Collaborating in engineering design

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Acknowledgments

In carrying out this research numerous individuals have influenced my work and need acknowledging.

First, I wish to acknowledge the support, advice and patience of my supervisors – Dr. Linda Newnes and Dr. Louise Knight. Guidance from both supervisors has been invaluable in determining how to accomplish my research bringing together literature and methods from a variety of academic disciplines. Secondly I would like to thank my two examiners – Professor Chris McMahon and Professor Bill Ion, for their time, questions and constructive thoughts.

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Finally, I wish to thank my family and friends. Those present in my life between 2006 and 2010 have all influenced me and in turn this thesis. Thank you.
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Abstract

Collaborating in engineering design is taking place increasingly across technical disciplines, departments and organisations. When collaborating, participants confront issues about how to share understanding and foster aligned project expectations. A review of literature suggests there is limited research about the process of collaborating in engineering design and how collaborating is influenced by context. Collaborating is distinguished as a relational concept (involving at least two parties) that is a social process occurring in both pairs and a group. Studies currently focus on group effectiveness, one or two processes (e.g. communication), and either a group (e.g. a collaboration) or pair-wise relations (e.g. inter-organisational relationships). A framework of relevant concepts was adopted from literature on collaboration practice to organise empirical data.

Collaborating in engineering design is explored in sixty semi-structured interviews focusing on participants’ interaction and shared understanding (as pairs and groups) in their activities. This is complemented by observations of group meetings and project documentation. Empirical data is presented from four industry-based case studies classified by design type (adaptive or original) and design setting (intra or inter-organisational). Cross-case comparisons draw attention to an increase in ambiguity and uncertainty in combining tasks, roles, expertise and participants in original design type or inter-organisational cases. Findings from cross-case analysis highlight seven new conceptual categories. Four features (Opportunity, Dependence, Results, Adjustments) are used to present a dilemma that participants face which is more acute where organisational and knowledge boundaries are crossed. Three mechanisms (Familiarising, Associating, Regulating) describe how pair-wise relations influence a group and individuals in collaborating. These show that through pair-wise relations individuals recognise, establish and maintain expectations of how to collaborate in engineering design. This reveals that pair-wise relations both help and hinder individuals and a group in how they adjust to foster aligned expectations of collaborating.
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Table 1 – Definitions of terms used in this research

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<th>Themes in collaborating</th>
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</tr>
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<tbody>
<tr>
<td>Accountability</td>
<td>Issues evoking individual or group responsibilities for accomplishing task(s) or role(s) in a project.</td>
</tr>
<tr>
<td>Commitment and determination</td>
<td>Topics that illicit motives and intentions of participants to contribute or continue in a project (Cullen et al., 2000).</td>
</tr>
<tr>
<td>Common aims</td>
<td>Elements that describe how aims (individual, group) overlap, are similar, or are complementary for individuals to accomplish activities.</td>
</tr>
<tr>
<td>Communication and language</td>
<td>Issues related to how individuals or groups intentionally exchange signals, data, information or knowledge.</td>
</tr>
<tr>
<td>Compromise</td>
<td>Issues evoking how participants reach agreement from different perspectives to establish aligned project expectations.</td>
</tr>
<tr>
<td>Culture</td>
<td>Characteristics and norms that are related to group identity at a national, racial, ethnic, or organisational level.</td>
</tr>
<tr>
<td>Democracy and equality</td>
<td>Topics related to how participants act towards each other and how they are involved in defining project expectations or taking decisions.</td>
</tr>
<tr>
<td>Identity</td>
<td>Issues linked to individual and group beliefs, traits, boundaries, values, and reputation that highlight differences to other individuals or groups.</td>
</tr>
<tr>
<td>Leadership</td>
<td>Issues relating to individuals or groups contributing action, direction, or supervision over others to achieve tasks or roles (see also power).</td>
</tr>
<tr>
<td>Learning</td>
<td>Topics linked to individuals or groups gaining knowledge and changing their behaviour, working processes, or principles.</td>
</tr>
<tr>
<td>Membership structures</td>
<td>Elements that describe how participants are linked together including project roles, group composition, formal hierarchies and internal infrastructures.</td>
</tr>
<tr>
<td>Power</td>
<td>Issues eliciting influence over another (individual or group) - the “ability to influence, control or resist the activities of others” (Huxham &amp; Beech, 2008: 555). Control is &quot;a regulatory process by which the elements of a system are made more predictable through the establishment of standards in the pursuit of some desired objective or state&quot; (Leifer &amp; Mills, 1996: 117).</td>
</tr>
<tr>
<td>Resources</td>
<td>Topics related to the availability or composition of human (e.g. expertise), social (see definition), or physical (e.g. tools) capital.</td>
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</table>
### Themes in collaborating

