleaners to further the concept. Through the co-development of the idea common ground is established between the team members with explicit consensus at the end of the topic. In summary the conversation activities that helped in achieving this were: domain knowledge, mental simulations, analogies and building on.

Table 7.6 Concept development discussion 3

<table>
<thead>
<tr>
<th>Examples</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kieran:</strong> The way I was thinking, this part could be stiffer and smaller or bigger but if you could get bags with a standard shape cut out that slots into that perfectly every time.</td>
<td>CRT</td>
<td>Mental simulation</td>
</tr>
<tr>
<td><strong>Riona:</strong> A snap fit</td>
<td>CT</td>
<td>Building on</td>
</tr>
<tr>
<td><strong>Kieran:</strong> And your inner flowery type opening always guides the fluid in. They still stick on to each other then you are sure that there is no contact with the skin. The problem there probably is this hole. Maybe you have to sell exclusively Holister bags with a standard hole size.</td>
<td>CRT, CT</td>
<td>Mental simulation, Building on</td>
</tr>
<tr>
<td><strong>Riona:</strong> There are two different options of bags, you can get ones that are cut to size and ones that are pre-cut, so they can sell a pre-cut.</td>
<td>KP</td>
<td>Domain knowledge</td>
</tr>
<tr>
<td><strong>Kieran:</strong> So they can do that.</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td><strong>Riona:</strong> So maybe just to further that if this was to go in you would nearly snap fit it in or that once it’s in, there is a rim that goes out this way in it, hooks into it. It might be harder to get it in but once it’s in; there is a lock on it.</td>
<td>CRT, CT</td>
<td>Mental simulation, building on</td>
</tr>
<tr>
<td><strong>Researcher:</strong> Like vacuum cleaners.</td>
<td>CRT</td>
<td>Analogy</td>
</tr>
<tr>
<td><strong>Kieran:</strong> That’s a clever mechanical lock all right but I would still be hoping that the adhesive we currently use in bags and manufacture would suffice to stick the bag onto whatever we have so that there is no leaking. But it would be a nice addition.</td>
<td>CT</td>
<td>Arguing</td>
</tr>
<tr>
<td><strong>Riona:</strong> I just thought that if you were getting direct contact between here and here that it is not touching the skin at all isn’t that it?</td>
<td>KP</td>
<td>Mental simulation</td>
</tr>
<tr>
<td><strong>Kieran:</strong> yeah that’s it. <strong>CONSENSUS</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The topic then shifts to get a consensus on a final direction see Table 7.7. Liam evaluates the product from the user’s perspective and uses a scenario to argue that there could be a leak path with smaller stomas. Riona argues that it may stretch to size and gives Liam a rough prototype to try. Liam considers the perspective of the user and in referring to a worst case scenario argues that a ring feature on the product would probably protect the user better than the current solution on the market. Riona argues that it could be about 95% effective and Liam agrees with this. The researcher refers to
one of the other concepts being proposed and argues that it may be a more simple yet effective design solution. Riona agrees to this and Liam who had been originally opposed to the idea comes around to agreeing to the solution. This solution is finally agreed on by the team. In summary the activities used were: scenarios and arguing.

In summary at the concept development phase decisions were required on the selection of concepts which prompted rigorous debate. Consensus could be described as difficult in this situation as the team members were trying to assess the viability of a number of concepts that were being put forward by different team members. It required negotiation to develop a shared understanding of each concept. This was critical as there was a risk of a concepts not getting support due to a lack of a clear understanding by all members on how it might work. Participants were required to critique ideas being put forward. It was up to those advocating for an idea to explain and defend the merits of a design and ensure that other team members could understand and agree with them. Critical thinking followed by knowledge processing was predominantly used as the team members explained and judged concepts. Building on was also used which reflected the
collaborative effort of the teams where members built on each other’s contributions to develop solutions. Consensus was often not reached easily and there was a strong emphasis on arguing as team members negotiated and attempted to persuade others. Arguing was often supported by scenarios and mental simulations to describe solutions and evaluate how effective they would be in different situations. At times the topic shifted to bring in further points in the discussion and it sometimes took more than one topic segment for the team to reach agreement on aspects of the project. When the topic shifted without consensus the team was able to look to an alternative solution. This avoided a stalemate position where consensus could not be reached. Having alternative solution options allowed the team to gravitate towards a preferred choice that the team could agree on.

7.2.4 Conclusion

This section has highlighted how consensus was reached across three different phases of the design process and shown variation between the phases. Whether consensus was explicitly required in shifting topics was dependent on the stage in the project and whether decisions were required. At the problem definition phase the team were scoring needs so explicit consensus was required to move through each need. This phase relied heavily on the domain knowledge of Christy to argue over the scoring. At the ideation phase the focus in contrast was on the exploration without the critiquing of ideas so decision making was not a focus. The building on statements which were prominently used reflected a high level of shared understanding amongst the team members as they built on each other’s ideas. Analogies and mental simulations also supported idea generation in both the generation and communication of ideas. The concept development phase required decisions on the selection of concepts. Critical thinking was mainly used to evaluate ideas which prompted some creative thinking in the proposal of modifications. Consensus was not easily achieved and involved strong negotiation with arguing which was regularly supported by scenarios. Having alternative solutions avoided a stalemate position where agreement could not be reached on a concept direction. The next section addresses issues of conflict amongst the team.

7.3 COGNITIVE CONFLICT

At times there was cognitive conflict between the team members. There were three topics that included conflict at the problem definition phase and three at the concept development phase. There was no conflict during ideation. Table 7.8 provides an example from the problem definition phase. The discussion is around whether the team
should factor in potential preventative measures within the scoring of the needs and how this could be measured. A decision is required and different perspectives on the matter prompt rigorous debate and negotiation. *Critical thinking* dominated the thinking during the topic with *arguing*. *Scenarios* were predominantly used to support *arguing* providing evidence and justification and clear examples for others. For example Christy *argues* that they have already factored in preventative measures in scoring the needs. He uses a *scenario* of “them taking their tablets right now” to *argue* that it “isn’t a saving for the health care service and we gave that a 4.” He argues that all the needs would have to be re-scored if that approach was taken. *Analogies* also supported arguments by drawing comparisons to other situations to justify claims being made. *Domain knowledge* was critical in swaying opinions and perspectives. Christy due to his *domain knowledge* was able to support his *argument* for example by making *analogies* to different health care conditions.

This topic has shown diversity in viewpoints which resulted in a moderate level of conflict as the team members disagreed with one another. Conflict had a positive effect in that it forced the elaboration and negotiation of the project information and the recognition of different perspectives. Liam provoked the conflict without holding a strong position reflected in the statement, “I don’t know, I’m not clear about it.” simply to elaborate on and debate the project information. This suggests that the conflict created was a strategy used to elaborate, negotiate and reframe the project information. What is achieved in this discussion is a thorough debate on whether preventative measures should be factored in to the filtering criteria. Important aspects of health care in terms of treatment versus prevention were raised which may have been overlooked had Liam not created the debate. Consensus was intentionally delayed but reached at the end of the topic with a degree of common ground. While the decision is not to change the scale, the team members recognise that it isn’t the perfect decision. however the decision allows the team to move forward to the next topic. The team had an enormous workload in filtering the needs and to add a new filter and rescore at this stage would have delayed the project. In summary *critical thinking* dominated the discussion with some *knowledge processing* to provide information. *Metacognition* was applied also as the team were reflecting on their approach to filtering the needs. The activities used to negotiate the conflict were: *Domain knowledge, scenarios, analogies, and arguing.*

<table>
<thead>
<tr>
<th>Table 7.8 Cognitive diversity and conflict</th>
<th>Cognitive processes</th>
<th>Conversation activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Examples</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Christy: The question there that you are bringing up Liam is if you have a device that prevents something will it be provided because it’s an immediate cost to pay for your device to save money down the line. But this is purely if you fix the need there’s going to be a saving to the health service. It doesn’t take into account when there is a cost to the health service. It’s purely about the impact is how I would read your criteria.

Liam: but even going into the G.P. If whatever the solution is and the G.P. is providing that, and it is a minor improvement in a care pathway. It can improve his efficiency and convenience in having to deal with something else. I don’t know, I’m not clear about it.

Kieran: What about if we built something in for preventative if we know it saves money down the line in prevention. Usually it saves money down the line in a health care system. Anything you can prevent is probably a massive saving down the line. So can we build something into the chart that if that is the case we give it a three?

Liam: I think we have to be very careful with that though. I’m not against it I’m just saying we have to be very careful about what the difference is between when we are assessing provider impact and what are the real cost savings. Because I think the way that we have defined it at the moment it’s almost a separate category, cost savings as a result of prevention.

Kieran: As a filter?

Liam: Yeah probably as a subsequent filter.

Christy: But you could argue that the one about compliance. I mean that’s a preventative cost saving.

Liam: It’s also enabling the provider to be more efficient because if as you said you have this old lady coming in late and you’re getting that information out of them in two minutes rather than an hour it’s making your job as a provider easier.

Christy: Oh that definitely is. If you scroll up, there’s one about compliance. See the top one a better way to instruct elderly patients how to follow their treatment plan in order to increase compliance and frequency of success. That scored a provider impact of 4 but you could say that the reason you want to do that is that you want to take your medications appropriately for example aspirin to prevent a stroke. So you want them to be compliant with their medication. Them taking their tablets right now isn’t a saving for the health care service and we gave that a 4. So if you take that stance a lot of them will have to be changed.

Liam: But it’s the treatment success. If it increases their treatment success. It’s like they are already in there and they need to get from A to B to be cured but if that is shortened from 6 months to 4 months because of better compliance that’s a better system measurable variable there.

Christy: I don’t know how that is different from if someone comes to your diabetic clinic and you diagnose them with peripheral neuropathy and you want them not to have this
huge cost of not developing an ulcer in six months’ time.

<table>
<thead>
<tr>
<th>Liam:</th>
<th>I know what you mean. CONSENSUS</th>
<th>CT, MC</th>
<th>Arguing, scenario,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I suppose it’s a question of once you.. One you’re talking about a specific treatment in a very defined pathway the other you are talking about a possible complication or side effect of having this disease. You’re coming with diabetes but you are trying to prevent a possible happening. I don’t know.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Christy:</td>
<td>it’s the same it’s not diabetes its peripheral neuropathy because its people you have assessed with peripheral neuropathy that you want to not have that complication. So it’s the same thing. In the other one you have assessed someone as having high blood pressure and you don’t want them to have a stroke. Or someone who is at risk of having a heart attack and you want to give them aspirin to prevent that. In my mind there is no difference. What are your thoughts on it?</td>
<td>KP, CT</td>
<td>Domain Knowledge, Arguing, scenario,</td>
</tr>
<tr>
<td>Kieran:</td>
<td>I still think it’s a very difficult one to gage on the scale we have. So I think we should build something into the scale to account for prevention.</td>
<td>MC</td>
<td>Arguing,</td>
</tr>
<tr>
<td>Liam:</td>
<td>I wouldn’t touch the scale. Even as it stands there is a lot built in there. If we build any more in I think we might dilute the effectiveness of the scale or else we need a separate filter.</td>
<td>MC</td>
<td>Arguing, Informed opinion</td>
</tr>
<tr>
<td>Kieran:</td>
<td>Well let’s answer in relation to the scale now.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Liam:</td>
<td>It’s fine is that what you mean? Just leave it as a 3?</td>
<td>KP</td>
<td></td>
</tr>
<tr>
<td>Kieran:</td>
<td>Yeah well sitting on the fence a bit and move on.</td>
<td>MC</td>
<td></td>
</tr>
<tr>
<td>Liam:</td>
<td>Yeah CONSENSUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kieran:</td>
<td>Yeah I’d say give it a 3.</td>
<td>CT</td>
<td>Informed opinion</td>
</tr>
</tbody>
</table>

KP: knowledge processing, CT: Critical thinking, CRT: Creative thinking, MC: meta-cognition

The next section looks at the frequency of use of the cognitive processes and conversation activities.

7.4 THE FREQUENCIES OF THE COGNITIVE PROCESSES AND CONVERSATION ACTIVITIES DURING TEAM DISCOURSE

This section addresses the break down and distribution of the cognitive processes and conversation activities during the team interactions across the three different phases of the project. This is the only case where the team carried out each of the three phases of the design process. The number of times a cognitive process and conversation activity was used in the data was counted to give the frequency and percentage of use. While most of the data was coded some utterances did not fall into any of these categories. The percentages were taken from the number of utterances made in each meeting, see Table 7.9. The total percentage often came to more than 100% as many of the
utterances could be coded to more than one cognitive processing or conversation activity type. The top three most frequently used conversation activities are shaded.

Table 7.9: Model of cognitive activities

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>problem definition utterances</th>
<th>ideation utterances</th>
<th>Concept development utterances</th>
<th>Total Frequency utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td>637 (100%)</td>
<td>348 (100%)</td>
<td>274 (100%)</td>
<td>1259 (100%)</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td>361 (57%)</td>
<td>114 (33%)</td>
<td>141 (51%)</td>
<td>614 (49%)</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td>2 (0.3%)</td>
<td>107 (31%)</td>
<td>23 (8%)</td>
<td>132 (10%)</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td>129 (20%)</td>
<td>26 (7%)</td>
<td>32 (12%)</td>
<td>187 (15%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>706 (110%)</td>
<td>387 (111%)</td>
<td>302 (110%)</td>
<td>1393 (110%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversation activities</th>
<th>problem definition utterances</th>
<th>ideation utterances</th>
<th>Concept development utterances</th>
<th>Total Frequency utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain knowledge</td>
<td>114 (18%)</td>
<td>42 (12%)</td>
<td>20 (7%)</td>
<td>176 (14%)</td>
</tr>
<tr>
<td>Analogies</td>
<td>17 (3%)</td>
<td>52 (15%)</td>
<td>10 (4%)</td>
<td>79 (6%)</td>
</tr>
<tr>
<td>Arguing</td>
<td>218 (34%)</td>
<td>18 (5%)</td>
<td>88 (32%)</td>
<td>324 (28%)</td>
</tr>
<tr>
<td>Mental simulations</td>
<td>13 (2%)</td>
<td>51 (15%)</td>
<td>26 (9%)</td>
<td>90 (7%)</td>
</tr>
<tr>
<td>Scenarios</td>
<td>91 (14%)</td>
<td>48 (14%)</td>
<td>31 (11%)</td>
<td>170 (14%)</td>
</tr>
<tr>
<td>Building on</td>
<td>28 (4%)</td>
<td>66 (19%)</td>
<td>26 (9%)</td>
<td>120 (10%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>467 (73%)</td>
<td>20 (78%)</td>
<td>201 (73%)</td>
<td>959 (76%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can coded to more than one category

There was a difference in the distribution of the cognitive processes used at each phase and a difference in the emphasis of the conversation activities as a result. The problem definition phase and the concept development phases were not dissimilar but the ideation phase had a significantly different emphasis. Figure 7.1 shows that as creative thinking increased at the ideation phase critical thinking decreased.

Critical thinking was high at the problem definition phase as the teams needed to evaluate the needs statements in terms of its clinical, patient, provider and commercial impact. During ideation creative thinking increased as this phase was predominantly generative and divergent where the participants brainstormed potential ideas. However critical thinking was still mainly used throughout this phase at 33%. As this was a brainstorming meeting creative thinking would have been expected to be more frequently used, however the findings show that in order to come up with creative solutions further analysis was required of the problem and of existing solutions and applications in other fields. There was also a limited amount of critiquing of proposed solutions. This is counter to the guidelines in the literature on brainstorming which states that the aim of
brainstorming is for divergence and not convergence and that ideas should not be
criticised and judged (Matthews 2009, Kelley 2001). However evaluations and some
level of critique were found to be productive for the teams as it allowed them to make
suggestions that would improve on initial ideas. Critical thinking also reflected co-
evolution; as ideas created uncovered a need for further information about the problem

At the concept development phase the frequency of the cognitive processes was similar
to that of the problem definition phase. Critical thinking was mainly used at 51%. While
the team were still progressing ideas and concepts the focus was more on critiquing and
evaluating proposed concepts and negotiating agreement on the selection of a solution.

Knowledge processing was the second most prominently used cognitive process overall
and was consistent across phases. This highlights the emerging nature of design
showing that knowledge is constructed throughout the process.

Meta-cognition showed a strong parallel to critical thinking with similar pattern of use
across the phases. While it was less frequently used it was significantly used particularly
at the problem definition phase, the most uncertain phase of the project as the team
were periodically planning, evaluating and monitoring their progress. It was least used at
the ideation phase showing that brainstorming is less controlled by self-reflection. Both
critical thinking and metacognition were also associated with the phases that required
explicit consensus and decision making and increased negotiation to reach common
ground.
Figure 7.1 The distribution of the cognitive processes across the design phases

The emphasis of the cognitive processing used at the different phases is also reflected in the conversation activities used, see Figure 7.2. The ideation phase is again significantly different to the other two phases. Arguing was the most frequently used activity at the problem definition and concept development phases showing its association to critical thinking and metacognition. It drops dramatically at the ideation phase where creative thinking is at a high frequency. Arguing was not compatible with creative thinking as the focus during ideation was on exploration without imposing judgements or critique. Analogies, mental simulations and building on are also at their highest at the ideation phase linking them to divergent and creative thinking. The high frequency of building on at the ideation phase shows that the interaction between members was more assistive and was opposite in frequency patterns to arguing. Domain knowledge was used most frequently at the problem definition phase dropping steadily across the subsequent phases highlighting its importance at the initial phases of a project. Scenarios were used consistently across phases dropping slightly at the concept development phase. This shows that they are not associated with a particular phase or a cognitive process highlighting their flexibility in being applied to support different thinking and reasoning across phases.
With regard to consensus the findings show that the generative phase of ideation supports the co-elaboration of information to collaboratively build common ground while the problem definition and concept development phases to a lesser degree requires increased negotiation to reach common ground.