<table>
<thead>
<tr>
<th>Theme</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Risk</td>
<td>Issues relating to individuals or groups evaluating potential losses in failing to achieve proposed plans or aims.</td>
</tr>
<tr>
<td>Social capital</td>
<td>Issues relating to the “sum of actual and potential resources embedded within, available through and derived from the network of relationships by an individual or social unit” (Nahapiet &amp; Ghoshal, 1998: 243).</td>
</tr>
<tr>
<td>Success</td>
<td>Events, outcomes or processes that were realised meeting or exceeding individual or group expectations.</td>
</tr>
<tr>
<td>Trust</td>
<td>Elements that increase confidence in matching expectations and outcomes (individual or group). Benevolent or goodwill trust covers individual ability to take initiatives for mutual benefit, and credibility or reliability trust includes expectations about partners intent and ability to meet obligations (Cullen et al., 2000; Das &amp; Teng, 1998). Credibility trust can be split into contractual trust focusing on shared norms of honesty and intent, and competence trust on ability to meet obligations (Sako, 2000).</td>
</tr>
<tr>
<td>Working practices</td>
<td>Topics linked to methods, styles, or approaches used by individuals or groups to accomplish their role(s) or task(s), e.g. organisational new product development process.</td>
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</table>

### Research Question (RQ)

This is interaction and understanding between two individuals. Interaction is any form of action or behaviour between two individuals, in essence it is what a pair of individuals do. This can be asynchronous e.g. email or synchronous e.g. telephone, and co-located e.g. face to face or distributed e.g. via video conference facilities. Interaction is broader than the term communication by including behaviour to recognise how interaction is conducted e.g. when a telephone call is made, or how openly participants express themselves. Understanding in pairs is based on the concept of shared understanding specifically focusing on two people and is split into two aspects – Task and Team.
<table>
<thead>
<tr>
<th><strong>Research Question (RQ)</strong></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Group relations</strong></td>
<td><em>Group relations</em> encompass data on interaction and understanding in groups. Interaction includes any action involving more than two participants in a project. Understanding in a group covers data that describes how more than two individual develop aligned expectations and is split into two aspects – Task and Team.</td>
</tr>
<tr>
<td><strong>Outcomes</strong></td>
<td><em>Outcomes</em> are observable consequences of process in engineering design teams. This covers project events (e.g. a finished product), interim events (e.g. revisions to designs) and participants’ affective reactions (e.g. establishing commitment to other participants).</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>A conceptual category referring to individual and organisational actions (Van de Ven, 1992).</td>
</tr>
<tr>
<td><strong>Social process</strong></td>
<td>Social process include task (e.g. communication) and socio-emotional (e.g. building trust) processes that involve or relate to individuals i.e. “the behaviour of people over time” (Pettigrew, 1973: 1).</td>
</tr>
<tr>
<td><strong>Collaborating</strong></td>
<td>Participants <em>interact</em> and transfer individual <em>knowledge</em> into shared knowledge. This promotes individuals and a group to learn and develop <em>common ground</em> or <em>shared understanding</em>. Consequently, participants explore constructively different perspectives on a problem to develop ideas that go beyond individual expectations of what is feasible. This is shown by joint ownership of and responsibility for solutions, aligned aims, and participants working together for common rather than individual ends (cooperating) (Jeffrey, 2003).</td>
</tr>
<tr>
<td><strong>Shared understanding</strong></td>
<td>Shared understanding is where individuals show an awareness about how tasks, behaviour and events are interpreted including being able to anticipate each others’ actions, needs, and adapting their behaviour (Klimoski &amp; Mohammed, 1994) to develop common or complementary expectations (Cannon-Bowers &amp; Salas, 2001).</td>
</tr>
<tr>
<td><strong>Task understanding</strong></td>
<td>Task understanding is knowledge about design procedures, scenarios, strategies etc (Mathieu et al., 2005; Mathieu et al., 2000; Mohammed &amp; Dumville, 2001); it sums up understanding about engineering design processes.</td>
</tr>
</tbody>
</table>
## Research Question (RQ)

<table>
<thead>
<tr>
<th>Team understanding</th>
<th>Team understanding is knowledge about roles, participant capabilities, attitudes, beliefs, behaviour etc (Mathieu et al., 2005; Mathieu et al., 2000; Mohammed &amp; Dumville, 2001); simply it is understanding about working with people.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common ground</td>
<td>A type of shared information such that the common ground between two people is the sum of their mutual knowledge, beliefs, goals, attitudes, etc. (Clark, 1992: 257).</td>
</tr>
</tbody>
</table>

## Features

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Prospects participants had for interacting and developing shared understanding in pairs or a groups.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dependence</td>
<td>The extent to which individuals require something from each other or a project group in order to achieve their aims and activities. This covers links between participants due to completion of specific activities and links to a project or each other due to participants’ reputation at stake.</td>
</tr>
<tr>
<td>Results</td>
<td>Events covering project and interim outcomes i.e. project completion, participants’ availability, delays, design revisions and requirements for additional resources.</td>
</tr>
<tr>
<td>Adjustments</td>
<td>Participants’ affective reactions in collaborating e.g. recognising how to trust other participants. These are concerned with building and maintaining relations with participants to work effectively together. This focuses on individuals’ adjustments to achieve their activities when Results challenged their expectations.</td>
</tr>
</tbody>
</table>