7.5 CHAPTER CONCLUSIONS

This case has described the cognitive processes and conversation activities used by a trans-disciplinary team to reach consensus during the three phases of the design process: problem definition, ideation and concept development. It highlights the challenges that arose for the team members, including conflict and how this was managed. The findings have confirmed many of the findings from the other cases with additional insights. The findings also validate the conceptual model to show that the teams followed the consensus process in the externalising, internalising and negotiation of knowledge to reach common ground and in turn consensus.

The cognitive processes and conversation activities used across the ideation phase was significantly different to the other phases and this was due to the purpose of this phase. The ideation phase was divergent and generative and emphasised exploration and the co-elaboration of information to collaboratively build common ground. In contrast the problem definition and concept development phases required much more convergent
thinking in the analysis of information and decision making. This resulted in increased
technique to reach common ground. The problem definition phase therefore saw an
emphasis on critical thinking and metacognition as the focus was on the elaboration and
analysis of information. The main conversation activities used were: arguing and
scenarios reflecting persuasive behaviour to negotiate consensus. At the ideation phase
the focus was on generative thinking and the communication of ideas with a sharp
increase in creative thinking. Building on, analogies and mental simulations were
frequently used showing the co-elaboration and shared building of ideas. At the concept
development phase the focus was on the evaluation, development and selection of
concepts with a return to persuasive behaviour with emphasis on critical thinking, domain
knowledge, arguing, and scenarios.

The co-evolution of the problem and solution occurred at the ideation and concept
development phases to different degrees accounting for the high levels of critical thinking
to analyse the problem as well as solutions.

The conversation activities were often used in combination. For example scenarios and
anallogies were used to support arguing. Mental simulations were often embedded in
anallogies. Domain knowledge was critical to this project and effective use of the other
conversation activities such as arguing and scenarios. Experts with domain knowledge
were in a better position to persuade others to their view.

Conflict occurred at the problem definition and concept development phases only. These
phases required decision making. Conflict required increased negotiation to reach
common ground and was associated with critical thinking, arguing and scenarios.
Conflict had a positive role and was often instigated intentionally in a ‘devil’s advocate
approach’ to force the elaboration of information, iterative framing of information and the
delay of early consensus. This ensured that all aspects of the project were fully
elaborated on and considered before decisions were taken. In contrast the activities
used in the ideation phase reflected more assistive and collaborative behaviour where
building on showed how team members internalised others contributions and made
subsequent contributions by building on those ideas.
8 Cross Case Analysis

While the four previous chapters have presented the four cases in the study separately this chapter makes a comparative analysis of all four. The goal is to compare the findings in each case. As outlined in the literature, maximum variation cases were selected in order to understand if similarities can be drawn across different design and innovation settings. This chapter seeks to account for the difference that arose between each case. The comparisons are presented under the following headings:

Section 8.1 compares the cognitive processes and conversation activities used across each case.

Section 8.2 compares the cognitive processes and conversation activities used at the problem definition, ideation and concept development phase.

Section 8.3 compares how novices and experts used the cognitive processes and conversation activities.

Section 8.4 describes the role of the cognitive processes and conversation activities in relation to conflict and consensus.

Section 8.5 presents the chapter conclusions.

8.1 THE COGNITIVE PROCESSING AND CONVERSATION ACTIVITIES

Table 8.1 lists in order of prevalence the most commonly used cognitive processing and conversation activities used across the four cases. The cognitive processes alternated between divergent and convergent thinking with knowledge processing and creative thinking corresponding to divergent thinking in the gathering of information and the search for solutions. Critical thinking and meta-cognition corresponded to convergent thinking with the analysis of information and the teams own performance.
### Table 8.1: The cognitive processing and conversation activities used in ranked order across the cases and all phases

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>1. CRITICAL THINKING (40%)</th>
<th>2. KNOWLEDGE PROCESSING (34%)</th>
<th>3. META-COGNITION (27%)</th>
<th>4. CREATIVE THINKING (7%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversation activities</td>
<td>1. Arguing (22%)</td>
<td>2. Building on (17%)</td>
<td>3. Domain knowledge (14%)</td>
<td>4. Scenarios (12%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5. Mental simulations (7%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6. Analogies (5%)</td>
</tr>
</tbody>
</table>

*Critical thinking* was the predominant processing type used highlighting the high degree of negotiation of information that takes place between teams to reach agreement. *Critical thinking* was applied to negotiate the meaning of utterances and negotiate the position to take on the information being put forward. *Knowledge processing* was the second most frequently used processing type highlighting the significant proportion of time that teams will spend in exchanging knowledge. *Meta-cognition* accounted for almost a third of the activities to show that consensus reaching in teams also requires strategizing how to progress the project and monitoring the performance of the team. Much of the literature in design has emphasised the importance of *creative thinking* for designers. Designers are expected to be strong creative thinkers yet this study shows that *creative thinking* only makes up a small proportion of a designers cognitive processing, even at the phases that are considered to be most creative. It was the exchange and the negotiation of information that dominated the team’s activities with *creative thinking* contributing to only 7%. Arguing was the main conversation activity used showing how consensus reaching in design teams requires negotiation and persuasion. However the high levels of *building on* also shows that there are times when common ground is collaboratively built where contributions support and develop on previous utterances. *Domain knowledge* is the critical foundation to support the cognitive processes along with *scenarios, mental simulations* and *scenarios*. The key findings from this section are that:

- In reaching consensus through common ground the findings have confirmed that the teams alternated between 4 cognitive processes: *critical thinking, knowledge processing, meta-cognition* and *creative thinking.*
• The teams engaged mainly in critical thinking and knowledge processing to exchange and negotiate on information. Only minimal levels of creative thinking were used.

• The process can require strong negotiation reflected in high levels of arguing but also collaborative co-elaboration reflected in building on.

• The process was better enabled by domain knowledge, scenarios, mental simulation and analogies.

To further understand how these cognitive processes and conversation activities were used the next section examines their use at the different phases of the design process.

8.2 HOW THE COGNITIVE PROCESSES AND CONVERSATION ACTIVITIES WERE USED AT THE DIFFERENT PHASES IN THE PROJECTS

The focus of the studies was on the problem definition, ideation and concept development phases of the design process. However not every case study captured each phase. Table 8.2 shows which phases were applied in each case.

Table 8.2: The phases of the design process captured for each team across all cases

<table>
<thead>
<tr>
<th></th>
<th>Bio 1 Team A</th>
<th>Bio 1 Team B</th>
<th>Undergrad. Team A</th>
<th>Undergrad. Team B</th>
<th>Professional Practice</th>
<th>Bio 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Problem Definition</strong></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Ideation</strong></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td><strong>Concept development</strong></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Only two cases could be compared for the ideation and concept development phases. This is a limitation of the study and the findings may not be generalizable, as factors other than the design phase may account for the results found. Only the problem definition phase was captured from the Bio-innovate 1 case as a team member wished not to be recorded during later phases feeling it may impact on his performance. The professional practice meeting was predominantly a problem definition meeting and has been defined as such for cross case comparisons. However, the team, due to the nature of the project also came up with ideas in this meeting. They did not hold specific ideation meetings and further design developments were done by individuals. Table 8.3 provides in order of frequency the cognitive processing and conversation activities used for each phase. Figure 8.1 shows the distribution between the cognitive processes at each phase and Figure 8.2 shows the distribution between the conversation activities at each phase.
There are marked differences between the phases which was due to the different objectives at each phase of the design process further impacting on the role of consensus. These findings are further discussed.

Table 8.3: The order of ranking the activities for each phase across all of the cases

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Problem definition</th>
<th>Ideation</th>
<th>Concept development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>CRITICAL THINKING (43%)</td>
<td>KNOWLEDGE PROCESSING (36%)</td>
<td>KNOWLEDGE PROCESSING (47%)</td>
</tr>
<tr>
<td>2.</td>
<td>META-COGNITION (35%)</td>
<td>CRITICAL THINKING (31%)</td>
<td>CRITICAL THINKING (38%)</td>
</tr>
<tr>
<td>3.</td>
<td>KNOWLEDGE PROCESSING (31%)</td>
<td>CREATIVE THINKING (23%)</td>
<td>META-COGNITION (14%)</td>
</tr>
<tr>
<td>4.</td>
<td>CREATIVE THINKING (2%)</td>
<td>META-COGNITION (13%)</td>
<td>CREATIVE THINKING (6%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversation activities</th>
<th>Problem definition</th>
<th>Ideation</th>
<th>Concept development</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Arguing (23%)</td>
<td>Building on (18%)</td>
<td>Arguing (24%)</td>
</tr>
<tr>
<td>2.</td>
<td>Building on (19%)</td>
<td>Scenarios (16%)</td>
<td>Scenarios (10%)</td>
</tr>
<tr>
<td>3.</td>
<td>Domain knowledge (16%)</td>
<td>Arguing (12%)</td>
<td>Building on (7%)</td>
</tr>
<tr>
<td>4.</td>
<td>Scenarios (13%)</td>
<td>Analogies (12%)</td>
<td>Mental simulations (6%)</td>
</tr>
<tr>
<td>5.</td>
<td>Mental simulations (4%)</td>
<td>Mental simulations (9%)</td>
<td>Domain knowledge (5%)</td>
</tr>
<tr>
<td>6.</td>
<td>Analogies (3%)</td>
<td>Domain knowledge (7%)</td>
<td>Analogies (3%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can coded to more than one category

Figure 8.1 The distribution of the cognitive processes across the design phases
Figure 8.2 The distribution of the conversation activities across the design phases

8.2.1 Knowledge processing across phases

Knowledge processing was at significant levels at the problem definition phase and continued to rise further across the phases of the project. This shows that knowledge is emergent throughout the process and not just a focus at the problem definition phase. The problem definition phase for these cases was typically unstructured and teams were required to determine from very open briefs the project requirements and the course to take to progress through the project. High levels of domain knowledge were necessary to gather and structure the project information. The exchange of information was a collaborative process reflected in the high levels of building on as team members built on one another’s contributions.

At the ideation phase the frequent use of knowledge processing can be attributed to the co-evolution account in the literature of creative design which is not a ‘creative leap’ from the problem to the solution space but an evolution of both where one informs the other. As solutions are developed the problem space evolves accordingly (Maher and Tang 2003, Dorst and Cross 2001). While creative thinking was used to generate solutions the teams applied knowledge processing to explain ideas and gather further information as the creation of ideas created new gaps in knowledge. Communication was supported by the use of scenarios, analogies and mental simulations. Therefore the building of knowledge was a stimulus for creating new ideas. Consensus at the ideation phase was
achieved by ensuring that ideas were well communicated facilitating the further
generation of ideas. Common ground therefore was instrumental in the co-creation and
proliferation of ideas. Consensus at this phase was required also on the re-framing of the
problem and the construction of new knowledge as ideas created posed new questions.

At the concept development phase *knowledge processing* was at its highest level to
show that information exchange is critical in the explanation of concepts and the
continued processing of emergent information. As new information emerges it must be
elaborated and agreed upon.

### 8.2.2 Critical thinking across phases

*Critical thinking* was at its highest level at the problem definition phase to show that
structuring and defining a problem requires significant critical analysis. Once information
was shared *critical thinking* was applied in a sense making process where emphasis was
placed in finding relationships and patterns between elements. With the use of
*knowledge processing* to expand the problem space and related information, *critical
thinking* was used to structure and analyse this information.

Once information was shared it was discussed, elaborated, refined, debated, negotiated
and then embraced, or rejected by others. Consensus building at this phase was both
collaborative and persuasive. *Critical thinking* however was more associated with
negotiation and persuasion to bring about conceptual change and align opposing
perspectives. *Arguing* was associated with *critical thinking*. *Domain knowledge*
and *scenarios* were key activities that supported *arguing*. Those with the greater level of
*domain knowledge* were better equipped to *argue* their point and were then supported by
*scenarios* in providing evidence and examples.

While *critical thinking* dropped at the ideation phase it was still used significantly which
can also be attributed to co-evolution. Rather than critiquing solutions the teams used
*critical thinking* for further analysis of the problem as ideas posed new questions about
the problem space and uncovered emerging sub problems and constraints. For example
ideas proposed could involve a radically new way of doing something leading the team to
re-examine new aspects of the problem. Common ground and consensus was required
on reframing the problem. The following is an example of this co-evolution process from
the Undergraduate case B team. The team had established that they needed to provide
a changing room for the FAs. Brian *proposes* using the area under the stairs in the crew
rest. Upon the creation of the idea the team then recognise that they need to gather more information about this area and analyse it further. Lisa argues that they need to know more about the problem state before they continue to propose solutions for this:

Brian: “I think from the pictures from Driessen that the space under the stairs is used as storage. We could convert that into some sort of changing room. We could be more creative with our storage space.”

Lisa: “But in reality, we need to get the size of that because there is no point in saying we’re putting it in there and then we can’t physically get it in there. We need to know the rise of it and the slope.”

Analogies also supported critical thinking. By evaluating related problems the current problem could also be re-evaluated. Mental simulations also supported evaluation by taking a step by step walk through of a product’s functions. Scenarios likewise had the role of imagining and predicting new design solutions and how users would behave and interact with them.

The emphasis at the concept development phase was on the analysis and development of concepts. As the co-evolution of problem and solution continued non-viable solutions had been dropped and the teams were focused on refining a few select options. As ideas were advanced and analysed the associate problem details were also analysed. Analysis involved the examination of how solutions might fail and the possible associated problems that could be created as a result. So while the ideation phase was collaborative the concept development phase returned to being more persuasive requiring negotiation as ideas were critiqued and defended accounting for the high levels of arguing. Consensus was required on the selection of solutions. Critical thinking was supported by scenarios which were mainly used to support arguments. Building on at the concept development phase was necessary not just to build on other’s ideas but to also build on the arguments of others.

8.2.3 Creative thinking across phases

As creative thinking levels increased critical thinking levels decreased. Creative thinking was used least at the problem definition phase. This is surprising as creative thinking is considered to be a core skill for designers. Many studies suggest that designers move rapidly to early solution conjecture using this as a means to further explore the problem (Cross 2004). The findings show that due to the increased complexity of design
problems, teams must first structure the problem before any solution searching can proceed. The problem definition phase in this study was predominantly independent of solution generation and the Bio-innovate teams were also encouraged to avoid solution focusing at this phase. Solution focusing at this point could start to narrow the focus of the problem space too early and limit the scope for new ideas bringing about premature consensus.

The focus at the ideation phase shifted as teams moved from the analyses of the problem to the creation of solutions. Creative thinking increased and was at its highest level while critical thinking decreased to its lowest level. The objective at this phase was to create multiple options and novel solutions which require divergent and creative thinking. Analogies, mental simulations and scenarios increased significantly at the ideation phase and can be associated with creative thinking. Analogies were used at this phase to transfer ideas from other products and applications to create new ideas. By making comparisons to something that was readily understood individuals were able to achieve a shared understanding of an idea.

At the concept development phase the critique of solutions also stimulated some creative thinking in the optimising and refinement of concepts. So while critical thinking was evaluative aimed at seeking consensus on ideas, creative thinking avoided premature consensus by assisting teams to explore other options. As outlined earlier knowledge processing also supported creative thinking to explain ideas and gather further information as ideation created gaps in knowledge.

The following is an example of this interchange between knowledge processing, critical thinking and creative thinking. Riona uses knowledge processing with a mental simulation to explain a proposed concept. Once Liam understands the concept, he analyses it and uses critical thinking to argue (with the use of a scenario) that the product may not function correctly. The evaluation prompts Riona to use creative thinking to further build on the idea.

Riona: “Yeah It comes from the base out to there like this, bear with me. Say this is flush with the skin and then this from the side is protruding out there.”  
Liam: “Yeah but it still begs the question, I’m just imagining if drips come out here they are going to be funnelled back.”
Riona: “yeah there would have to be a seal. Like what you said there, can you bring it out and let it funnel into the bag. There is the same splash back there as well and much more of a possibility of leaking.”
8.2.4 Meta-cognition across phases

Meta-cognition was also at its highest levels at the problem definition phase dropping significantly over the next two phases. This reflects the highly unstructured and uncertain nature of this phase and the need to strategize how to structure the problem elements. Meta-cognition was most frequent at this phase to strategize how to solve the problem and make order out of chaos in organizing and structuring disparate information. It was linked to resolving uncertainty and involved teams repeatedly reviewing their own progress, recognizing the gaps in knowledge to solve the problem and reflecting on the effectiveness of their progress. As the teams structured and restructured and created a shared representation of the problem elements meta-cognition was used to plan, monitor and evaluate the team approach.

The following is an example where the Bio-innovate 2 team monitors how the team are handling one of their ‘needs’ (requirements that came from their research findings). There is a difference between Christy’s and Kieran’s interpretation of the requirement. Christy argues that the criteria Kieran uses are not written into the ‘need’. In applying his domain knowledge he argues why convenience is an important factor in the assessment of the need. Through his application of critical thinking to assess the ‘need’ and metacognition to monitor and evaluate how the team has managed this ‘need’ he convinces Kieran to incorporate these “measurable outcomes”. He has managed to elevate the importance of the ‘need’ and get consensus.

Christy: “You said you want to achieve real time feedback of blood pressure through a non-invasive technique.”

Kieran: “Efficiency and convenience, they’re the two benchmarks.”

Christy: “Well that’s not how it’s written in the needs statement. Are we just assuming that it is and we score it through non-invasive techniques, to make the procedure more accessible and convenient? In my mind if the need statement was need a way to provide real time feedback of blood pressure to the clinician, then in my mind it scores at least a three because it’s completely inaccessible at the moment, invasive monitoring. There are complications which cost money and it requires a HDU overnight.”

Kieran: “Fair enough, I think that is where that one was going too. There’s no measurable outcome in the needs statement. If we can build those in as measurable outcomes then you’re definitely addressing convenience at least or access.”
Critical thinking and meta-cognition were often combined, while critical thinking was focused on the analysis of the task, meta-cognition focused on the analysis of the team performance. Therefore it can be argued that the un-structured nature of this phase calls for critical thinking and meta-cognition, as diversity of information and opinions are analysed and structured.