## Mechanisms

| Familiarising      | Familiarising describes how pair-wise relations lead to increasing familiarity of a group’s Task (e.g. design procedures, scenarios etc) and Team (e.g. participant capabilities, behaviour etc) shared understanding [group relations]; and through pair-wise relations individuals recognise what to expect from each other i.e. who knows what and how to trust each other [outcomes]. |
### Definitions

#### Mechanisms

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Associating</td>
<td>Associating describes how <em>pair-wise relations</em> increase participants’</td>
</tr>
<tr>
<td></td>
<td>connections to a group’s Task (e.g. design procedures scenarios etc) and</td>
</tr>
<tr>
<td></td>
<td>Team (e.g. participant capabilities, behaviour etc) shared understanding</td>
</tr>
<tr>
<td></td>
<td>[<em>group relations</em>]; and through <em>pair-wise relations</em> individuals establish</td>
</tr>
<tr>
<td></td>
<td>what to expect from each other (e.g. commitment, obligations) [<em>outcomes</em>].</td>
</tr>
<tr>
<td>Regulating</td>
<td>Regulating describes how <em>pair-wise relations</em> lead to increased control of a</td>
</tr>
<tr>
<td></td>
<td>group’s Task (e.g. design procedures, scenarios etc) and Team (e.g.</td>
</tr>
<tr>
<td></td>
<td>participant capabilities, behaviour etc) shared understanding [*group</td>
</tr>
<tr>
<td></td>
<td>relations*], and through <em>pair-wise relations</em> individuals maintain what to</td>
</tr>
<tr>
<td></td>
<td>expect from each other, specifically aligned expectations [<em>outcomes</em>].</td>
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</table>

#### Additional terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
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<tbody>
<tr>
<td>Norms</td>
<td>Standardisation of what or how activities are performed by a group (Radley, 1991: 34-5) or pair. Norms are shared beliefs, attitude and behaviour uniformities that define group membership and differentiate between groups (both descriptive and prescriptive). Norms and stereotypes are closely related; norms refer to behaviour that is shared in a group, and stereotypes to shared generalisations about other groups.</td>
</tr>
<tr>
<td>Involvement</td>
<td>This comprises of data relating to interactions, partnerships and information flow between participants within a collaboration (Hardy et al., 2003).</td>
</tr>
<tr>
<td>Embeddedness</td>
<td>Data relating to interaction, representation and information flow with third parties through inter-personal networks (Granovetter, 1985).</td>
</tr>
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1 Introduction

1.1 Purpose of thesis

Collaborating in engineering design is not a new phenomenon as engineers have been sharing, combining and synthesising their expertise to develop products since the advent of mass production after the second industrial revolution. What has altered since then is the setting and process of collaborating. Engineers now regularly work across organisational boundaries (including departments) with individuals from diverse technical fields to solve complex problems. Participants typically only have expertise in a fraction of the technical disciplines involved and are required to build and maintain a shared understanding of the product to collaborate successfully. Furthermore, participants’ activity on a project varies as organisational priorities change and individuals join and leave a project. This influences design, and group, development processes and thus the process of collaborating.

In this thesis, the intention is to contribute a holistic understanding of the process of collaborating in engineering design focusing on how pair-wise relations influence group relations and outcomes. Pair-wise relations cover interaction and understanding between two individuals. Group relations includes interaction and understanding in a project group. Outcomes cover project events e.g. a finished product, interim events e.g. revisions to designs and participants’ affective reactions e.g. establishing commitment to each other (see Definitions p. xii for full descriptions).

This holistic understanding is based on empirical data from four industry-based projects involving ten organisations; influences from design setting (intra-organisational versus inter-organisational) and design type (adaptive versus original) are compared. Findings are aimed at both academic and practitioner audiences. Academically, an empirically derived framework with three mechanisms (Familiarising, Associating and Regulating) is introduced to describe the influence of pair-wise relations on group relations and outcomes. Secondly, implications for practitioners are presented to provide guidance topics for planning and making sense of events to improve the likelihood of fostering aligned expectations, and hence successfully collaborate in engineering design.

To achieve this, the setting and process of collaborating is elaborated first in section 1.2. Next the Research Question and Objectives are set out in section 1.3 followed by defining how collaborating differs from teamwork (1.4). Lastly, selected themes of literature are outlined (1.5) to describe where this research is positioned and provide a structure to this thesis.
1.2 Setting & process of collaborating

Collaborating in engineering design is carried out through a number of entities that cross organisational and discipline boundaries e.g. sub-contracting, R&D agreements, joint ventures. Collaborating is being strongly promoted by professional associations (e.g. ASME, 2008, 2009) and governments, and is frequently central to an organisation’s strategy (Huxham & Vangen, 2005: 7). It is becoming a popular approach to create a competitive advantage (under the guise of innovation) to solve complex problems (Trist, 1983) by sharing resources and risks (Littler et al., 1995; Schilling & Hill, 1998) through virtual teams (Gibson & Cohen, 2003). These motives to collaborate however change the setting and process of collaborating for engineers.

In engineering design, concurrent working practices and cross-functional project teams are prevalent in organisations. These are part of organisational structures that represent the specialisation of knowledge; they influence how individuals design by balancing how labour is divided into distinct tasks and how it is coordinated to achieve those tasks (Mintzberg, 1989: 100-1). Engineers no longer carry out product development in isolation to each other (Frankenberger et al., 1998: x; Pahl et al., 2007: 138); they are more likely to share information, knowledge and understanding across technical disciplines and organisational structures (Günther et al., 1996) to collaborate successfully.

In the process of collaborating engineers experience ambiguity and change in design and group development processes. Design development in a project, i.e. completing a number of phases (planning, conceptual, embodiment, detailing, manufacture), may no longer be represented by one common technical, or even compatible, approach. Simultaneously group development, i.e. individuals learning to perform effectively as a group, is more exposed to a greater variety in individual participation, project goals and prior experience of working together. Figure 1 illustrates the dynamic co-existence of design and group development process using two helixes that intertwine during a project.

Figure 1 – Representation of design and group development processes in a project
This lack of existing common design or group development processes creates an inherent ambiguity of what knowledge is shared between participants. In design there is value in economy i.e. keeping things simple and leaving as much as possible ambiguous (Brown, J.S. & Duguid, 1996: 133); yet considering ambiguity and sharing understanding this is potentially both positive e.g. removing heavily detailed instructions, and negative e.g. failing to acknowledge task inter-dependencies. Cramton (2001) highlights that sustaining mutual knowledge in collaborations is problematic, and other researchers outline that many collaborations fail to produce innovative solutions or be mutually successful (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005) or meet participants’ expectations (Killing, 1982; Ring & Van de Ven, 1989). Further tension is created as one of the implicit consequences in collaborating is that outcomes are shared (Gray, 1998: 472; Jeffrey, 2003), yet participants in collaborations have reduced control of design process (Littler et al., 1995) and may have conflicting goals or unequal power (Hardy & Phillips, 1998). Participants are encouraged to follow their own interests yet simultaneously are required to limit this approach to make an alliance work (Das & Teng, 1998) – they need to learn how to balance competition and cooperation (Teece, 1992). Some researchers even oppose collaborating unless you have to (Huxham & Vangen, 2005: 37) as successful collaboration is not achieved without significant time and effort from those involved (Gray, 1998: 479; Huxham & Vangen, 2004).

These changes in design setting and process, in conjunction with a prevalence of collaborations and yet numerous challenges and limited success in collaborating, points to a need for research to uncover and understand existing complexities in design projects and provide further insight to why researchers notice disjunction or discrepancy between theory and practice (Bucciarelli, 2003; Hales, 1991; Stempfle & Badke-Schaub, 2002).

1.3 Research Question and objectives

In this thesis there is one research question (RQ) and six objectives:

Research Question: How do pair-wise relations influence group relations and outcomes in collaborating engineering design teams?

Objective 1: To review relevant literature and develop, or adopt, a framework of concepts to investigate engineering design teams, group behaviour and collaboration.

Objective 2: To design and conduct a longitudinal cross-case comparison of engineering design projects.
Objective 3: To describe influences on the process of collaborating in design project teams.

Objective 4: To analyse how pair-wise relations influence collaborating in design project teams.

Objective 5: To develop existing or new (if applicable) concepts and theories based on empirical findings about how pair-wise relations influence collaborating in engineering design.

Objective 6: To develop implications for practice of collaborating in engineering design based on empirical findings.

In the research question, the focus is on three conceptual constructs – pair-wise relations, group relations, and outcomes. This stems from literature on Inter-Organizational Relations (IOR), Group Development and Group Processes. First, the relevance of all three constructs is evident in social network approaches in IOR literature [e.g. Burt (1992), Granovetter (1985), social capital perspectives]. These emphasise understanding individuals, pairs and networks through actors’ relations, i.e. the interaction between individuals and their understanding gained. This recognises that how relationships are organised has an impact on both individual and group (Kenis & Oerlemans, 2008: 290) and hence knowledge about all three conceptual constructs is key to understand how engineers collaborate across organisational and technical boundaries.

Secondly, literature on Group Development (e.g. Bales, 1966b; Bion, 1961; Tuckman, 1965) considers inter-personal relations as being fundamental for individuals to develop and work together effectively as a group, yet few have considered how pair-wise relations influence the development of a group. In literature on Group Processes, there is a consensus that pairs are not groups (Moreland, 2010; Williams, 2010) with both constructs having their own independent research domains. However, excluding the study of pairs in groups is short sighted (Williams, 2010) and illustrates a gap in literature about phenomena that can involve both pairs and groups e.g. collaborating in design teams.