In summary the findings show that the objectives during each phase can vary and will impact on how consensus is reached. Consensus requirements change as the emphasis shifts from problem structuring and analysis at the problem definition phase to solution generation at the ideation phase and then a return again to problem analysis at the concept development phase. These variations impacted on the cognitive processing and conversation activities used.

The key findings from Section 8.2 are:

The cognitive processing and conversation activities used to reach consensus were dependent on the objectives at each phase of the design process.

- Knowledge processing increased across the design phases to show that the requirement to agree on new information continues throughout the process.
- Critical thinking was at high levels across all phases of the design process dropping only slightly at the ideation phase.
- Creative thinking was at low levels across all phases rising significantly only at the ideation phase. During concept development creative thinking helped to avoid early consensus on solutions by exploring other options.
- Meta-cognition was at high levels at the problem definition phase to manage the uncertainty and diversity in perspectives at this phase.
- When critical thinking and metacognition (convergent in nature) levels were high creative thinking (divergent in nature) was at low levels.
- Analogies, mental simulations and scenarios were linked to creative thinking and increased significantly at the ideation phase.
- Arguing was linked to critical thinking and featured strongly at the problem definition and concept development phases. Domain knowledge and scenarios supported arguing

These findings are further explored in the next section by comparing the differences between the cases with regard to the levels of expertise.
8.3 THE DIFFERENCES BETWEEN EXPERT AND NOVICES

The professional practice team could be described as the most experienced of the teams as they were the longest established team, working together on similar projects for more than ten years. The Bio-innovate 2 team were the second most experienced team as all members had worked within their discipline for a minimum of 5 years and the team was established six months. This was followed by the Bio-innovate 1 teams who had similar levels of expertise but were newly formed. The Undergraduate teams are considered as novices as they were students and involved newly formed teams.

The experts had a higher frequency of cognitive processing per utterances than the novice teams. Many of the utterances expressed by novices could not be assigned to a cognitive process type. These were statements that were either off the topic and not task focused, or statements that did not contribute to the project. This suggests that the expert’s utterances were more productive and aimed at both the development of common ground and the progression of the project. The experts also had more utterances that displayed more than one cognitive process showing for example that they could in one utterance share information but also apply a critical analysis of that information.

Experts appeared to be better at strategizing how to conduct the projects, and reflecting on their progress. The information exchange between the novice teams was at a more surface level lacking the depth of critical analysis shown by the experts. While consensus reaching for the novice teams was not necessarily difficult it was at times premature, coming at the expense of the elaboration and analysis of the project information. There were also differences in the conversation activities used between the more expert and novices teams. The experts had a higher frequency of conversation activities per utterances than the novice teams. The undergraduate teams used the least amount of conversation activities at 35% for Team A and 73 % for Team B.

The differences are examined in further detail at the different phases of the projects.

8.3.1 The differences between experts and novices at the problem definition phase

Table 8.4 compares the cognitive processes and conversation activities between cases at the problem definition phase.
Table 8.4: A comparison of the cognitive processing and conversation activities used at the problem definition phase (top cognitive processing shaded & top 4 conversation activities shaded)

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Undergrad. Team A Frequency 102 utterances</th>
<th>Undergrad. Team B Frequency 134 utterances</th>
<th>Bio. 1 Team A Frequency 431 utterances</th>
<th>Bio. 1 Team B Frequency 503 utterances</th>
<th>Bio-innovate 2 Frequency 637 utterances</th>
<th>Prof. practice Frequency 401 utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge processing</td>
<td>22 (22%)</td>
<td>64 (48%)</td>
<td>85 (20%)</td>
<td>169 (34%)</td>
<td>214 (33%)</td>
<td>125 (31%)</td>
</tr>
<tr>
<td>Critical thinking</td>
<td>30 (29%)</td>
<td>55 (41%)</td>
<td>132 (31%)</td>
<td>151 (30%)</td>
<td>361 (57%)</td>
<td>218 (54%)</td>
</tr>
<tr>
<td>Creative thinking</td>
<td>4 (4%)</td>
<td>4 (3%)</td>
<td>1 (0.2%)</td>
<td>13 (3%)</td>
<td>2 (0.3%)</td>
<td>27 (7%)</td>
</tr>
<tr>
<td>Meta-cognition</td>
<td>43 (42%)</td>
<td>18 (13%)</td>
<td>282 (65%)</td>
<td>267 (53%)</td>
<td>129 (20%)</td>
<td>38 (9%)</td>
</tr>
<tr>
<td>Total</td>
<td>99 (97%)</td>
<td>141 (105%)</td>
<td>500 (116%)</td>
<td>600 (119%)</td>
<td>706 (110%)</td>
<td>407 (101%)</td>
</tr>
<tr>
<td>Conversation activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domain knowledge</td>
<td>0 (0%)</td>
<td>2 (1%)</td>
<td>42 (10%)</td>
<td>97 (19%)</td>
<td>114 (18%)</td>
<td>107 (27%)</td>
</tr>
<tr>
<td>Analogies</td>
<td>5 (5%)</td>
<td>12 (9%)</td>
<td>4 (1%)</td>
<td>18 (4%)</td>
<td>17 (3%)</td>
<td>19 (5%)</td>
</tr>
<tr>
<td>Arguing</td>
<td>3 (3%)</td>
<td>12 (9%)</td>
<td>60 (14%)</td>
<td>81 (16%)</td>
<td>218 (34%)</td>
<td>135 (34%)</td>
</tr>
<tr>
<td>Mental simulations</td>
<td>1 (1%)</td>
<td>0 (0%)</td>
<td>1 (0.2%)</td>
<td>2 (0.3%)</td>
<td>13 (2%)</td>
<td>80 (20%)</td>
</tr>
<tr>
<td>Scenarios</td>
<td>11 (11%)</td>
<td>25 (19%)</td>
<td>78 (18%)</td>
<td>71 (14%)</td>
<td>91 (14%)</td>
<td>22 (5%)</td>
</tr>
<tr>
<td>Building on statements</td>
<td>22 (21%)</td>
<td>24(18%)</td>
<td>143 (33%)</td>
<td>181 (36%)</td>
<td>28 (4%)</td>
<td>31 (8%)</td>
</tr>
<tr>
<td>Total</td>
<td>42 (41%)</td>
<td>75 (56%)</td>
<td>328 (76%)</td>
<td>449 (92%)</td>
<td>467 (73%)</td>
<td>394 (98%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can coded to more than one category.

The more experienced teams applied more **critical thinking** associated with higher order thinking, problem solving reasoning and decision making. This was reflected in their ability to analyse and negotiate a shared understanding of the project information.

The expert teams spent more time analysing information, investigating cause and effect relationships, identifying patterns and relationships and forming judgements. The Undergraduate teams, the most novice of the teams used **knowledge processing** most frequently. This was more focused on the exchange of information rather than the critical analysis of that information. Figure 8.3 and 8.4 graphs the distribution of the conversation activities from the novices to more expert teams at the problem definition phase.
The novice teams particularly the undergraduate Team B used less *domain knowledge*, less *arguing* and less *mental simulations* than the more experienced teams. *Domain knowledge* was the foundation to the construction of discipline specific knowledge and the ability to explore and analyse the project in breadth and depth. The novices were hampered by their lack of *domain knowledge* and prior experience. Not only did the expert teams have more *domain knowledge* but they were able to apply it to *critical thinking* to analyse the project information. They used *domain knowledge* to expand the problem space, form strong judgements and support *arguments*. The following compares...
two examples. The first involves the Undergraduate Team A as they try to establish factors that would affect the quality of the experience when in a crew rest. While the team identify that fresh air is important there’s no expansion or critical analysis of the subject. While there is consensus, it is an easy consensus. The novice team also show high levels of metacognition. While metacognition can reflect higher order thinking the findings also show that it can be linked to uncertainty and unsureness. The focus for this team was more about considering what the next item was to address and the management of the project rather than on the critical discussion needed to expand the problem space. Where critical thinking did occur it was still at a surface level without expansion.

Rachel: “What else can we say?”
Kieran: “The air”
Rachel: "Oh yeah the air."
Kieran: "Cool clean fresh air."
Rachel: "So just put in air and put in cool clean and fresh."
James: "So we’re doing well here on freshness just looking at it."

The level and quality of arguing was also a differentiating factor between the experts and novices. The following example from the Professional practice case shows that they were able to apply a deeper level of analysis with stronger arguments. Harry provides his analysis of the Clients program. As shown in Section 8.2 domain knowledge and scenarios were key activities that supported arguing. In applying his domain knowledge he is able to establish with conviction good design from bad. He argues using a scenario to predict that the first time experience is going to be confusing. This convinces Fay who agrees.

Harry: The first time experience is going to be really confusing because it doesn’t really tell you what it does in any way. Even the iconography is pretty abstract and so they would almost be better with text which they used to have funnily enough. A lot of UI conventions are broken unnecessarily making the whole UI counter intuitive. For example drop downs are very standard thing which they have managed to mess up. Data visualization is clumsy and inefficient and leads to unnecessary scrolling.

Fiona: Crazy yeah

In addition there was a rise in the use of mental simulations amongst the experts. This activity is also linked to domain knowledge as it requires the knowledge of the step by
step interaction with a process. In contrast while the novice teams were able to argue they were less informed. The more expert teams were better able to draw on prior learning to make inferences. The experts particularly in the professional practice case were able to make estimates on unknown information based on having solved related projects. They were able to estimate the intentions of their client as follows:

Harry: “I know what’s going on, there is an opportunity and the way you make that tick is through those. So that must be yes, no and unknown.”
Fay: yeah the alt text is wrong.
Harry: “Yeah I think so. It has to be.”

Likewise in the Bio-innovate cases team members were able to make inferences as to the consequences of solving particular needs. These inferences enabled them to make judgements which in turn were used to construct knowledge and persuade and convince others to adopt a position.

The Professional Practice team and the Bio-innovate 2 teams, in their use of critical thinking were able to question and not necessarily accept information or practices as being correct. The use of arguing meant that these teams did not reach a premature or easy consensus and when consensus was reached it was due to a thorough critique and exploration of the project elements. These findings also support the literature to show that experts will spend more time in defining the problem, activating prior knowledge, elaborating on the information presented (Brand-Gruwel et al. 2005). This had a positive effect on the development of common ground. This would suggest that experts may delay consensus in order to have a thorough negotiation of the project information and a shared representation that in turn will bring about better consensus. In the following example in the Bio-innovate 2 case Christy questions how a ‘need’ is defined. He has a different perspective in how the “need” should be emphasised. This is accepted by the team and revised. This reflects the expert’s ability to reframe and restructure the problem. Therefore experts through their ability to elaborate and negotiate knowledge are more inclined to restructure and reframe the problem.

Christy: “To me when you say a better way to manage hypothermia you have already allowed hypothermia to occur in the patient so I think it’s the prevention of hypothermia that is the issue.”
Kev: “ok”
However the less experienced teams tried to compensate for their lack of *domain knowledge*. *Building on* was an activity linked to resolving uncertainty and was used also by the least experienced teams. It allowed these teams to collectively piece together the information required by drawing out the related knowledge of each team member to structure the problem.

*Analogies* also supported the novice teams to understand the problem. While the experts were able to use *analogies* directly related to the topic the novices tended to use *analogies* indirectly related to the topic and from their own personal experiences. In the following example in the Undergraduate case Lauren recounts a flying trip with young children to make a connection with the crew rest environment.

Lauren: “Again for example space for children because I have had the experience of having two children in the plane and people sleeping so it might be awkward for parents. What do I do if others are resting and the baby is crying.”

In contrast while expert teams referenced from their own experiences they also referenced other sources such as case histories other 3rd parties’, the media and literature showing that experts are better able to draw from a wider variety of sources. The following is an example from the Bio-innovate 2 case.

Liam: “There was a big court case a few years back about hypothermia. So there was a high incidence rate, and the health authorities in the US were taken to court and this protocol came in as a result to manage hypothermia which led to the heat blankets.”

In summary the experts were better at applying *critical thinking* to elaborate and negotiate shared knowledge. They were able to apply *domain knowledge* and prior experience to make analyses, judgements, and interpretations. They were able to fill in gaps in knowledge by making inferences based on their experiences. Expert’s *domain knowledge* led them to make better *arguments* which in turn were better supported by *scenarios*. Experts tended to reframe and restructure the problem to increase the problem understanding. In turn experts seemed to delay consensus as a strategy if it was felt that the information was not sufficiently elaborated on. While novices were able to make reference to prior experiences to support problem definition those experiences were often indirectly related to the topic. Experts were able to draw from a variety of sources.
8.3.2 The differences between experts and novices at the ideation phase

Table 8.5 outlines the frequencies. While there were a lot of similarities in the proportions of the cognitive processing between the teams there were differences in how the teams progressed.

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Team B Undergraduate Frequencies 345 utterances</th>
<th>Bio-innovate 2 Frequencies 348 utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td>110 (32%)</td>
<td>140 (40%)</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td>98 (28%)</td>
<td>114 (33%)</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td>54 (16%)</td>
<td>107 (31%)</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td>64 (19%)</td>
<td>26 (7%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>326 (94%)</td>
<td>387 (111%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversation activities</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain knowledge</td>
<td>5 (1%)</td>
<td>42 (12%)</td>
</tr>
<tr>
<td>Analogies</td>
<td>30 (9%)</td>
<td>52 (15%)</td>
</tr>
<tr>
<td>Arguing</td>
<td>63 (18%)</td>
<td>18 (5%)</td>
</tr>
<tr>
<td>Mental simulations</td>
<td>10 (3%)</td>
<td>51 (15%)</td>
</tr>
<tr>
<td>Scenarios</td>
<td>60 (17%)</td>
<td>48 (14%)</td>
</tr>
<tr>
<td>Building on statements</td>
<td>59 (17%)</td>
<td>66 (19%)</td>
</tr>
<tr>
<td>Total</td>
<td>227 (66%)</td>
<td>270 (78%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can coded to more than one

Creative thinking was at a lower level for the more novice Undergraduate team. They spent less of their meeting proposing ideas and a greater proportion of time critiquing ideas reflected in the higher levels of arguing and scenarios. This led to a limitation in the number of ideas proposed and the chance to maximise solution options. The following is an example where an idea is critiqued quickly without due consideration.

Brian: “even if we could split the stairs so it could open or extend another small bit so you could walk in and get a little more room. I don’t know.

Lisa: “Yeah but for health and safety that’s not going to be realistic. You know if the slope was in too far they’re going to fall down and break their necks.”

In contrast for the Bio-innovate 2 team while there was an emphasis on critical thinking it was more about the further analysis of the problem to understand the solution.
requirements. In the following example Kieran uses *critical thinking* to analyse the current approaches and issues when trying to surgically remove adhesions.

Kieran: So you have two layers of tissue stuck together by adhesions and if you try to lift this you lift this as well. To address it as far as I could see they stick an injection in there and they inject saline water and salt in between the two layers and force a bit of separation in order to gain access to two different planes.

By understanding the problem in more depth Kieran was then able to make a proposal that involved looking at the problem from a new perspective

Kieran: “What about going from the other angle instead of trying to address all the adhesions and trying to find all the adhesions, just spending your time separating the fascial layer of the peritoneum cavity from everything else?”

So the notable difference between the teams was while the novice team applied *critical thinking* in the early critique of ideas the more expert team applied *critical thinking* mainly to expand the problem which supported idea generation. The findings indicate that experts are better at maintaining this balancing.

Figure 8.5 and 8.6 graphs the distribution of the conversation activities between the two cases at the ideation phase.
In developing solutions the expert team were better able to draw support from their *domain knowledge* which in turn better enabled them to use *mental simulations* to examine step by step procedures and explain ideas to others and *analogies* to draw ideas from other applications. The experts were more effective at using *analogies* to transfer ideas from a variety of sources. While the novices tended to simply explain with *analogies*, they supported the more expert teams to analyse the problem further, make comparisons to similar cases and in turn propose solutions. The quality of the *analogies* and *mental simulations* created by the experts were at a higher level in terms of the detail explored. What this meant was that they were able to apply these activities to clearly communicate their reasoning of much more complex information to achieve common ground and consensus. In the following example Kieran from the Bio-innovate 2 team uses the *analogy* of scar tissue to propose an idea for treating adhesions. In using a *mental simulation* within the *analogy* to propose and explain an idea in detail he gathers support from his team members.

Kieran: “If you pull a muscle you get scar tissue around the muscle. You get fibrous tissue and that stays there and the muscle isn’t right until that scar tissue is broken down and massaged. So if you perform surgery on an abdominal injury you’ll have scar tissue, fibrous tissue that you need to massage out of the way to prevent or reduce the effect of the adhesions. If you pull a muscle and a scar tissue forms you can get ultra sound treatment, you can get electrical stimulation treatment. So I wonder would ultra sound or electrical simulation work to breakdown or reduce the scar formation post-surgery for adhesions or improve the breaking down of the fibrous tissue?”
Liam: “Yeah, if it would work, it would be like a device to put on after surgery while they are in hospital to administer some kind of ultra sound to stop the scaring.”

While the novice teams made analogies they were from team member’s limited personal experiences and lacked the same depth of knowledge that the experts had.

Louise: Like a shower, I have a shower at home where you pull the two side doors, you pull the front one and then the side one, so that could be the same thing.

In summary the more expert teams were better at expanding the problem as ideas were generated to create a greater breadth of ideas. The experts avoided the early critique of ideas and were more supportive of ideas proposed. They had a greater depth of analysis of both the problem and how solutions could function which was reflected in their more frequent use of all of the conversation activities.

8.3.3 The differences between experts and novices during concept development

Table 8.6 compares the frequencies. The focus at this phase was on the analysis and development of a limited number of concepts. The significant difference between the experts and novices was that the experts engaged in much more critical thinking than the novices who spent more time in knowledge processing. While some of this can be accounted for the distributed communication between the two halves of the novice Undergraduate team forcing them to spend more time in the exchange of knowledge, the experts showed a greater level of analysis of concepts and a higher frequency of arguing.
Table 8.6: A comparison of the cognitive processing and conversation activities used across cases at the concept development phase (top cognitive processing shaded & top 3 conversation activities shaded)

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Team A Undergraduate</th>
<th>Bio-innovate 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequencies</td>
<td>161 utterances</td>
<td>274 utterances</td>
</tr>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td>98 (61%)</td>
<td>106 (39%)</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td>24 (15%)</td>
<td>141 (51%)</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td>3 (2%)</td>
<td>23 (8%)</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td>31 (19%)</td>
<td>32 (12%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>156 (97%)</td>
<td>302 (110%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conversation activities</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain knowledge</td>
<td>0 (0%)</td>
<td>21 (8 %)</td>
</tr>
<tr>
<td>Analogies</td>
<td>2 (1%)</td>
<td>10 (4%)</td>
</tr>
<tr>
<td>Arguing</td>
<td>18 (11%)</td>
<td>88 (32%)</td>
</tr>
<tr>
<td>Mental simulations</td>
<td>0 (0%)</td>
<td>26 (9%)</td>
</tr>
<tr>
<td>Scenarios</td>
<td>11 (7%)</td>
<td>31 (11%)</td>
</tr>
<tr>
<td>Building on statements</td>
<td>5 (3%)</td>
<td>26 (9%)</td>
</tr>
<tr>
<td>Total</td>
<td>36 (22%)</td>
<td>201 (73%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can coded to more than one category.

Figure 8.7 and 8.8 graphs the distribution of the cognitive processes and conversation activities between the two cases at the concept development phase.
The experts were also able to analyse proposed concepts from a variety of perspectives and consider a variety of issues together. The novices tended to review proposed concepts from one perspective and only focused on few issues. For example in reviewing concepts to prevent dermatitis and leakage with ileostomy bags the expert team were able to assess the functionality of the product but also looked at the concept in terms of manufacturability, cost, and the different requirements of each of the stakeholders involved. The following is an example where a proposed idea is considered from the perspective of a potential supplier.

Liam: “You could use the backing like here, or put the glue on it even as an option if we are pitching to Holister. You could say that you make it out of the Hemmingway and the only new material involved in the whole process for them is this. They don’t have to think about making these in silicone.”

With regard to consensus the novices seemed to be anxious to get consensus on a concept selection from their distributed team members at the expense of a thorough analysis of the solution. In contrast the expert teams at times delayed consensus reaching to thoroughly explore and develop concepts. They were able to recognise the limitations of proposed solutions and defer decision making until they had evidence and proof. Knowing when a team is in a position to make a decision is therefore a necessary skill in terms of consensus reaching in design. As supported by the literature they appeared to view problems as more difficult (Björklund 2013, Cross 2004) and were able...
to recognise the multi layered interconnections and constraints involved in the design task as follows:

Riona: We need to work on more of the detail on this. What do you think?
Liam: yeah I think so.
Riona: let’s make up some prototypes and see.

In summary the experts demonstrated more depth and width in their analysis of proposed solutions. They again applied the conversation activities to elaborate a number of concept variations on a number of levels. Unlike the novice teams they deferred consensus to ensure that concepts were adequately refined.

The key findings from Section 8.3 are:

- Experts used more cognitive processes and conversation activities than the novices, particularly critical thinking and domain knowledge reflecting higher order thinking.
- The experts delayed consensus at times to reframe, elaborate and negotiate on the project information and appeared to treat problems as being more complex.
- Expert’s high level of domain knowledge supported them in a more effective use of conversation activities: analogies, arguing and mental simulations.

At the problem definition phase
- Experts used more critical thinking than novices and higher levels of domain knowledge, arguing and mental simulations.

At the ideation phase
- Creative thinking was at a lower level for the novices who spent less time proposing ideas at the expense of the critique of ideas.
- The experts avoided the early critique of ideas, avoided arguing and were more supportive of ideas using critical thinking mainly to further analyse the problem.

At the concept development phase
- Experts engaged in more critical thinking and arguing to analyse concepts from a variety of perspectives considering a variety of issues together deferring consensus.

The next section shows how conflict influenced the use of the activities.
8.4 THE COGNITIVE PROCESSING AND CONVERSATION ACTIVITIES USED DURING CONFLICT

This section compares the cognitive processes and conversation activities used during conflict. As the data was divided into topic segments for units of analysis Table 8.7 details the number of topic segments that featured conflict in each phase. The Bio-innovate Team A and the Professional Practice team did not experience instances of disagreement or conflict, so do not feature in the comparison. Conflict appears to be associated with the cases that involved more complex and unstructured problems with teams that were multidisciplinary.

Table 8.7: No. of topics segments per team at each phase with cognitive conflict

<table>
<thead>
<tr>
<th></th>
<th>Bio 1 Team B No of topics 27 utterances</th>
<th>Undergraduate Team A No of topics 46 utterances</th>
<th>Undergraduate Team B No of topics 42 utterances</th>
<th>Bio 2 No of topics 104 utterances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem Definition</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Ideation</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Concept development</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

Conflict is a potential barrier to reaching common ground and consensus. However the findings show, that cognitive conflict overall had a positive role in consensus reaching. As supported by some of the literature conflict forced the elaboration of the project information, the consideration of a larger number of ideas and perspectives during discussions (Badke Schaub et al. 2010). Conflict prevented teams reaching premature decisions and also helped to avoid misinterpretations.

Table 8.8 compares the cognitive processes and conversation activities used across each case during topic segments with and without conflict. The cognitive processes and conversation activities with increased levels during conflict are shaded in the table. During conflict the levels of critical thinking rose for all teams. This was accompanied by an increase in: domain knowledge, arguing and scenarios. This was because during conflict individuals were required to have knowledge and facts to back up assertions being made. They were required to have strong critical thinking ability in being able to analyse, evaluate, hypothesize, critique, judge, defend and then persuade others to the same view. During conflict team members did not accept information or assertions made by others as a given but challenged them. Creative thinking levels dropped significantly
during conflict showing that conflict was not compatible with creative thinking and ideation. Creativity required exploration and the imagining of new possibilities which can be restricted by conflict and critique.

Table 8.8: A comparison of the cognitive processing and conversation activities used across cases during times with conflict (C) and without cognitive conflict (NC)

<table>
<thead>
<tr>
<th>Cognitive processes</th>
<th>Undergrad. Team A</th>
<th>Undergrad. Team B</th>
<th>Bio 1 Team B</th>
<th>Bio 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNOWLEDGE PROCESSING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>19 (41%)</td>
<td>7 (17%)</td>
<td>13 (48%)</td>
<td>32 (31%)</td>
<td>73 (34%)</td>
</tr>
<tr>
<td>NC</td>
<td>101 (46%)</td>
<td>167 (38%)</td>
<td>156 (33%)</td>
<td>428 (37%)</td>
<td>811 (35%)</td>
</tr>
<tr>
<td>CRITICAL THINKING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>12 (26%)</td>
<td>19 (45%)</td>
<td>18 (67%)</td>
<td>71 (68%)</td>
<td>116 (53%)</td>
</tr>
<tr>
<td>NC</td>
<td>42 (19%)</td>
<td>134 (31%)</td>
<td>133 (28%)</td>
<td>544 (47%)</td>
<td>805 (35%)</td>
</tr>
<tr>
<td>CREATIVE THINKING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0 (0%)</td>
<td>1 (2%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (0.4%)</td>
</tr>
<tr>
<td>NC</td>
<td>7 (3%)</td>
<td>57 (13%)</td>
<td>13 (3%)</td>
<td>132 (11%)</td>
<td>208 (9%)</td>
</tr>
<tr>
<td>META-COGNITION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>9 (20%)</td>
<td>0 (0%)</td>
<td>3 (11%)</td>
<td>16 (15%)</td>
<td>21 (10%)</td>
</tr>
<tr>
<td>NC</td>
<td>65 (30%)</td>
<td>82 (19%)</td>
<td>264 (55%)</td>
<td>135 (12%)</td>
<td>562 (25%)</td>
</tr>
</tbody>
</table>

Conversation activities

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain knowledge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>14 (52%)</td>
<td>18 (17%)</td>
<td>32 (15%)</td>
</tr>
<tr>
<td>NC</td>
<td>0 (0%)</td>
<td>7 (1%)</td>
<td>83 (17%)</td>
<td>159 (13%)</td>
<td>249 (11%)</td>
</tr>
<tr>
<td>Analogies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1 (2%)</td>
<td>0 (0%)</td>
<td>4 (15%)</td>
<td>3 (3%)</td>
<td>8 (4%)</td>
</tr>
<tr>
<td>NC</td>
<td>5 (2%)</td>
<td>42 (9%)</td>
<td>14 (3%)</td>
<td>76 (7%)</td>
<td>127 (5%)</td>
</tr>
<tr>
<td>Arguing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>13 (28%)</td>
<td>26 (62%)</td>
<td>18 (55%)</td>
<td>57 (55%)</td>
<td>114 (52%)</td>
</tr>
<tr>
<td>NC</td>
<td>5 (2%)</td>
<td>49 (11%)</td>
<td>63 (13%)</td>
<td>267 (23%)</td>
<td>361 (15%)</td>
</tr>
<tr>
<td>Mental simulations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>2 (0.4%)</td>
<td>85 (7%)</td>
<td>98 (4%)</td>
</tr>
<tr>
<td>NC</td>
<td>1 (0.4%)</td>
<td>10 (2%)</td>
<td>0 (0%)</td>
<td>5 (5%)</td>
<td>5 (2%)</td>
</tr>
<tr>
<td>Scenarios</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3 (6%)</td>
<td>11 (26%)</td>
<td>12 (44%)</td>
<td>34 (33%)</td>
<td>60 (27%)</td>
</tr>
<tr>
<td>NC</td>
<td>23 (11%)</td>
<td>85 (19%)</td>
<td>59 (12%)</td>
<td>136 (12%)</td>
<td>303 (12%)</td>
</tr>
<tr>
<td>Building on</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>4 (7%)</td>
<td>6 (14%)</td>
<td>2 (7%)</td>
<td>1 (1%)</td>
<td>13 (6%)</td>
</tr>
<tr>
<td>NC</td>
<td>22 (10%)</td>
<td>77 (18%)</td>
<td>174 (38%)</td>
<td>119 (10%)</td>
<td>401 (16%)</td>
</tr>
</tbody>
</table>

Total percentage may be more than 100% as utterances can coded to more than one category

The instigation and management of conflict was as follows. Questioning others often stimulated conflict when team members did not accept information or assertions from others as a given. When there was a difference in perspectives this often triggered arguing which was used to negotiate the conflict and facilitated team members to exchange diverging or opposite views. Domain knowledge supported assertions and opinions.

Scenarios featured significantly during instances of conflict and were a powerful critical thinking activity that supported arguing. They had several functions as follows:
Scenarios helped to justify claims by predicting hypothetical situations. They conveyed powerful imagery of the cause and effect of a situation by putting it into context with the interactions of people. They enabled forecasting or the predicting of likely events. They provided worst case examples and extremes of situations to enforce a point. They helped individuals to adopt a ‘devil’s advocate’ approach by identifying “what if” situations. They enabled the critiquing of solutions by imagining how users would interact with them. They allowed for objective reasoning and empathy for others by imagining how others would behave and feel in certain situations.

Domain knowledge also supported rich scenarios. The following is an example of a scenario from the Bio-innovate 2 case. Riona questions a point raised by Christy who responds with a scenario to provide justification for his view. He uses domain knowledge, to put forward a powerful scenario to argue his position. The scenario depicts the worst case impact of diabetes, the cause and effect of this and forecasts the impact it would have on the health system. Through the scenario Christy uses empathy to show the effect this has on the patient. In concluding Christy negotiates a high score for the ‘need’ being assessed that is justified in the case he has just made.

Riona: But they can still move their feet.
Christy: They can move their feet but if you ask them to close their eyes and point their feet up they won’t know that they are pointed up. The problem arises when they bring a hot water bottle to bed and put their feet on it and they don’t actually feel that it’s burning them and they often end up burning their skin. The chances are if they are a diabetic they also have poor circulation which means if the skin becomes broken because they have burnt it, they will end up with an ulcer which is a huge cost to the service because ulcers are massive. It’s also a pain in the neck for the patient, there’s issues with manoeuvrability as they feel like they are walking on a cloud. There is more of a chance of falling over...You could have a long nail coming off your big toe digging into the toe beside it and you don’t feel it and the next thing is you’ve got a big ulcer, and then an infection in the bone. So I think that is a 4.

Arguing therefore was the key conversation activity to negotiate conflict which was driven by the activities of: domain knowledge and scenarios.
The role of conflict at the different phases of the design process,

Conflict was more appropriate at certain phases; the problem definition phase and the concept development phase. At the problem definition phase conflict helped teams to expand the problem area and balance the conflicting views of team members. By *arguing* the different opinions that were brought to bear on the project the team members were able to examine their own assumptions and recognise the validity of differing perspectives to bring about conceptual change. This then led to grounding and consensus that was based on exposing and resolving issues rather than letting them go unnoticed or ignored to surface at a later stage. It helped teams to challenge the conventional thinking approach to the problem and challenge the status quo. By questioning attitudes, behaviours, methods and processes with existing practices there was an increased opportunity for innovation. The following is an extract from a topic segment around a lengthy debate amongst the Bio-innovate 2 team about factoring in potential preventative measures within the scoring of ‘needs’ and how this could be measured. By the end of the topic Christy sums up Liam’s argument showing that they have reached a shared understanding. He recognises the validity of the argument but convinces Liam to his way of thinking. This conflict has brought about a number of positives. It has made the team aware that preventative costs may not be recognised as a cost by the stakeholder in question. While the decision is taken not to change the filtering criteria to factor this in, the differing perspectives of the team members are accommodated resulting in a deeper level of understanding of the problem and the impact of this moving to the next phase of the process. Common ground is established and a decision is taken based on the elaboration of the information.

Chris: “They’re not going to roll it out because they don’t see the immediate cost benefit is that what you are saying?”
Liam: “yeah.”
Christy: “That I suppose is an argument but I suppose for the purpose of what effect it will have on the system in actually preventing those injuries it is still reducing the cost on your health service. It’s whether or not they will fund it because you’re…”
Liam: “It’s whether or not that impact factor will be there. Ok so let’s just stick to our scale.”

At the ideation phase conflict was not productive for the teams. It only occurred in the Undergraduate B case to critique ideas. This team’s natural instinct was to critique ideas whereas the Bio-innovate 2 teams were more conscious of the need to suspend judgement at this phase. The issue with conflict at this phase meant that the teams put
their efforts into disagreeing about ideas rather than generating more ideas. Research has shown that following the rules of brainstorming where ideas are not evaluated allows for the generation of a range of ideas (Paulus et al. 2006, Kelley 2001). It has also been shown that the quantity and quality of ideas are strongly correlated (Dennis et al. 1996). Therefore conflict at the ideation phase risks the limiting of ideas to a narrow few, of lower quality. As shown in Table 8.9 creative thinking which is divergent in nature was not evident during conflict. Conflict emphasises convergent thinking to analyse and critique.

At the concept development phase the teams were required to make decisions on the direction and selection of concepts which often sparked differences in opinions. Conflict had a positive effect at this phase. By arguing and debating the features of proposed solutions the team members were able to highlight potential design flaws. Conflict highlighted emerging issues and constraints and provoked team members to consider alternative options and uncover new information. Early agreement on concepts could result in costly changes later on in the process. In the following example from the Bio-innovate 2 case there is disagreement between two concepts. Liam in arguing against a proposal brought up issues of cost and introduced constraints that needed to be considered due to the manufacturing method:

Liam: “I’m trying to think of it from a manufacturing point of view, as soon as you put this protrusion on it you have a different mode of selection, like what size is your stoma? It’s almost like you have to buy these as customised. I’m just thinking production line.”
Riona: “It’s three different moulds.”
Liam: “It’s three different moulds and becomes more expensive very fast.”

Therefore conflict at this phase ensured that early decisions were not taken on concept selection without an evaluation that uncovered potential problems and constraints.

8.4.2 The differences between how experts and novices negotiated conflict

The negotiation of conflict was better managed by the use of critical thinking and the activities of domain knowledge, scenarios and arguing. As shown in Table 8.10 the expert teams had much higher levels of this. Due to their domain knowledge they were able to make informed arguments that were supported by scenarios to provide examples and justify their reasoning.
Another notable difference between the experts and novices was that experts appeared to deliberately instigate conflict in conversations as a means to provoke a thorough exploration of the topic. They seemed to have a more positive attitude towards cognitive conflict and seemed to view it as a positive means to progress through the project. In the following example from the Bio-innovate 2 team Liam states that he wants to “play devil’s advocate as usual.” He applies this as a strategy to challenge others and information.

Liam: just to play devil’s advocate for a minute as usual. How would that be a 5 in terms of care pathway through efficiency and convenience?

In the following example despite taking one side in an argument he is still not sure that he fully supports the argument. This suggests that he was motivated to instigate conflict in order to create the debate necessary to elaborate on the project information. By arguing different viewpoints the team were more informed to make better decisions.

Liam: “It can improve his efficiency and convenience in having to deal with something else. I don’t know I’m not clear in my mind about it.”

The novice teams in contrast used arguing during conflict but these arguments were less effective. These teams had limited domain knowledge and used scenarios infrequently. Their arguments were less informed and lacked the degree of justification that the experts were able to show. The novices also displayed a more defensive attitude towards conflict and seemed to deem it as negative behaviour. The following example is from the Undergraduate case:

Matthijs: “Remember at the earlier Skype meeting we told our Ideas and you were ok with that, now all of a sudden you are not.”