Finally, as collaborating is a relational construct the basic form for collaborating is inherently limited to a pair of individuals (see also section 1.4, and Definitions p. xii). A pair can be used to understand inter-organisational relationships (Knight, 2000) as they often act as representatives of organisations (Ring & Van de Ven, 1994) or internal relations representing departments. Thus, the Research Question is formed around understanding the influence of a pair of individuals providing a contribution to three areas of literature beyond engineering design.
Current empirical research in engineering design on human behaviour has focused on one or two social processes in groups [e.g. communication Eckert et al (2005), Maier et al (2008), Minneman (1992)], in projects crossing only departmental boundaries [e.g. Kleinsmann & Valkenburg (2008), Larsson (2007)], and with limited recognition of how the novelty of design tasks may influence designing [e.g. Frankenburger & Badke-Schaub (1998b: 156), Ostergaard & Summers (2009)]. These gaps in empirical research fail to recognise the influence of context (design setting or design type) on collaborating or the influence of pairs on a project group or individuals. This calls for a holistic approach to investigate how pairs influence collaborating across organisational and discipline boundaries in different types of design projects.

To pursue the Research Question and Objectives, topics concerning outcomes, pair-wise relations and group relations are investigated in detail to locate this research in the general topic of collaborating in engineering design. Advantages and limitations of current theory and concepts are explored and a suitable framework is selected (Objective 1) [chapters 2&3]. To achieve Objective 2 assumptions and validity of selected approaches and methods are assessed and presented in chapter 4. Findings are presented to address Objectives 3&4 [chapters 5&6] with implications for research and practice described to address Objectives 5&6 [chapters 7&8]. Next (1.4) the process of collaborating is described to outline how the author views collaborating in engineering design.

**1.4 How collaborating differs from working as a team**

Collaborating is a process and in this section the researcher describes how collaborating is conceptualised and differentiated from working in a team. As product design activities become increasingly integrated working as a team becomes increasingly important (Cross & Clayburn Cross, 1995) where a team is a small group of interdependent individuals organising themselves to achieve a joint purpose sharing responsibility for outcomes (Katzenbach & Santamaria, 1999; Sundstrom et al., 1990). Individuals can have unique and specific roles, e.g. performing stress analysis for a design, but in being part of a team members focus beyond individual tasks such as considering customers needs (Amason et al., 1995).

Collaborating is often assumed when working in a team or group, yet in this research collaborating is defined as more than individuals carrying out their role or considering needs of other participants in a coordinated team. When collaborating, project participants interact and transfer individual knowledge into shared knowledge. This promotes individuals and a group to develop common ground [mutual knowledge, beliefs, goals, attitudes, etc (Clark, 1992: 257)] or shared understanding [anticipating each others actions,
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needs, values and adapting behaviour (Klimoski & Mohammed, 1994)]. In collaborating, participants’ different perspectives on a problem are then constructively explored to develop ideas that go beyond individual expectations of what is feasible (Gray, 1998: 469). Consequently participants can generate and assess novel solutions together to achieve its goals; they have a collaborative advantage (Huxham & Vangen, 2000) that individual efforts alone could not achieve. This emphasises joint ownership of, and responsibility for, solutions. Collaborating is hence a process where participants work together towards a common end rather than individual ones [cooperating] (Jeffrey, 2003).

Collaborating is thus an inter-personal process where participants often go beyond simply cooperating or coordinating (Gray, 1998: 475); they search for novel solutions together and recognise the interests of those involved (Hardy et al., 2005). A similar term to collaborating is co-design; this though focuses solely on the process of creating shared knowledge (about design content and processes) across disciplines (Kleinsmann & Valkenburg, 2008). In collaborating participants recognise different expectations, establish aligned expectations and maintain them.

Collaborating in a project team is recognised when there are high levels of interaction and a high dependency between individuals (Gray, 1998: 472). This dependency may occur in either or both affective and task aspects of group development. Task aspects relate to accomplishing group tasks and goals, affective aspects concern building and maintaining relations with participants to develop an effective working group. Collaborating is not exclusive to teams working across organisations, though the term ‘collaboration’ is used frequently in literature to emphasise the involvement of multiple organisations (e.g. Emden et al., 2006; Hardy et al., 2003; Littler et al., 1995). In this research ‘collaborating’ includes working within and across organisational boundaries.

1.5 Themes and thesis structure

This thesis is split into nine chapters. Relevant literature is reviewed and critiqued in chapters 2 and 3 to address Objective 1. In chapter 2 the author reviews current types of design process, how engineering design is considered a group activity, and research on design collaboration tools specialising in knowledge management and group work facilitation. This chapter covers:

- Literature on engineering design (chapter 2).
  a. Established models and theories to understand processes in engineering design.
  b. How knowledge in engineering design informs understanding collaborating.
The focus of this research is on the interaction of design and group development processes; so it is necessary to consider research from disciplines that study social process (e.g. communicating, negotiating, building trust) in project teams. To achieve this research from social sciences and management academic disciplines is reviewed and critiqued in chapter 3. In this chapter the author presents influences of interacting and working with other individuals, how information may be shared, and differentiates between collaborating and group work. In summary:

- Literature on Groups (chapter 3).
  a. Established models and theories to understand group dynamics, behaviour, shared cognition, collaborations.
  b. How knowledge about groups informs understanding collaborating.
  c. How understanding group behaviour and collaborating relates to engineering design.