The comment above shows that a level of relationship conflict had emerged due to the defensive nature of the members towards critique. The risk with being afraid of critique and conflict is that cognitive conflict then shifts towards relationship conflict which can have a very negative effect on team performance (De Dreu and Weingart 2003). This indicates that experts due to their positive attitude and openness towards cognitive conflict may be better able to avert the negative risk of developing relationship conflict.

The key findings for Section 8.4 are:
• Conflict had a positive impact at times as it helped the teams to avoid premature consensus and forced the elaboration of information to bring about informed and considered consensus.

• During conflict the levels of critical thinking rose with domain knowledge, arguing and scenarios used to instigate and manage the conflict.

• Conflict was more appropriate at the problem definition phase and the concept development phase. At the ideation phase conflict risked the limiting of ideas to a narrow few, of lower quality, preventing creative thinking. Conflict was incompatible with creative thinking.

• Experts used a devil’s advocate approach to thoroughly explore the topic indicating that they may as a strategy deliberately instigate conflict.

• Novices appeared to display a more defensive attitude towards conflict and appeared to associate it with negative behaviour. They also seemed to be more at risk of allowing cognitive conflict lead to relationship conflict which has a negative impact on team performance.

• Conflict was associated with the cases that had complex unstructured problems and multidisciplinary teams.

8.5 CHAPTER CONCLUSIONS

This chapter has provided a cross case analysis of the four cases and six teams involved in this research. The following conclusions are drawn from the findings.

• The teams engaged mainly in critical thinking and knowledge processing to exchange and negotiate on information followed by metacognition to manage the process.

• Minimal levels of creative thinking were used.

• Six conversational activities were identified that support the cognitive processes: domain knowledge, analogies, arguing, mental simulations, scenarios and building on.

There are different consensus objectives at each phase of the design process impacting on the emphasis of the cognitive processes and conversation activities used.

• Knowledge processing increased across the design phases to show that the requirement to agree on new information continues throughout the process.
• Critical thinking was at high levels across all phases of the design process dropping slightly at the ideation phase.

• Creative thinking was at low levels across all phases rising significantly only at the ideation phase.

• Meta-cognition was at high levels at the problem definition phase to manage the uncertainty and diversity in perspectives at this phase.

There were differences in how expert and novice teams reached consensus.

• Experts used more cognitive processes and conversation activities than the novices, particularly critical thinking and domain knowledge reflecting higher order thinking.

• Experts deferred consensus at times to reframe, elaborate and negotiate on the project information and treated problems as being more complex.

• Expert’s high level of domain knowledge supported them in a more effective use of conversation activities: analogies, arguing and mental simulations.

• Experts appeared to be better at deferring judgement on early ideas and better able to judge when argumentation was appropriate.

Cognitive conflict overall had a positive role in reaching informed consensus.

• Conflict prevented teams reaching premature consensus and misinterpretations.

• Arguing was the key conversation activity during conflict supported by domain knowledge and scenarios to both instigate and manage the conflict.

• Conflict was more appropriate at the problem definition phase and the concept development phase. At the ideation phase conflict risked the limiting of ideas to a narrow few, of lower quality, preventing creative thinking. Conflict was incompatible with creative thinking.

• Experts used a devil’s advocate approach to thoroughly explore the topic indicating that they may as a strategy deliberately instigate conflict.

• Novices appeared to associate conflict more with negative behaviour and seemed to be at more risk of allowing cognitive conflict lead to relationship conflict which has a negative impact on team performance. Experts were found to be better able to negotiate conflict.
9 Discussion

This chapter has a number of purposes. Having previously established the gaps in current research and practice in Chapters 2 and 3, this chapter brings together the main research findings from the four case studies carried out in Chapters 4, 5, 6 and 7 and the cross case analysis in Chapter 8. Parallels with existing work are made in order to identify the unique and novel aspects of the research. The implications of the findings for the design and decision making literature are also discussed. This chapter further develops theories on how teams reach consensus in design. The findings are discussed under the following headings:

- The cognitive processes and conversation activities to reach consensus.
- The impact of the design phases on reaching consensus.
- The difference between expert and novice teams in managing consensus.
- The impact of conflict on consensus.
- Consensus process and revised conceptual model.

9.1 MAIN RESEARCH FINDINGS

There is limited literature drawing together the three strands of design practice, team cognition and consensus reaching in design and innovation projects. Achieving consensus based on common ground is a complex process and this research has identified a number of interesting issues and insights which have highlighted these complexities and shown how it can be successfully arrived at during the initial phases of design projects. In a meta-analysis DeChurch et al. (2013) argue that the literature has disproportionately addressed cognitive states over cognitive processes. Rather than focusing on the cognitive state at any one time this research addresses the process of arriving at consensus in the course of a project. A contribution of this study’s findings lies in its validation of a process-oriented view of team cognition that contrasts the content view that dominates prior related research.

What the findings have shown is how consensus is achieved in design. Achieving consensus in design is not necessarily difficult. At no point in any case was consensus not achieved. A greater concern during design problem solving is reaching agreement at the expense of the elaboration of information. This involves reaching consensus without common ground. This supports the literature which shows that perspectives may not be aligned and common ground not achieved in early consensus (Weinberger and Fischer...
2006, Clark and Brennan 1991). While teams may be under pressure with deadlines in both practice and education, to create innovative solutions design teams must tease out the problem and explore it in an effort to uncover insights and opportunities to innovate. The importance of conversation and debate in achieving good performance in teams cannot be overlooked. What this study provides is an insight into the complexity of team designing. What for many years has been an individual implicit cognitive activity has become explicit now that designers co-design with others. This study has shown that individuals in a team must make their thinking explicit to others. Therefore a fundamental aspect of team designing is conversation and verbal communication. Team members also need to know when they have understood one another to avoid misunderstandings and this can be communicated via consensus.

As outlined in Section 3.4.3 consensus was evidenced as participants made verbal indications to others through acknowledgements such as: uh, yeah, yes, mm, Ok and by repeating another’s utterance as a confirmation. As shown in the literature consensus did not require unanimous agreement but aimed to accommodate through negotiation the views of others to gain sufficient consensus to move forward. Consensus was analysed on a number of levels within each topic. The first level was consensus during knowledge sharing where team members reached consensus on the intended meaning of a contribution and acknowledged that they had understood the contribution of others. The focus was on clear communication and the clarification and verification of information. The second level indicated a level of common ground as team members reached consensus on their beliefs and views about that contribution which is consensus on position. This required a further commitment and increased levels of negotiation. The third level involved consensus to make decisions. As commitment levels increased through the requirement to reach different levels of consensus the effects of diversity were further brought to bear on team interactions which often brought about conflict.

Conflict was defined as a disagreement between one or more participants that was disputed over a number of utterances within topic segments. In the work place more moderate definitions of consensus have been adopted to show that conflict does not necessarily involve aggressive and hostile warfare, and that it can be of benefit to problem solving. While cognitive (task) conflict may have delayed consensus it resulted in the bringing to light more than one perspective on a task which was then debated by participants. The outcome of these instances was often a shifting in perspective which can be associated with the good design practice of framing and reframing. While the outcome of cognitive conflict did not always result in agreement it did increase levels of
common ground and heighten the team’s awareness to important issues that may have further implications later in the project. It also helped the teams to reflect and recognise the limitations of their decisions. An example of this is where the Bio-innovate 2 team recognised after a lengthy dispute that they had not factored in preventative measures in their filtering criteria. While it was too late to factor this in, the conflict allowed the team to recognise this limitation. So while consensus and cognitive conflict can be viewed as opposites, they can be complimentary in that conflict can lead to a more informed consensus. Consensus reaching is a process and teams must recognise that in design, knowledge must be shared, elaborated and negotiated to build consensus based on common ground.

While the literature stresses the importance of knowledge elaboration and integration there is limited focus on the competencies and ways this can be achieved. A core issue for this research was to identify the cognitive processes and conversation activities that were conducive to the elaboration, exchange, discussion and integration of task relevant information and perspectives as advocated by Kooij-de Bode et al. (2010) to reach consensus based on common ground. This is discussed in the next section.

9.1.1 The cognitive processes and conversation activities to reach consensus

In compiling different bodies of literature, four cognitive processes had been identified that are components of design cognition: Knowledge processing, critical thinking, creative thinking and metacognition. How this research has contributed to the literature is to show how teams applied these cognitive processes to reach consensus.

Cognitive processes:
This research has confirmed that all four cognitive processes were instrumental in facilitating teams to share knowledge and beliefs, negotiate and elaborate to reach common ground and consensus. What was surprising was the proportion used. The teams used mainly critical thinking followed by knowledge processing and metacognition. Creative thinking accounted for only 7% of cognitive activity yet much of the literature in design and design thinking emphasises creativity. For example design thinking has been described as the means to being creative and innovative (Johansson-Sköldberg et al. 2013). Tom Kelly the founder of IDEO has published ‘lessons in creativity’ to describe design activity, while Nussbaum (2013) published ‘creative intelligence’ which promotes creativity as the key aspect of design and innovation.
However what the findings show is that arriving at creative solutions in design teams requires more than *creative thinking*. While *creative thinking* is essential to generate ideas, it is stimulated by engaging with the other cognitive processes. Design has been shown to alternate between divergent and convergent thinking (Dym et al. 2006, Ferreira and Lacerda dos Santos 2009). In support of this and in building on this, this study found that design behaviour shifts from divergent behaviour in knowledge processing and *creative thinking* to then convergent and analytical behaviour during *critical thinking* and *metacognition*. *Critical thinking* dominates the process reflecting the analytical and persuasive nature of team discussion. Design teams during discussion spend most of their time in rational, pragmatic thinking and problem solving and in justifying their reasoning to others. *Critical thinking* is also not simply about the critique of solutions but also about the analysis of the problem. By questioning and critiquing the problem and reframing it from different perspectives this creates the opportunity to then apply *creative thinking* to generate solutions. Therefore by encouraging strong *critical thinking* ability in design teams this can pave the way for creative solutions. Christiaans and Venselaar (2005) found a strong relationship between the acquisition of knowledge and creativity and found that the more time spent in defining and understanding a problem, the better the creative result. *Knowledge processing* accounted for 34% of team activity to show that the construction of knowledge is a critical part of enabling teams to progress towards the development of solutions. An increase in knowledge can increase the opportunity for ideas with an increase in understanding of the problem and solution options. *Metacognition* is also essential. It is linked to uncertainty and was at higher levels in the more unstructured problems. It was instrumental in building common ground by providing team reflection to monitor interpretations and make corrections. *Metacognition* can also influence social interactions (Leinonen and Järvelä 2003) and team members must use it to guide their behaviours to the requirement of the task and the effectiveness of their interactions with others.

Effective collaboration in design therefore requires more than creativity or information exchange as emphasised in other studies (Curseu et al. 2008, Mesmer-Magnus and DeChurch 2009, Deken et al. 2012). Collaboration in design calls for four high-level cognitive processes and recognition needs to be given to their proportion of use and dependency on one another.

**Conversation activities:** The findings identified 6 conversation activities that supported the cognitive processes: *domain knowledge, analogies, arguing, scenarios, mental simulations* and *building on*. The study has captured the breadth of conversation activity of design teams. This is significant because rather than focusing on one or two this
research has addressed their combined effect, the relationship between them and how they are used for different purposes. It has also inductively uncovered conversation activities that have not been a focus in the design literature. Some have been addressed by the decision making or design literature but not in the context of consensus reaching in design. There were further contributions to the conversation activities as follows:

Domain Knowledge: The use of domain knowledge was critical to the effective use of the cognitive processes and other conversation activities. Without domain knowledge teams will be hampered to apply the cognitive processes effectively. Domain knowledge followed the paths of critical thinking and metacognition and was at high levels when these cognitive processes were also at high levels. Domain knowledge supported, in particular: arguing, mental simulations and analogies. Those with strong domain knowledge were better able to justify arguments, provide a step account of the process of using a product or service when making mental simulations and make comparisons to other applications and products when making analogies. Domain Knowledge also supported teams to make inferences and piece together unknown information. Domain knowledge was also associated with expertise. Experts have been found to have superior mental representation which has a bidirectional relationship with knowledge (Alibali et al. 2009). In building on this, this research has shown that domain knowledge provides the foundation to the effective use of the cognitive processes and other conversation activities that are essential in negotiating consensus in teams.

Arguing: Arguing was strongly associated with critical thinking. It was the most frequently used conversation activity to negotiate, persuade and bring about conceptual change. This concurs with the natural Decision Making (NDM) which proposes that decision making comes about through argumentation and persuasive means. (Ramiah and Banks 2015, Lu and Lajoie 2008). Likewise the literature shows that progress in design is negotiated and persuaded collaboratively (McDonnell 2012, McDonnell 2009, Stumpf and McDonnell 2002). However while arguing supports critical thinking, negotiation and persuasion it was not always associated with disagreement. Argumentation was often used to support an individual’s own or another’s rational. Team member’s responses to the arguments of others often entail further building on of those arguments. This supports the findings of Ramiah and Banks (2015) who found that during argumentation reasons were often used to support a position but not to challenge it. This was also evident at the generative phases of the project where team members argued in support of their own or another’s reasoning and provided justification for pursuing new directions and possibilities.
While the critique of ideas is not beneficial at the ideation phase, arguing can have a positive role at this phase. It facilitates *critical thinking* in the analysis and negotiation in understanding of emergent aspects of the problem. *Arguing* often preceded or followed *creative thinking* in justifying the rational to pursue a direction or a line of thinking. Therefore this would indicate that while argumentation is not associated with *creative thinking* it can *support creative thinking* by questioning conventional thinking and justifying alternative perspectives. This supports the work of Hoever et al. (2012) who found that alternative perspective taking was an important mechanism to boost team creativity.

**Scenarios:** Scenarios were a versatile conversation activity and mainly linked to *creative thinking*. They also support *knowledge processing and critical thinking*. They helped individuals to imagine new possibilities during ideation and convey them to others. In addition *scenarios* supported *critical thinking* and *arguing* to evaluate procedures and interactions at the problem definition phase and ideas at the concept development phase. As *scenarios* can depict vivid examples of cause and effect this makes them a forceful tool to explain, persuade and convince others to a different position. These findings build on the literature which has only shown *scenarios* as a method or tool applied to design situations as a pre-planned deliberate action to roleplay and analyse proposed solutions (Carroll 2002, Bødker 2000). This study found that scenarios also have a wider and greater application as a spontaneous conversational tool to imagine new ideas and also provide justification during the negotiation of common ground and consensus. While *scenarios* were better enabled by *domain knowledge* they did not necessarily require *domain knowledge* and were also used frequently by the novice Undergraduate team to imagine how people might behave in certain situations. Therefore *scenarios* are an activity that can support both expert and novice teams to reach consensus.

**Analogies:** Analogies were directly linked to *creative thinking* and used mainly at the ideation phase to support the creation of ideas. The findings concur and build on the literature (Hey et al. 2008, Ball and Christensen 2009). Christensen and Schunn (2007) have shown that *analogies* are used in solution generation to transfer ideas from the source domain, noticing a possible problem in the emerging design and explanation. While the findings replicate that of the literature (Christensen and Schunn 2007) this study found that in addition *analogies* though less frequently, were used at the problem definition phase to explain, evaluate and create a shared understanding of the problem.
By evaluating related problems the current problem can be re-evaluated. Analogies therefore have a wider application and are not limited to the generative phase of design. Many studies in the area of analogies have looked at them in isolation, for example (Daugherty and Mentzer 2008, Hey et al. 2008, Christensen and Schunn 2007). What this study has shown is how the conversation activities were used in combination to navigate the consensus process. Ball and Christensen (2009) found that analogies are sometimes interleaved with mental simulations. This research showed this to be the case but also found analogies embedded in other activities particularly scenarios. Analogies therefore can be used in conjunction with other conversation activities to carry out a variety of purposes. This also poses implications for design research to show that studying activities or strategies in isolation may lose out on some of their rich interdependencies.

Mental simulations: Mental simulations like analogies and scenarios are mostly used at the ideation phase and linked to creative thinking. However unlike scenarios they are dependent on domain knowledge to understanding the step by step interaction of using various products or applications. Mental simulations have received limited attention in design except from (Ball and Christensen 2009, Christensen and Schunn 2009). These studies have focused on the generative phase of design and have shown mental simulations as a generative tool to enable designers to reason about new possible states of a design solution. The findings support the literature but also show that mental simulations are also employed to communicate detailed procedures and processes to understand the problem state and had a clear role in supporting teams to define the problem. The use of both analogies and mental simulations at the problem definition phase highlights the increased complexity and importance of this phase. Many of the projects used in previous design research have used less complex design problems that use prescribed briefs which are not representative of the very early phases of the process where designers must define the problem to address.

Building on: The literature has only addressed this activity in the form of ideas building during brainstorming and idea generation (Kohn et al. 2011, Kelley 2001) This research found that building on was used across the full process not just to build ideas but to also build information and arguments. While the consensus process is highly persuasive and argumentative at times building on also helped team members to support one another. Therefore building on can promote more collaborative and assistive behaviour which can at times be more beneficial for consensus over more challenging behaviour.
The findings have also shown that the emphasis on the cognitive processes and conversation activities depends also on the phase in the design process.

9.1.2 The impact of the design phases on consensus

Many of the studies on design have focused on short prescribed projects or a brief stage in a project (Atman et al. 2007, Hey et al. 2008, Valkenburg and Dorst 1998). One exception to this is the work of Deken et al. (2012) who found some differences with regard to knowledge seeking and creation across the phases of task clarification, concept design and detailed design. Likewise this research has shown that the steps to reaching consensus can vary depending on the phases of the design process so the process should not be treated as a single activity. The different objectives at each phase influences how consensus is achieved and call for different cognitive processes and conversation activities. Many design processes do not make a significant distinction between the phases particularly the ideation and concept development phases and see these two phases as one generative phase. Therefore by recognising the phase in the process and the objectives of the team interactions it is possible to guide the focus of cognitive activity. The differences at each phase are discussed as follows.

Knowledge processing increases across the design phases. This is significant as it shows that is not just at the beginning of a project where information is shared and agreed upon but that this continues and increases during the process. This highlights the requirement to iteratively cycle through the consensus process of sharing and negotiating on information. The findings support the theory of co-evolution for the ideation and concept development phases (Maher and Tang 2003, Dorst 2011, Dorst and Cross 2001). As teams develop ideas this often poses further questions and gaps in knowledge about the problem state and the requirement to gather and process further information. Knowledge processing is also critical to communicate ideas at the later phases. If other team members fail to understand a good idea it may not get buy in from others and thus possibly dropped. Scardamalia and Bereiter (1989) have shown that the social interaction with ideas can lead to the generation of new ideas. Therefore effective knowledge processing can lead to an increase in ideas. Deken et al. (2012) found that the time spent on information seeking decreased, while the time spent on knowledge creation increased across similar design phases. At a macro view of the consensus process the findings support Deken et al. (2012) showing that knowledge seeking shifts to knowledge creation over the course of a project. However this study found that the process is iterative with knowledge processing increasing during the phases.
Critical thinking is at high levels across all phases of the design process dropping only slightly at the ideation phase. While the problem definition phase is about gathering and sharing information critical thinking is also needed at this phase to consolidate and negotiate on distributed information and views and define and agree on the scope of the design project. This is also the point in the process where there is the greatest amount of diversity amongst team members. As this stage is at the beginning of a project and may involve newly formed teams there is a risk that team members may be reluctant to disagree or contradict others. van Ginkel and van Knippenberg (2008) found that teams were more concerned with maintaining common ground than on the elaboration of information. Teams therefore should be encouraged to elaborate, challenge, and negotiate on shared information. Arguing can support critical thinking to question and challenge along with the other conversation activities.

Critical thinking dropped significantly at the ideation phase but was still more frequently used than creative thinking. As teams develop ideas this often poses further questions about the problem state and the subsequent reframing of the problem to view it from different perspectives. While creative thinking is used to explore alternative options it requires critical thinking not necessarily to judge ideas but to analyse the problem further. Therefore while the ideation phase is focused on solution generation it is important to recognise that, analysis and reframing of the problem can support creativity. This again supports the theory of co-evolution.

As supported by the literature Critical thinking is important during concept development to analyse solutions (Dorst 2011). While the ideation phase does not require major decisions but a shared understanding of ideas, the concept development phase requires the analysis of proposed solutions with a view to making a decision on selecting the best one. As the emphasis shifts to the critique of solutions critical thinking is also applied to the analysis of the problem. Creative thinking is at relatively low levels across all phases rising significantly only at the ideation phase. The complexity of many of today’s design problems and the vast amounts of information that must be synthesised would show that forming solutions at the problem definition phase may be premature and potentially come at the expense of the elaboration of the problem elements and in forming a shared representation of the problem. The literature however suggests that designers are solution focused uncovering information about the problem as they develop solutions known as co-evolution (Maher and Tang 2003, Dorst and Cross 2001, Dorst 2011). While co-evolution may work at this phase for less complex problems such as the Professional Practice project where
solutions are more obvious with less possible options, this study shows that in order to form a shared representation of ill-structured and complex problems teams need to suspend solution focusing at this phase and therefore creative thinking. Designers are now working on more open briefs becoming problem finders as well as solvers and not just creating solutions around predefined problems.

During ideation creative thinking increases but requires the support of knowledge processing and critical thinking, enforcing the theory of co-evolution. The ideation phase was focused on the generation of ideas and while creative thinking increased significantly it was still at relatively low levels at this phase. This was surprising as creative thinking is considered to be a key competency for designers. While creative thinking is used to explore alternative options it was regularly supported by knowledge processing and critical thinking not necessarily to judge ideas but to construct new information and analyse the problem further to give opportunities for further ideas. Teams therefore at the solution generation phases should be encouraged to elaborate on information to support creative thinking. This is in line with the literature which found a strong relationship between the acquisition of knowledge and creativity and that the more time spent in defining and understanding a problem, the better the creative result. (Li et al. 2007, Christiaans and Venselaar 2005). This highlights the iterative nature of design and consensus building. Therefore while teams may reach consensus during the problem definition phase at the ideation phase they will still need to switch back to the problem definition phase for further consensus building on the problem.

Critical thinking was also a means of supporting creative thinking by questioning conventional lines of inquiry creating greater scope for innovative solutions. Critical thinking stimulated the teams to break from a narrow focus on the project and paved the way for creative thinking. Therefore when critical thinking is applied to question how the problem is viewed rather than on the critique of ideas it can benefit ideation. The findings for this phase also support the literature on brainstorming which advocates for creative and divergent thinking where ideas are not criticised or judged (Matthews 2009, Kelley 2001). It is also about suspending decisions on concept directions.

During concept development creative thinking helped to avoid early consensus on solutions and encouraged the exploration of other options. While critical thinking was at high levels during concept development to critique solutions this prompted creative thinking to propose alternatives to optimise solutions. Critical thinking is evaluative aimed at seeking consensus on ideas and creative thinking avoids early consensus by assisting
teams to explore other options. This is where convergent thinking follows divergent thinking to disregard non-viable solutions and divergent thinking is used again to create further alternatives upon analysis (Ferreira and Lacerda dos Santos 2009). Therefore the negotiation of a creative solution at the concept development phased requires the alternation between knowledge processing and critical thinking to boost creative thinking. This phase requires the most negotiation and arguing to critique, justify and negotiate solution directions. Teams at this phase should be encouraged to critique and challenge proposed solutions to uncover sub problems thereby reframing the problem and solution which can in turn lead to the creation of better alternatives. Therefore while creative thinking is at low levels at this phase it was not less important as it prevented early consensus on solutions and forced the refinement of options.

Meta-cognition is required most frequently at the problem definition phase to manage the uncertainty and diversity in perspectives at this phase. This is the most unstructured phase of a project and teams may only be recently formed. Teams must monitor and evaluate their approach and representations in order to identify gaps or misrepresentations. This is the phase where the teams must plan and strategize their approach. Any oversights or misunderstandings at this phase will have a detrimental knock on effect to subsequent solution phases. The literature has also shown that groups can fail to realise the importance of information elaboration and that through team reflexivity are made aware of the importance of information elaboration (van Ginkel et al. 2009). This research concurs with that to show that meta-cognition can boost a team to gather further information, analyse information and create further ideas. At subsequent phases metacognition is required less frequently. The design process therefore is nuanced and each phase has a different focus which impacts on consensus and the cognitive processes and conversation activities used.

While the phase in the process had a bearing on how consensus was achieved whether the team is made up of experts or novices also has an impact. The next section discusses the difference between experts and novices in reaching consensus.

9.1.3 The differences between expert and novice teams in managing consensus

Previous research has demonstrated differences between expert and novice problem solving performance in design (Cross 2004, Lawson and Dorst 2009, Björklund 2013). This has addressed the different traits of experts and novices but has not looked at consensus reaching. This research has sought to build on those findings by accounting
for how the management of consensus plays a role in differentiating between experts and novices. For several reasons the experts were more effective than the novices in progressing through projects and reaching consensus based on common ground.

The expert teams compared to the novices produced a greater amount of utterances that fell into a cognitive process and conversation activity. Some of the utterances of the novices were not task focused and off the topic so were not coded. In support of the literature the experts treated problems as more difficult processing greater quantities of information with greater levels of analysis (Björklund 2013, Cross 2004). Expertise is mediated by superior mental representations which have a direct relationship to knowledge (Alibali et al. 2009). The findings show that the expert’s superior levels of *domain knowledge* and prior experience were the foundations to their problem solving ability and consensus building. In processing large volumes of information the experts had more information that they were able to analyse. This is evident in the high levels of both *critical thinking* and *knowledge processing* that occurred within the expert teams. This can also explain why experts spend more time defining the problem (Goel and Pirolli 1992, Cross 2004) and that novice designers often refrain from explicit problem decomposition most likely due to limited knowledge of a domain (Liikkanen and Perttula 2009).

This research has shown that experts seemed to realise the importance of processing greater amounts of information and considering alternative perspectives, which in turn delayed consensus. This was also reflected in the use of the term “devil’s advocate approach” more than once in the Bio-innovate 2 case which showed a willingness to address alternative perspective taken. The literature has found that groups tend to focus on information that supports a preference rather than focusing on evidence driven information (van Ginkel and van Knippenberg 2008). Therefore teams may fix towards emerging consensus and finalize decisions without full exploration of the information available to the group. However this research found a difference between experts and novices with regard to this tendency. Experts discussed greater amounts of more diverse information suggesting in accordance with the literature that they treated problems as more complex, and delay consensus to ensure the thorough elaboration and negotiation of the problem and carry out iterative shared representations or frames. The ability to frame and reframe is also associated with high levels of expertise (Paton and Dorst 2011). The findings indicate that the more novice teams were inclined to seek earlier consensus which prevented the same depth of exploration. In delaying consensus the experts applied more *critical thinking* and higher levels of *arguing*. It has also been
shown that the use of arguments is associated with increased accuracy of decision-making (Ramiah and Banks 2015). However this claim may be taken with caution as the behaviour adopted may be due to other factors other than expertise such as, personality type or the nature and the time frame of the projects.

Previous research in other fields has demonstrated experts to be more proactive increasing the amount of identified options and opportunities (Björklund 2013). A feature of proactive behaviour is intended impact as those who are proactive intend to have a discernible effect and make a difference (Grant and Ashford 2008). This type of behaviour is necessary amongst design teams to achieve innovative solutions by provoking, challenging and questioning conventional thinking. The delay at times in consensus amongst the experts reflected their proactive behaviour in their ability to process and analyse greater amounts of information. Grant and Ashford (2008) recommend examining the role of cognitive processes to understand proactive behaviour characteristics (Grant and Ashford 2008). The use of the cognitive processes and conversation activities by the experts indicated more proactive behaviour over the novices.

There was also a direct relationship to the use of domain knowledge and the use of the other conversation activities. Due to their domain knowledge the experts were better able to apply the cognitive processes and conversation activities. An increase in domain knowledge can provide a team with more scope for discussion and analysis, options and choice. An increase in domain knowledge for example means that a team can make analogies to other applications and mental simulations increasing informed decision making. An increase in knowledge can also provide a better foundation to build stronger arguments. This was an added disadvantage for novices. Their lack of domain knowledge limited their ability to elaborate on and expand the problem space which in turn limited their ability to use the conversation activities that were instrumental in enabling the experts to progress effectively. This builds on the literature to show how experts can be more proactive and that the degree and quality of knowledge sharing and integration are important distinguishing characteristics between novice and expert teams (Kleinsmann et al. 2012, Ahmed et al. 2003).

The implications are that novices may simplify the process as they fail to recognise the need to expand discussions and lack the know how to do this. Novice teams therefore may need to be encouraged to delay consensus and treat problems as more difficult in order to increase their levels of critical thinking and conversation activities. They may
need to research in order to bring about more domain knowledge. In addition as advocated by Deken et al. (2012) an important means of acquiring knowledge is to consult experienced colleagues or experts.

It may not always be advisable to delay consensus but the experts seemed to be better at judging where further elaborations were necessary and when consensus should be delayed. The experts also seemed to be better aware of where in the process to use critical thinking. They were more inclined to avoid the early critique of ideas and were more supportive of new ideas unlike the novices who tended to judge early ideas. The experts recognised that by suspending judgement this encouraged a breath of ideas. A possible source for the observed differences lies in more developed relevancy perceptions and perceptions of interconnections in the problem representations of design experts (Kolko 2012). Novices may need to be guided to recognise the different objectives between ideation and concept development. What these findings show is that consensus reaching requires the ability to judge where and when to use the different cognitive processes. Again this finding may be taken with caution as this finding came through the analysis of only two cases; the Undergraduate case and the Bio-innovate 2 case. It may have been that the Bio-innovate 2 team were more aware of the rules of brainstorming which advocate that ideas should not be judged and critiqued at this stage which may also have accounted for the differences.

9.1.4 The impact of conflict on consensus

This study supports the view that overall cognitive conflict has a positive role in channelling the conflict amongst design teams into the elaboration and negotiation of diverse perspectives. Cognitive conflict avoided early consensus by challenging and provoking the status quo and forcing new lines of thinking. Deferring consensus can be positive as it can avoid groupthink which can result from inadequately considered decisions and the early rejection of possible alternatives (Janis 1982, Burnett 1991). It can also prevent information bias where groups focus on information that is consistent with other member’s preferences out of fear of being rejected (Wittenbaum and Park 2001). In support of some of the literature cognitive conflict can boost information exchange and accommodate a number of perspectives with increased decision understanding, and commitment (De Dreu 2006, Song et al. 2006, Badke Schaub et al. 2010, Carnevale and Probst 1998, Olson et al. 2007, Xie et al. 2014). This finding is
significant as the literature has been mixed with regard to whether cognitive conflict has a benefit on team performance.

Teams can also benefit from cognitive conflict when they avoid affective conflict (De Dreu 2006, Greer et al. 2008). The conversation activities identified in this study may have a role also in preventing affective conflict, in particular domain knowledge, scenarios and arguing. Conflict often begins when a team member disagrees with and then challenges the content of another’s utterance. This in turn triggers arguing which enforces the elaboration of information and its negotiation in order to resolve the conflict. The conversation activities are instrumental in supporting clear and rational arguments. Domain knowledge helps team members to produce facts and evidence to support claims being made. Scenarios can facilitate arguing to explain and justify reasoning by providing hypothetical examples to resolve the conflict. They provide a clear rationale for others and therefore have a role in preventing affective conflict. The implications are that these conversation activities are important in instigating conflict while controlling the negative effect of conflict. Teams may benefit from being conscious of applying them.

The findings show that depending on the objective of the task, conflict may or not be of benefit. It had a positive impact only at certain stages of the design process, the problem definition and concept development phases. While moderate levels of conflict are recommended at these phases conflict has the potential to have a detrimental effect at the ideation phase by restricting the proliferation of ideas. Conflict was also found to restrict creative thinking. Therefore the focus for design teams at the ideation phase should be on producing a breath of ideas which is beneficial to design and innovation (Paulus et al. 2006). It has also been shown that positive affect may be more conducive to creativity than negative affect as stressful conditions can lower creativity (De Dreu et al. 2008). While ‘wild’ ideas are encouraged during brainstorming teams experiencing conflict may be less inclined to offer solutions that may appear ridiculous or humorous. Teams need to recognise that the ideation phase needs supportive behaviour to create ideas and that conflict should be avoided.

These findings are at odds with the findings of Badke Schaub et al. (2010) who maintain that conflict using competing behaviour is of benefit to creativity during ideation and that “collaboration is required mostly later, at the phase of development and fine-tuning of the concept.” In their study the teams involved were given a design task that took 50 minutes. Over this time frame it was not possible to separate out distinct phases and the authors acknowledge that the concept development phase was barely captured. This
has implications for further research into conflict. The literature in design has not addressed the effect of conflict at different stages in a project where the objectives may be different. It is important for teams to understand where in the process conflict can be of benefit or harmful. In addition it has also been shown that to benefit from conflict during concept development it is advisable to have more than one concept to avoid a stalemate situation as choice will allow teams to gravitate towards a preferred option.

The literature has been limited in addressing the differences between novice and expert teams in the negotiation of conflict. In building on the findings of de Wit et al. (2012) who found a positive link between cognitive conflict and performance amongst top management teams over teams at lower levels in the organisation this research also indicates that experts may be better at negotiating and gaining from conflict. Experts showed a positive attitude towards conflict and knew where and when to apply it. Experts are thought to be more politically savvy and better able to handle complex interpersonal situations thus preventing cognitive conflict from escalating into relationship conflict (de Wit et al. 2012). The experts showed less of a tendency to be affected by group bias. They also appeared to be less stressed by the presences of conflict and did not display a fear of being rejected. They had a better understanding of its benefits. By using a ‘devil’s advocate’ approach the experts’ deliberately instigated conflict simply to argue a different position without necessarily holding strong beliefs in their argument to ensure that the topic was fully explored from multiple perspectives. Therefore the ‘devil’s advocate’ approach is a means to guide teams to routinely look at opposing arguments. This is one way of instilling cognitive conflict while adverting the mutation to affective conflict as team members would accept this as part of the process and that opponents may argue from a position that they do not have an emotional attachment to. They also avoided conflict at the ideation phase where it was not appropriate.

Instances of conflict amongst the novice Undergraduate teams were often at inappropriate times like the ideation phase where conflict was not constructive. They were also more inclined to let cognitive conflict shift towards affective conflict. This would indicate that novices need to be encouraged to recognise the benefits of moderate levels of conflict and the importance of negotiation. However these findings must be taken with caution as the novice student’s incidents of conflict were with their distributed partners. The effects of being distributed may have had a bearing on their treatment of conflict due to the less behavioural integration of the team. Behavioural integration has been shown to foster trust among team members (De Dreu 2006).
The risk of cognitive conflict leading to affective conflict can be mediated by collaboration and behavioural integration (De Dreu 2006, Mooney et al. 2007). The two teams that had the most behavioural integration were the Professional practice and Bio-innovate 2 teams. Both teams were together for a minimum of five months and displayed a trust between team members in their positive approach to conflict. The clear link to behavioural integration to benefit from conflict means that the socialising of teams is extremely important. This raises questions as to whether the face to face experience can be recreated virtually to induce the necessary discussion and debate. The undergraduate teams distributed location hampered their ability to integrate and generate trust which impacted on their ability to reach common ground.

Conflict may be more beneficial in more unstructured problems. As shown in the professional practice project, conflict was not present and not necessary. Therefore understanding the type of task involved will determine whether conflict has the potential to be of benefit. The level of conflict witnessed in this research was also moderate. High levels of conflict could also have a counterproductive effect on a project and result in unnecessary delays to consensus and decision making.