This literature critique provides a foundation to describe in chapter 4 how Objective 2 is addressed and how potential hurdles are overcome. This chapter is split into five sections that cover:

- Methodology (chapter 4).
  a. Selection of research approach to establish how the research phenomenon is viewed through coherent epistemology, ontology, methodology and methods.
  b. How cases were selected contrasting design type and design setting.
  c. How selected methods are used to develop understanding of collaborating.
  d. How reliability, validity and ethics are addressed in this research.

Findings from analysis and interpretation are presented in the next three chapters (5, 6, 7). The first two address Objectives 3&4 with individual case descriptions presented for four industrial case studies (chapter 5). Moving beyond individual cases, findings from cross-case comparisons are presented in chapter 6 to understand patterns and links between cases to provide empirical data to respond to the Research Question. These chapters cover:

- Four case studies of collaborating in engineering design (chapter 5).
  a. Case histories of four design projects involving a total of 10 organisations.
  b. Who was involved, how the project started and what happened.
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- Cross case findings – a comparison of design case studies (chapter 6).
  a. A theoretical framework specific to pair-wise relations, group relations, outcomes in collaborating in engineering design teams.
  b. How pair-wise relations, group relations, and outcomes are influenced by design type and setting.

The final stage of analysis develops cross-case findings by relating them to existing theory and literature in chapter 7. This addresses Objective 5 and provides a detailed answer to the Research Question. Reflections on how research has been achieved including limitations and future research conclude chapter 7. Implications for practice are outlined in chapter 8 specifically aimed at practitioners in engineering design projects. Implications are presented through a series of questions to improve the success of projects by providing a structure for participants to make sense of their circumstances (addressing Objective 6).

In summary:

- Discussion: influences of pair-wise relations (chapter 7).
  a. How research findings contribute to current literature.
  b. How pair-wise relations influence group relations and outcomes in collaborating engineering design teams.
  c. Reflections on completing this research.

- Implications for practice – meeting expectations (chapter 8).
  a. How research findings are relevant for practitioners to improve the success of collaborating.
  b. A series of questions for individuals and group to make sense of collaborating.

To conclude, findings and contributions of this research are summarised in chapter 9.

1.6 Summary

The setting and process of collaborating in engineering design is evolving. Engineers increasingly work simultaneously on multiple projects involving different departments, organisations and technical disciplines. Furthermore, the process of collaborating has become more dynamic involving change in both design and group development processes. Recognising these changes has prompted the author’s aim to develop a holistic understanding of how collaborating in engineering design is achieved.

In this thesis the author sets out claims for how pair-wise relations influence collaborating in engineering design focusing on group relations and outcomes. Findings
emphasise that the study of pairs, in addition to individuals and a group, are critical in understanding how human behaviour influences collaborating in engineering design. Implications of findings are set out for practitioners in guidance topics to improve the success of collaborating in engineering design.

In the next two chapters, current literature is reviewed to understand what is known about collaborating in engineering design. This starts in chapter 2 with literature from the domain of engineering design.
2 Literature on engineering design

Engineering design research is reviewed and categorised into three themes: Design processes (2.1), Group processes (2.2), and Design collaboration tools (2.3). These topics outline what current literature tells us about collaborating and how interactions of design and group development processes are portrayed. Gaps for further research are identified in each section. The chapter then concludes with a critique and summary (2.3).

2.1 Design processes

Design processes provide essential details for individuals to learn about and practice engineering design. Two significant approaches – sequential and concurrent design processes, are contrasted to illustrate influences of design process choice on both design and group development processes. This is supplemented with a critique on the type of design problems and suitable design approaches.

2.1.1 Sequential and concurrent design processes

The sequential approach was developed in parallel to using traditional functional structures in organisations and engineering design. This is supported by a number of theorists (Checkland, 1981; Pahl & Beitz, 1984; Suh, 1990; Ullman, 2003; Ulrich & Eppinger, 2000) with each theorist taking design through a linear series of phases shown on the right hand side of Figure 2.

Task clarification is a sequential search, selection and development of new ideas from market responses. Concept design is the identification of the essential problem through abstraction. This establishes functional structures and the complexity between each component’s input and output requirements. This phase places particular importance on creativity, relating a concept to a body of knowledge, where groups are often used for idea generation or problem solving (e.g. brainstorming). Embodiment involves the specification of various layouts for construction to find a definitive one. The final phase of detailing is developing a production specification that includes different layouts, approaches and surface properties.