9.1.5 The consensus process

In drawing the findings together a revised conceptual model is presented in Figure 9.1 which summarises the findings to show how consensus was reached within the cases. It highlights the cognitive processes and conversation activities used to support the process and where in the design process conflict is appropriate to support consensus.

In validation of the initial conceptual model teams may start out with cognitive diversity in that each member may have distributed unshared knowledge, attitudes and belief structures. In order to pool these resources and co-ordinate their efforts teams must share their knowledge and negotiate on that knowledge to reach common ground and consensus. Teams must go through a process of externalising unshared knowledge and internalising that knowledge to create shared knowledge. They must then elaborate on information and negotiate or build sufficient common ground to reach consensus and make decisions. For clarity the model shows a linear process but the process is not always linear and depending on the topic teams may skip steps or may only need to go to shared knowledge on the model to progress to the next topic. Grounding and consensus occur repeatedly throughout discussions as new information is processed.
Consensus therefore is not linear but iterative, as information is shared and processed this leads to the further exploration of the topic detail and connected subject matter.

In navigating through this process teams will alternate between divergent thinking in knowledge processing and creative thinking to convergent thinking with critical thinking and metacognition. It is the verbal exchange and conversation activities that support these processes. It is through conversation that information is shared and negotiated. It is through conversation that team members can agree or disagree with one another.

In design the consensus process is influenced by the stage in the design process and the presence of conflict. The model can be viewed on a macro and micro level. At a macro level the consensus process can map on to the initial phases of the design process where the problem definition phase emphasises the sharing of knowledge, the ideation phase the reaching of common ground in the proposal of solutions and at the concept development phase the arrival at consensus in the selection of concepts. At a micro level this process is carried out several times at each phase of the design process and within each topic segment. At this level, consensus is viewed as the consensus to move the team to the next topic. Conflict is shown to be of benefit at the problem definition phases and concept development phases only.

The model highlights the emphasis of the cognitive processes and conversation activities that were used for each phase. It shows that arguing was one of the key activities to support the problem definition and concept development phases. Building on and scenarios supported all phases and while domain knowledge was important also at each phase it was most critical at the problem definition phase to support the construction of knowledge. Mental simulations and analogies were shown to be mainly generative and essential to ideation and concept development.
Figure 9.1: Revised conceptual model
9.2 CONCLUSIONS

The findings from the case studies carried out and cross case analysis allow for the further refinement of the conceptual model as outlined in Chapter 3 and a new revised model has been developed. The model has expanded on and detailed the path to consensus, the cognitive processes and conversation activities used in the process based on the findings from the four case studies examined. The findings have:

- Identified the cognitive processes and conversation activities teams use to reach consensus when solving design problems.
- Shown how the cognitive processes and conversation activities used by teams enable consensus during the initial phases of design.
- Shown how consensus reaching varies across the different phases of the design process.
- Shown the differences between how experts and novice teams approach consensus.
- Identified the role of conflict in the negotiation of consensus.

Comparisons with existing work in the area have been made to identify the contribution to knowledge.
10 Conclusions, Contributions and Future Research

This chapter presents the overall conclusions and contribution to knowledge of the empirical research findings presented in chapters 4 to 8. It begins with addressing how the findings meet the research aims and objectives. The chapter concludes with recommendations, the scope and limitations of the research, its contribution to knowledge and suggestions for future research.

10.1 MEETING THE RESEARCH AIMS AND OBJECTIVES

The aim of this research is to understand how consensus is reached during the initial phases of design and how it is negotiated within design teams.

The aim was met by fulfilling a number of key research questions, as outlined in Chapter 1 and as follows:

1. What are the cognitive processes and conversation activities used by teams during the initial phases of design?
2. How do the cognitive processes and conversation activities used by teams enable consensus during the initial phases of design?
3. What is the impact of different design phases on reaching consensus?
4. What are the differences between how experts and novices reach consensus?
5. How does conflict impact on consensus reaching in design teams?

The research questions were met by initially carrying out a literature review of the area. From this a conceptual model was devised which depicted the factors involved in reaching consensus in design. Data collection involved four case studies of six teams solving design and innovation problems in context. This was followed by conducting a cross case analysis of all four case studies.

10.2 CONTRIBUTION TO KNOWLEDGE

This study contributes to the literature in several ways.

- It has shown that design teams engaged mainly in critical thinking and knowledge processing followed by metacognition to reach consensus with only minimal levels of creative thinking.
The study has identified six conversation activities that supported the cognitive processes and consensus reaching in design teams: *domain knowledge, analogies, arguing, mental simulations, scenarios* and *building on*.

The study has found that consensus reaching varies across the design phases impacting on the cognitive processes and conversation activities used.

Experts appeared to be more cognitively active compared to novices in that they used more cognitive processes and conversation activity per utterance than the novice teams mainly due to increased *domain knowledge*. Experts in processing greater amounts of information seem to delay consensus to elaborate and negotiate on information.

Moderate levels of conflict were found to benefit teams at the problem definition and concept development phases but not at the ideation phase. Experts were found to instigate cognitive conflict which may be a strategy used, they were better at negotiating it and in avoiding affective conflict.

The new understanding and knowledge generated through this research has contributed to original knowledge in the areas of: design practice, consensus and decision making in design and conflict management. These contributions are further detailed as follows:

The cognitive processes and conversation activities used in reaching consensus amongst the design teams have also been shown (RQ1).

- The cognitive processes used were: *Knowledge processing, critical thinking, creative thinking* and *meta-cognition* and the conversation activities:
  
  - *Domain knowledge*
  - *Analogies*
  - *Arguing*
  - *Mental simulation*
  - *Scenarios*
  - *Building on*

How these activities were used to navigate consensus has been shown (RQ2). Design has been shown to be emergent and dynamic. The process of reaching consensus is repeated cyclically during a project as new information is processed.
• Early consensus is not necessarily desirable in design but must come through the sharing of the distributed knowledge, the elaboration and negotiation of this information to bring about common ground and then consensus.

• The cognitive processes and conversation activities were instrumental in enabling this process and the study shows how this was achieved.

The objectives for consensus at each phase in the design process vary. The different emphasis of the cognitive processes and conversation activities at these phases has been highlighted (RQ3).

• Knowledge processing increased across each phase.

• Critical thinking was at high levels at the problem definition phase and concept development phase dropping at the ideation phase.

• Creative thinking was at minimal levels rising only at the ideation phase.

• Meta-cognition was at high level at the problem definition phase and at minimal levels at subsequent phases.

The research has contributed to an understanding of the difference between experts and novices in reaching consensus (RQ4).

• Experts engaged more frequently than the novices, and at a deeper level with the cognitive processes and conversation activities to reach consensus.

• Experts deferred consensus, treated the problem as complex in order to share, elaborate and negotiate upon a wider range of distributed information.

• Experts due to their domain knowledge and prior experience were better able to use the other conversation activities.

• Experts were better at judging where to apply the cognitive processes and conversation activities.

The research has shown the impact of conflict on reaching consensus in design teams and how this is negotiated with the cognitive processes and conversation activities (RQ5).

• Overall cognitive conflict had a positive effect on team performance preventing teams reaching premature consensus and misinterpreting.
• Arguing, scenarios, and domain knowledge had a key role in the instigation and management of conflict.

• Conflict was shown to be of benefit only at the problem definition and concept development phases and not at the ideation phase where it was incompatible with creative thinking.

• Experts may deliberately instigate conflict using a ‘devil’s advocate’ approach in order to elaborate on and reframe the project information.

• Experts had a more positive approach to conflict and were less likely to allow cognitive conflict to dissolve into affective conflict.

10.3 RECOMMENDATIONS
The findings have implications and the following are some recommendations for both educational and industry practice:

Cognitive processes and conversation activities: In design education there has been a move towards self-directed learning, collaborative learning and learning related to practice (Dym et al. 2006, Yang et al. 2005) yet there is a belief also that design education is not keeping abreast of current design practice including collaboration and team work (Weightman and McDonagh 2006, Kieman and Ledwith 2014). Design education is very focused on teaching the practical skills of the discipline. The solving of ill-structured problems requires complex learning and discourse consisting of thought-provoking cognitive processing. Therefore:

• Teams during discussions may need to be encouraged to defer consensus to encourage the elaboration and negotiation of diverse information and perspectives. This may be achieved through the facilitation of the use of the cognitive processes and conversation activities to bring about consensus that is based on consolidating diverse perspectives to reach common ground. The findings have shown how the conversation activities supported the cognitive processes of the teams to enable individuals to externalise unshared knowledge for other team members to internalise and create shared knowledge which must be then negotiated on to create common ground and consensus to progress through a project.

• Experts were found to be better at elaborating and negotiating on project information to synthesise diverse perspectives. They used more cognitive processes and conversation activities than the novices, particularly critical
thinking and domain knowledge reflecting higher order thinking. Novices may need to be supported in developing their critical thinking ability. This can be achieved by encouraging the questioning and negotiation of project information to promote better arguments. Novices may need access to domain knowledge to support the cognitive processes and other conversation activities. This may include access to experts in the area or facilitation to conduct research. The provision of analogous cases can also make up for a shortfall in experience and domain knowledge. In doing so, the novice may begin to build that experience base to become an expert. This is supported by the literature which states that identifying underlying cognitive processing and skills, allows for the targeting of deliberate practices to support the problem solving strategies of novices. (Björklund 2013). Novices may also need to be guided during the process in using the conversation activities. For example an overemphasis of arguing would not be appropriate at the ideation phase but should be encouraged at the concept development phase to critique ideas.

- Moderate levels of cognitive conflict was found to have a contributory effect during discussions as through the negotiation of conflict a number of perspectives were synthesised to reach consensus. It brought about more knowledge of the task, in terms of complexity due to the exchange and sharing of ideas and information and the shifting of individual perspectives. Teams may need to be encouraged to view cognitive conflict as a positive aspect of team interaction to promote alternative perspective taking. Using a ‘devil’s advocate’ approach as a tool to stimulate conflict at certain times may be a means of avoiding relationship conflict as team members may be able to accept conflict if they are aware that it is a constructive part of the process. Conflict should be encouraged at moderate levels at the problem definition and concept development phase but avoided at the ideation phase where it was found to limit the flow of ideas. Facilitating the use of the cognitive processes and conversation activities can stimulate cognitive conflict while negating any negative effect of the conflict.

10.4 SCOPE AND LIMITATIONS

This study involved conducting four case studies to understand the role of consensus during the early phases of the design process and how it is negotiated. However to what extent can the findings and the conceptual model be generalised? Yin (1994)
affirms that a common criticism of case studies is the difficulty of generalising from one case to another. He suggests that the findings need to be generalised to existing theory. However the generalisation from the findings is not automatic due to a number of limitations. These findings are based on a limited number of varied cases of which three were in an educational setting and one was set in industry. The risk is that building theory from few cases may result in a narrow theory as the theory may describe a unique phenomenon (Gray 2009).

There were also some limitations in the methodology. The data collection and analysis was not carried out at the same phase in the process for all cases which may have contributed to some of the variations found in the cases studied. Only two cases were analysed for both the ideation and concept development phases. In addition when comparing across only two cases, the meetings captured for each phase may not be equivalent for the stages in the project and may have had slightly different objectives which may have impacted on the results. It was also only possible to record the teams over short durations of the project; approximately 1.5 hours for the Design professional case study, four hours for the Bio-innovate 1 case, five hours for the Undergraduate project and 20 hours for the Bio-innovate 1 study of which 5.5 hours were transcribed for analysis which may not be representative of the full process. Decisions taken to select material from the recordings for transcription and analysis was based on a subjective interpretation that the material was representational, which again may have narrowed the findings to isolated instances. Therefore only a short but detailed insight into the activities of the teams was obtained. However a protocol study is very time consuming and for every hour of recorded material up to 25 hours of additional time is necessary to transcribe and analyse the data. The effect of being recorded may also have hindered or effected the performance of individuals (Rosenthal 1966b). One participant on the Bio-innovate 1 project stated a preference not to be recorded after the first day of recordings, limiting the extent of that study. To reduce this effect, participants were told that the recorded material was not to be used to judge or evaluate them. The findings with regard to the cognitive processes may also be a limitation. Four cognitive processes were selected as being the main cognitive processes adopted by design teams. There may arguably be others such as visual thinking. In addition the definitions for each may not be distinct enough, making coding difficult particularly when there was overlap of thinking types within utterances.

Differences were found between the experts and novices. The findings for novices were based on only one case which again lessens the degree to which claims can be
made. Some of these differences particularly in the area of conflict may have been as a result of other factors such as a lack of trust and behavioural integration due to the distributed locations of the two sides of the novice Undergraduate teams. Therefore the findings in this aspect may be treated with caution. Therefore repeated studies could benefit from eliminating many of the variables involved in this study.

The sampling of the data representing conflict may also be a limitation. The difference between what constitutes debate and conflict is difficult to quantify, and the subjective nature of this selection may mean that the differentiation between the two may not be accurate.

10.5 FUTURE RESEARCH

Although the research has made several contributions to theory it has some limitations which present opportunities for further studies. The findings are based on a limited number of maximum variation cases. While the discourse analysis was carried out at specific stages in each study a more prolonged study across cases could improve or further develop the theories defined in the conceptual model. Reducing many of the variables in this study could allow for increased generalisation of further studies.

A Conceptual model has been developed that summarised the path to consensus in this study. The next step for this research would be to test the model as a tool to support the collaboration process of novice teams in order to define best practice.

What has also emerged from the findings is the role of the cognitive processes and conversation activities in the management of conflict. More prolonged studies of design collaboration are required to further understand this relationship. Further research could verify the role the cognitive processes and conversation activities play in the management of cognitive conflict and also what role they play in the prevention of relationship conflict. The research uncovered relatively moderate levels of cognitive conflict which resulted in more collaborative behaviour, future research in understanding the cognitive activity adopted in circumstances of higher levels of cognitive conflict could be of benefit.

Providing a context within which cognitive conflict can be stimulated has been proposed by some authors (De Dreu 2006, De Dreu and Van de Vliert 1997). Another clear opportunity for further exploration would be to induce different levels of conflict
within projects to determine their effect on both consensus and the cognitive processes and conversation activities.

The findings in this study were made over the early phases of the design process of problem definition, idea generation, and concept development. This is a critical stage in the process to establish common ground. Further research could provide an understanding of the relationship between the cognitive processes and conversation activities to consensus at the latter phases of the design process from concept development to implementation.

This research addressed how each team as a whole collaborated to solve unstructured problems in design. While it addressed individual inputs to some degree by showing that those with a high level of expertise and domain knowledge were better able to engage in the cognitive process and conversation activities it did not focus on the impact and contributions of each member and the effect of any differences between team members. A possible line of enquiry is to compare the individual's cognitive contributions to gaining common ground and consensus and how this is influenced by skills, expertise, disciplinary background, and personality profile.

The case studies were of maximum variation in that there were a number of differences between each such as: multidisciplinary versus single discipline, professional versus educational and distributed versus co located. While the effect of these differences was not the main focus of this research, further studies could establish the impact of these factors on teams' abilities to reach consensus.
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APPENDIX A: DATA ANALYSIS

EXAMPLE 1 Making initial sense of the data

Colin:
The patient doesn’t necessarily know they have a problem. They want to get checked out. (They want 0) stress.

Wayne:
There looking for a quick solution am I ok not ok. This is diagnostic for them: it could be their first time.

Colin:
They’re potentially sick and they’re seeking an outcome.

Marie:
Their apprehensive as well.

Wayne:
As a result of this they’re potentially stressed and apprehensive as well. So that’s important.

Waqar:
And they’re anxious to know if they can do something about it themselves. They often want to do something themselves rather than seek some medical intervention. You know?

Colin:
What do they want or need. What they would want is to be shown respect when they are in there. (Human understanding) Not why the hell didn’t you come to me before.

Colin:
That’s pretty much it.

Wayne:
Yeah. The knowns unknowns?

Marie:
(Have we thought about the external ones?)

Wayne:
Like medical device suppliers?

Wayne:
Are there any other stakeholders interacting with the system?
Are there any other stakeholders, anyone with a vested interest?

Wayne:

Yeah they would have. They're questions that we can ask tomorrow. Does the HSE mandate you to buy any specialised equipment? (6:00)

Colin:

Families want assurance about loved ones. (8:00)

Wayne:

It's more than just admin, its costs in general. Staff costs, medical costs. (10:00)

Wayne:

These are the questions we're going to have to ask and if there are any assumptions here we're going to have to validate them. If we're not sure of any of these we might put them in unknowns.

Colin:

We should be looking to see exactly what CROI do. What services they have.

Wayne:

Funds are always going to be an issue so funds are important. (11:00)

Waqar:

They want more information on what options they may have to address those important health issues themselves and what things are available to them in CROI. (12:00)

Wayne:

So they have a support group.

Waqar:

The patients would feel at ease that there is a place out there where I can go to get my heart checked. There is a service where they can go.
EXAMPLE 2

I was looking at the different beds and the way some beds fold up. Your bed isn't going to be necessarily two metres by 800 in width when you're moving it around the room.

Barry:

Yes.

Louise:

so I think we should concentrate on a few bed designs first and see what kind of sure they'll take up first and then put them into the space.

Laura:

As but you have to consider that if the bed when open is two metres long you have to have that space clear.

Louise: Yes.

Laura: because otherwise if you put another bed in the space they're going to crash together.

Louise: Yes.

Laura: that's why I say it's important to play with the blocks which is the space that the person is going to be and see how you can manage it (metre 60 high by the 4m. And from that space that is designed for that person. I believe to make it spaces and then play around with them.

Louise: ya again should they all be the same? because if they are all flexible maybe they should be different. Why should my space be the same as your space if I'm different to you.

Barry: you saying you'd make the beds different sizes?

Louise: not the bed sizes but even the bed structure or the rest structure or the bed out structure. It is like a transformer in some ways it can transfer to different things. (metre) The space isn't always going to be bed bed bed, it's not always going to be like a dormitory.

Barry: I don't agree with that. You might have one section where there will be fixed beds but you might have another that will have beds but it can turn into a social area where there is a bed that turns into a coach.

Laura: but what if all of them want to sleep that day.

Barry: then they'll have that option then.

Louise: the bed should turn into a bed. 

Barry: Ya. Do you see how you want to use the space? Any ideas? (metre) I saw the photos you put up. I liked the one on dropbox, picture 1. I was the one that came out. (section) Did you see that? I thought it was a good idea, it was a good use of space.
Barry: It was just that the issue had been addressed. You know we have tons of concepts for beds and spaces.

Louise: As I had seen from the thing I put up last week from your one on the foreign right. She got dressed upstairs in the bed. Can you say your not allowed get dressed upstairs? (8:24) [MSOffice10]: informed opinion

Laura: But I think that the space is so small you cannot even change there. Anytime we go to the coast I bring a tent which is 1 metre and I tried to change inside and even my daughters couldn’t because of the space you can’t change. What’s your height?

Barry: 180

Laura: If the person has 180 how are you going to change properly? So I think that’s why they don’t have this (changing room in nest).

Louise: What about under the stairs. You need to allow the women have somewhere to change...

Marco: The fact is the women are changing in the toilet.

Barry: But in the particular study you saw where the lady changed in the toilet. I think it’s very easy to say that look they can get changed in the toilet but you know we should be able to design something for them.

Louise: What if there is 2 or 4 passengers queuing for the toilet?

Barry: Exactly. But there’s nothing to say that when you go into the toilets that the toilets are clean...

Marco: It’s the same toilet as the passengers right?

Louise: Ya

Marco: 10:00 so there are no kind of things like mirrors to freshen up in the first place.

Barry: I think from the pictures from Driessen that space under the stairs is used as storage. We need to design that into some sort of changing room. We could be more creative with are storage space.

Analogy: Reference to other products

Informed opinion (analysis or review)

Concrete (Positive encouragement to others)

Planning: identify issues and issues to be addressed (sub heading)
CODING ANALYSIS SAMPLES PHASE 1 OPEN CODES:

Bio Ideation Jan 30th 1Hr 25min

L: are the adhesions hard or soft? EXPLAINING Q
Leon: fibrous EXPLAINING

L: so this is for breaking down the adhesions. So you slice someone open and go in with these blades EXPLAINING SCENARIO. Is there a risk of injuring them? QUESTIONING

R: they’re not blades EXPLAINING
L: they’re mini chainsaws. All laugh HUMOUR

R: we were thinking that we wanted to go from a level of detecting adhesions over any other tissue so that the technology in it would detect a certain physiology and upon detection of an adhesion it would only cut then. And it will have some kind of energy transfer that will zap it like a laser. EXPLAINING SCENARIO But its all conceptual we don’t know. MONITORING

L: lets say this is your adhesion you go in and you identify that it is the right consistency to be an adhesion and then it would administer the cutting if it was diathermia or something. SCENARIO EXPLAINING

L: so laser will cut through tissue will it? CLARIFICATION Q
R: yeah CLARIFICATION

L: does it cut it through or does it zap it away? CLARIFICATION
Kev: it cuts and coagulates at the same time. EXPLAINING
R: how do you want to do this so? PLANNING Q
Leon: come up with some ideas. PLANNING S
R: I think its our best written need. EVALUATION

Kev: yeah a faster quicker way to break down adhesions. EXPLAINING
Lou: did ye talk about prevention of adhesions? EXPLAINING Q
Kev: yeah we are not going to touch that it’s a crowded space. Even so there is still a risk that someone can develop adhesions. The problem is not going away. EVALUATION EXPLAINING
Lou: how do you get rid of the material then when you cut it? EXPLAINING Q
R: they don’t take anything out. They just cut them. They just break them down. EXPLAINING
L: it just sits inside the body? EXPLAINING Q
R: yeah they just leave them hanging broken. They don’t chop out a bit and then pull it out on to something. But it takes ages. EXPLAINING SCENARIO

Kev: aren’t they usually stuck to the peritoneal cavity? DOMAIN K Q QUESTIONING
R: yeah
Chris: That's one way of ranking them. **METACOGNITION** If something has a huge impact on the system to something that has a minor improvement in efficiency or comfort for the doctor or clinician or something that has no improvement. **SCENARIO** But then if you just look at the impact on the doctor, and the impact on the user. **ARGUING, ANALYSIS CRITICAL THINKING**

Rhona: oh no I'm definitely saying that it will have provider impact, just as long as you don't lose the fact that it could be either. **CLARIFYING KNOWLEDGE PROCESSING, CRITICAL THINKING**

Leon: I think its fine if you capture the overall provider and the clinician in one, Because you'll get the best picture then sooner rather than later. The only danger of splitting them out again is you could get two lows and you'd be gone before you even get to the clinician. **ARGUING, ANALYSIS CRITICAL THINKING, METACOGNITION**

Rhona, Your dead right Yeah, OK **CONSENSUS METACOGNITION**

Chris: It's just a suggestion. Just take it as a thing that is going to provide the biggest provider impact. It's the thing that's going to have the big saving and then putting it down to something that has an impact on the user but is maybe not going to be a cost saving and everything in between. I think it captures things. *(proposal, ARGUING, TO MAKE SUGGESTIONS, DOMAIN KNOWLEDGE) ANALYSIS CRITICAL THINKING, METACOGNITION*

Rhona: that's fine **CONSENSUS**

Chris: What are your thoughts on it: **KNOWLEDGE PROCESSING**

Kevin: the more I think about it the more sense it makes. I think as long as you structure it so that it makes sense whether you are talking about the clinician or the provider. I think you can word that so it makes sense. **KNOWLEDGE PROCESSING ARGUING, BUILDING ON, PLANNING CRITICAL THINKING, METACOGNITION**

Chris: And then take degrees of impact. **BUILDING ON CRITICAL THINKING**

Kevin: What might you lose in terms of the clinician if you do it like this?. Some of the ergonomics or the ease of use, or having it working like this. Some of that stuff you might lose. If your saying improvement is efficiency of the procedure. If you build it in, efficiency or ease of procedure, then do you get it back? *(ARGUING ANALYSIS proposing) CRITICAL THINKING, METACOGNITION*

Rhona: Yeah cost and time, so ease. Could you put in ease? **BUILDING ON proposing CRITICAL THINKING**

Kevin: cost time and ease, so efficiency and ease. Id put it here. Just because its easy doesn’t mean its more efficient. If you put in ease in here your redefining the word efficiency in my mind. *( ARGUING). ANALYSIS CRITICAL THINKING, METACOGNITION*
APPENDIX B: INTER-RATER CODING RESULTS

Case Processing Summary

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Coder1 * Coder2 Cross-tabulation

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DATASET ACTIVATE DataSet1.

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/COMPRESSED.

SAVE OUTFILE='C:\XP files\PHD\Inter-coder-SPSS.sav'
/COMPRESSED.

DATASET ACTIVATE DataSet1.

SAVE OUTFILE='C:\XP files\PHD\Inter-coder-SPSS.sav'
/COMPRESSED.

CROSSTABS
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/FORMAT=AVALUE TABLES
/STATISTICS=KAPPA
/CELLS=COUNT
/COUNT ROUND CELL.

Symmetric Measures

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<td>N of Valid Cases</td>
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a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.
APPENDIX C: EXCERPTS FROM PEER DEBRIEFING

Coder 1:

Kev: no you can age quicker if you are exposed to ultra violet light but maybe that a whole load of nonsense. But there’s tests to see the longevity of different plastics by exposing them to ultra violet lights and seeing how long it takes before they go harder. **DOMAIN K EXPLAINING**

R: IT changes the molecules. **DOMAIN K EXPLAINING**

K: you see the adhesions are big strips of things so instead of cutting them when they are big if you could shrink them and then just one snip. If you could inject sclerotic into them and they shrivel up. **DOMAIN K EXPLAINING MENTAL SIMULATIONS**

R: to further that you are really talking about changing their state so you were on about freezing can you change their colour, spray them with some colour identifier so you have a luminous. Its about visuals really you cant .. there’s adhesions here and you don’t know what is behind, vessles and organs and stuff. You don’t know how to proceed because you cant see behind the adhesion **EVALUATION**. But if you could spray colour on and only change the adhesions and make them luminous and make them more visible. **BUILDING ON MENTAL SIMULATION**

K: yeah if they are fibrous then maybe the fibre has some kind of, you know how fluoroscopy works? **ANALOGY** if you have a certain protein for example fibroinogen then you could make it show up by getting certain luminous markers to bond to it. **BUILDING ON** You could use a special camera so it shows up on that camera. That could be good. **BUILDING ON MENTAL SIMULATION**.

L: Could you just vacuum them, just suction them with a powerful suction. You were saying that you can just pull them. **ANALOGY**

R: you can pull then yeah. Like use a certain force to vacuum them? **CLARIFICATION**

L: yeah

R: write it down L. **MONITORING** You love that Dyson stuff don’t you? **HUMOUR**

L: maybe that might need a locator before you suck them out. **EVALUATION INFERENCE**

R: awesome

Leon: so what have we got so far covered blades, direct into the adhesion blade that cuts only adhesions, vacuum, hot cold treatment, ice pack heat pack, electrical stimulation breakdown of scar tissue, ultrasound to break down scar tissue, injects sclerotin into the tissue to shrink before the cut, **MONITORING**

Kev: what if you just froze them and hit them with a hammer? **HUMOUR WILD IDEAS** (22:40)

R: no seriously yeah shatter them. **BUILDING ON**

K: like they do for verrucas, nitrogen oxide and you just freeze it. And you get a mallot of some kind. **BUILDING ON**

Leon: Maybe if you just froze the centre of the adhesion like it the top of the thing just froze instantly and then you just cut it. **BUILDING ON MENTAL SIMULATION**
K: with a hammer and anvil or something BUILDING ON

Leon: A mini hammer BUILDING ON

L: what do they use for verucas it's a solution isn't it? EXPLAINING Q

R: liquid nitrogen EXPLAINING

L: would you be able to put that inside the body? EXPLAINING Q

R: possibly not but something along those lines. INFERENCE

Leon: you might spill it. QUESTIONING EVALUATION

K: You could put it on a swab so it doesn’t actually come out. You inject it through a long chord and a drop lands on a tip of a swab and you hit the swab off the adhesion. Proposal, MENTAL SIMULATION

L: could you inject it into the adhesion? Proposal, MENTAL SIMULATION BUILDING ON

K: that’s kind of like the sclerosis one where you inject liquid nitrogen. WITHIN DOMAIN, EVALUATION

R: what about you're trying to get a safe way to cut adhesions and not cut anything else? MONITORING (earlier idea)

L: how do you single them out? If you could twist them. EXPLAINING Q (rhetorical) QUESTIONING

Leon: what about a snare? WILD IDEAS, ANALOGY

K: chinese burn. WILD IDEAS, ANALOGY A snare?

Leon: yeah it snakes around a few of them and then you slowly bring it in. EXPLAINING

K: what about going from the other angle instead of trying to address all the adhesions and trying to find all the adhesions just spending your time separating the fascial layer of the peritoneum cavity from everything else. Id just work off of the fascia. The fascia is at the base of the peritoneum cavity, underneath that adheres the adhesions. So if you could go in and do a big kind of a blitz to free everything underneath the fashia. QUESTIONING lateral Proposal

R: a big swipe yeah. BUILDING ON

K: And then you can inflate the whole thing properly and see where everything is. MENTAL SIMULATION BUILDING ON

R: I had this idea as a cutting action but the dangers aren’t alleviated, EVALUATION that you would use a sickle to cut. ANALOGY And maybe to decrease the danger that the head has the tip of the sickle has a cover on it so your first action is (draws). This is the piece that goes in and it is not cutting and you can feel the pull and tension and it goes in and when you know you are proceeding correctly that this is going to cut it after. EXPLAINING, MENTAL SIMULATION, PERSPECTIVE OF OTHERS
Coder 2:

Kev: no you can age quicker if you are exposed to ultra violet light but maybe that a whole load of nonsense. But there’s tests to see the longevity of different plastics by exposing them to ultra violet lights and seeing how long it takes before they go harder. **DOMAIN K EXPLAINING**

R: IT changes the molecules. **DOMAIN K EXPLAINING**

K: you see the adhesions are big strips of things so instead of cutting them when they are big if you could shrink them and then just one snip. If you could inject sclerocent into them and they shrivel up. **DOMAIN K EXPLAINING MENTAL SIMULATIONS**

R: to further that you are really talking about changing their state so you were on about freezing can you change their colour, spray them with some colour identifier so you have a luminous. Its about visuals really you can’t have adhesions here and you don’t know what is behind, vesseles and organs and stuff. You don’t know how to procede because you cant see behind the adhesion **EVALUATION**. But if you could spray colour on and only change the adhesions and make them luminous and make them more visible. **BUILDING ON MENTAL SIMULATION**

K: yeah if they are fibrous then maybe the fibre has some kind of, you know how fluoroscopy works? **ANALOGY** if you have a certain protein for example fibroinogen then you could make it show up by getting certain luminous markers to bond to it. **BUILDING ON** You could use a special camera so it shows up on that camera. That could be good. **BUILDING ON MENTAL SIMULATION**

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L: yeah

R: write it down L. **MONITORING** You love that Dyson stuff don’t you? **HUMOUR**

L: maybe that might need a locator before you suck them out. **EVALUATION INFERENCES**

R: awesome **CLARIFYING**

Leon: so what have we got so far covered blade, direct into the adhesion blade that cuts only adhesions, vacuum, hot cold treatment, ice pack heat pack, electrical stimulation breakdown of scar tissue, ultrasound to break down scar tissue, injects scleratin into the tissue to shrink before the cut, **MONITORING**

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R: no seriously yeah shatter them. **BUILDING ON**

K: like they do for verrucas, nitrogen oxide and you just freeze it. And you get a mallot of some kind. **BUILDING ON** **ANALOGIES**

Leon: Maybe if you just froze the centre of the adhesion like it the top of the thing just froze instantly and then you just cut it. **BUILDING ON MENTAL SIMULATION**
K: with a hammer and anvil or something BUILDING ON ANALOGIES
Leon: A mini hammer BUILDING ON ✓
L: what do they use for verucas it's a solution isn't it? EXPLAINING Q ✓
R: liquid nitrogen EXPLAINING CLARIFYING
L: would you be able to put that inside the body? EXPLAINING Q ✓
R: possibly not but something along those lines. INFERENCE ✓
Leon: you might spill it. QUESTIONING EVALUATION ✓
K: You could put it on a swab so it doesn't actually come out. You inject it through a long chord and a drop lands on a tip of a swab and you hit the swab off the adhesion. Proposal, MENTAL SIMULATION ✓
L: could you inject it into the adhesion? Proposal, MENTAL SIMULATION, BUILDING ON ✓
K: that's kind of like the sclerosis one where you inject liquid nitrogen. WITHIN DOMAIN, EVALUATION ✓
R: what about you're trying to get a safe way to cut adhesions and not cut anything else? MONITORING (earlier idea) BUILDING ON ✓
L: how do you single them out? If you could twist them. EXPLAINING Q (rhetorical) QUESTIONING ✓
Leon: what about a snare? WILD IDEAS, ANALOGY ✓
K: chinese burn. WILD IDEAS, ANALOGY A snare? ✓
Leon: yeah it snakes around a few of them and then you slowly bring it in. EXPLAINING ✓
K: what about going from the other angle instead of trying to address all the adhesions and trying to find all the adhesions just spending your time separating the fascial layer of the peritonium cavity from everything else. Id just work off of the fascia. The fascia is at the base of the peritonium cavity, underneath that adheres the adhesions. So if you could go in and do a big kind of a blitz to free everything underneath the fascia. QUESTIONING Lateral Proposal elaborating ✓
R: a big swipe yeah. BUILDING ON ✓
K: And then you can inflate the whole thing properly and see where everything is. MENTAL SIMULATION BUILDING ON ✓
R: I had this idea as a cutting action but the dangers aren't alleviated, EVALUATION that you would use a sickle to cut. ANALOGY And maybe to decrease the danger that the head has the tip of the sickle has a cover on it so your first action is (draws). This is the piece that goes in and it is not cutting and you can feel the pull and tension and it goes in and when you know you are proceeding correctly that this is going to cut it after. EXPLAINING, MENTAL SIMULATION, PERSPECTIVE OF OTHERS ✓
Participant Consent form

Title of study: The strategies, processes and methods used in real world problem solving in the area of design and innovation.

Principal researcher: Louise Kiernan

Institute: University of Limerick

Purpose of this research study: To investigate what strategies, methods and processes designers and other disciplines use to progress through real world problems in design and innovation.

Participant Selection: You are being invited to take part in this research because I feel that the bio-innovate process and your collective experience as interdisciplinary teams is a very progressive approach to innovation. This can contribute much to my understanding and knowledge of the strategies and methods used in problem solving in the area of design and innovation.

Voluntary Participation: Your participation in this research is entirely voluntary. It is your choice whether to participate or not. You may withdraw from being part of this research at any time and this will not affect your status within the project either now or in the future.

Procedures: The research methods involve the mini project with audio recordings of the first day of the mini project, observations, field notes and a survey.

Confidentiality: The data from the research will be held confidentially, in a secure place in a pass-word protected computer in the form of hard and electronic copies of surveys and audio files. This data will be accessible to the researcher only. Your name and identity will not be disclosed at any time. However the data may be seen by the ethical review committee and may be published in a journal and elsewhere without giving your name or disclosing your identity

Who to Contact: If you have any questions about this research, you can contact:

Louise Kiernan Email: Louise.kiernan@ul.ie telephone:

Authorization: I have read and understand this consent form, and I volunteer to participate in this research study. I voluntarily choose to participate, but I understand that my consent does not take away any legal rights in the case of negligence or other legal fault of anyone who is involved in this study.

Print Name of Participant______________________

Signature of Participant _____________________

Date ___________________________