New Product Development (NPD) processes encompasses these phases starting with input from marketing to task clarification, followed by concept design and detailing, before product prototyping, process design and process manufacture.
Concurrent engineering is an adaptation of sequential approaches where design phases are completed in parallel instead of sequentially. It is an approach that uses the synergy of integrated product and process design and considers a number of product life cycle elements including quality, cost, and user requirements (Volpertesta et al., 2004). This promotes decision-making involving multiple functions, high use of technology and process controls (Hull et al., 1996). A cited advantage over sequential methods is the aim to reduce lead times and hence time to market (see Figure 3). Research findings suggest an ambiguous picture in the use of concurrent process in product development. Increasing planning in early design phases has had mixed results on development time and effort: little impact (Datar et al., 1997); decreased time and effort (Cooper & Kleinschmidt, 1994; Hull et al., 1996) or increased time and effort (Eisenhardt & Tabrizi, 1995)].

Contrasting sequential and concurrent approaches illustrates influences on design and group development processes. Delimiting steps in sequential approaches aims to allow analysis and synthesis of problems in fixed steps. This allows in depth knowledge to be developed, retained and used focusing on one aspect of design process at a time. In delimiting steps individuals need to remain aware of the entire design process and relevant interdependencies to avoid problems being passed from one phase to another. Reducing lead times in the concurrent approach imposes increased interaction between individuals
and departments blurring delimitation of phases and increasing planning and coordination in early phases. This also places increased effort on organising tasks and individuals to improve efficiency in design and communication (Tomiyama, 1998) affecting design and group dynamic processes. Concurrent processes promote information sharing (Prasad, 1995), highlight interdependencies and awareness in designing, which can provide advantages in reducing unnecessary changes and redesigns (Tomiyama, 1998) when teams are co-located (Eckert et al., 2005).

Figure 3 – Sequential and Concurrent engineering approaches [adapted from Yazdani and Holmes (1999)]

2.1.2 Type of problem

Each design process has benefits yet these are influenced by the type of product or process being designed (Valle & Vázquez-Bustelo, 2009). Characteristics of a design problem (e.g. design type) influence design objectives, process and solution (Ostergaard & Summers, 2009) where the novelty of a task influences the availability of information for clarifying concepts or requirements (Frankenberger & Badke-Schaub, 1998b: 156). Two classifications of type are used in designing new products or processes: design type and innovation type. Design type establishes links between new and old designs with Pahl & Beitz (1984) describing three types:

- Original - generation of an original solution.
- Adaptive - solution principle remains the same changing how the task is achieved.
- Variant - solution and function principle remain the same changing only size and/or arrangement of systems.
Each type can introduce different requirements between inputs and outputs of a design’s functions. A simple change between types at conceptual design stage (e.g. from variant to original) can have significantly implications for manufacturing processes (e.g. requiring a new process). Interaction of individuals allows these implications of design type choice to be declared encouraging discussion and joint decision making to assist individuals to adapt and change together.

Similar to design type, innovation type determines links between new and established designs considering the level of uncertainty, complexity and knowledge creation (Dewar & Dutton, 1986; Valle & Vázquez-Bustelo, 2009) involved in development. High levels are typically breakthrough or radical innovations with low levels being associated with derivative or incremental innovations. There are clearly similarities between design and innovation types with radical innovations approximated to original design type, and incremental to adaptive and variant design types.

The purpose of describing these two classifications is to highlight mixed findings in suitability of design processes. It is suggested concurrent engineering processes may be less suitable for radical innovations (Handfield, 1994; Takeuchi and Nonaka, 1986) while others (Schilling & Hill, 1998) state that concurrent processes are more suitable for breakthrough rather than derivative products. The level of management involvement also varies due to design type with less involvement in latter stages in original projects speeding up product development (Kessler & Chakrabarti, 1999); however senior management are more involved in innovative projects (Clift & Vandenbosch, 1999) as there is more at stake. This sets up a dilemma for managers to be involved in a project yet without limiting the speed of product development. Understanding how design and group development processes are influenced by the type of design problem may help explain these findings.

2.1.3 Review

In summary design and group dynamic processes are influenced by:

1. Design approach.
2. Type of design (e.g. original, adaptive or variant) required.

These choices influence design and group processes by influencing how project teams are organised and achieved in practice. The importance of team selection and team building are acknowledged [e.g. (Ullman, 2003)] but influences on and of group processes are not recognised in design processes. Schön (1983) and other researchers (e.g. Bucciarelli) see traditional design approaches (e.g. sequential and concurrent) as
positivistic idealisations of technology and science that struggle in describing design practice. Empirical studies cite design methods as useful frameworks for participation and provide powerful heuristics and strategies for problem solving (Minneman & Harrison, 1998; Roozenburg & Dorst, 1998). They are not a rigid prescription (Minneman & Harrison, 1998) and fail in ideal conditions (Günther & Ehrlenspiel, 1999) with researchers expressing concern in the discrepancy between theory and practice (Bucciarelli, 2003; Hales, 1991; Stempfle & Badke-Schaub, 2002). Understanding interactions of design and group processes aims to enlighten discrepancies between theory and practice and address calls to provide descriptive input for developing and validating design methods (Blessing et al., 1998).

2.2 Group processes

Changes in organisational structures have impacted upon engineering design approaches and methods affecting how individuals work. Designing in a group has become necessary and common practice (Frankenberger et al., 1998: x; Pahl et al., 2007: 138). Designers still work on their own for 85% of the time, but 88% of critical processes (e.g. goal / solution analysis, conflict management) are across cultural boundaries, or are to resolve disagreements (Daft & Lengel, 1984) that require interaction with other people (Badke-Schaub & Frankenberger, 1999a; Frankenberger & Badke-Schaub, 1998a, 1998b). Engineering design typically crosses discipline boundaries and collaborating is epitomised by inter disciplinary design (Brereton et al., 1996). This draws on benefits from synthesising different perspectives, sharing understanding, recognising design as a social process involving inter-personal communication and informal networks.

2.2.1 Acknowledging different perspectives

When interacting in a design group there are many individual perspectives representing each functional perspective (e.g. manufacture, mechanical design etc) that are used to solve problems and create successful designs. Diversity of perspectives is desirable at the beginning of a product development project as it often leads to innovations (Moenaert & Souder, 1990). Interaction of different perspectives in engineering design is described as uncertain and ambiguous as a group tries to achieve a mutually suitable solution (Bucciarelli, 1994). Suitability depends upon the object world (Bucciarelli, 1994, 2002) used to evaluate the problem where object world relates to an individual perspective. Dougherty (1992) extends the notion of a perspective beyond an individual to a department or group in an organisation with thought worlds where each thought world has a distinct
system of meaning that colours interpretation of information, filters issues and produces qualitatively different understandings.

Bucciarelli and Dougherty note that object (individual) and thought (groups) worlds impede individuals from synthesising expertise, but when object worlds can synthesise or even create a thought world, groups open paths to access participants’ knowledge. Researchers show that creating an intermediate interface by using an artefact (Minneman, 1992; Perry & Sanderson, 1998), or by using a customer’s perspective (Dougherty, 1992) can also convey a object or thought world in designing a product. Even if there is similarity or synthesis in perspectives there is still an inherent ambiguity in communicating an idea (Eckert et al., 2003). For effective communication this demands a coherent understanding of the required and received information. In a group this can be developed through sharing understanding and knowledge.

2.2.2 Sharing understanding and knowledge

Group design work has been described as negotiation to be able to understand (Minneman & Harrison, 1998). Shared understanding is where individuals show an awareness about how tasks, behaviour and events are interpreted including being able to anticipate each others’ actions, needs, and adapting behaviour (Klimoski & Mohammed, 1994) to develop common or complementary expectations (Cannon-Bowers & Salas, 2001). This is a similarity in how key issues in design content are conceptualised and comes from industrial and organisational psychologists use of a team mental models concept (described further in section 3.3). In engineering design Kleinsmann et al (Kleinsmann, 2006; Kleinsmann et al., 2010; Kleinsmann & Valkenburg, 2008) extend this definition to include how transactive memory is achieved. Transactive memory is a set of individual memory systems that combine knowledge possessed by individuals with a shared awareness of who knows what (Wegner, 1986). Transactive memory is recognised as important (Brown, P.E.S. et al., 1995) and a leading source of information (Marsh, 1997) in designing. Baird et al (2000) in an ethnographic study of Rolls Royce found that tacit social skills aided sharing knowledge with engineers exhibiting transactive memory.

Empirical studies looking at shared understanding focus on single cases of design in one organisation (Kleinsmann et al., 2005, 2010; Kleinsmann & Valkenburg, 2003, 2008), in undergraduate teams at university (Bierhals et al., 2007b; Song et al., 2003; Valkenburg & Dorst, 1998) or in one off design workshops comprising of members from the same organisation (Valkenburg, 2000). Only research by Kleinsmann (2006) provides a
comparative analysis of industry based cases. Research specifically looking at mental models, e.g. Bierhals et al (2007a; 2007b), is covered in section 3.3.

Research emphasises that shared understanding is key to group interaction and is shaped through social processes i.e. conversation, personal dynamics (Minneman & Harrison, 1998). Stempfle and Badke-Schaub (2002) propose further that developing shared understanding may be a reason why heterogeneous teams consistently outperform homogenous teams in complex problem-solving tasks [quoting Thomas (1999) as an example]. This adds further evidence to Belbin’s Apollo syndrome (1981) [described in section 3.1.2]. A heterogeneous team is described as one that has different levels of understanding that compels participants to question each other and encourages discussion and analysis before evaluation.

If participants fail to have shared understanding then the quality of a product is reduced as not all problems are ultimately solved (Dong, 2005; Valkenburg, 2000) and there are numerous iterative loops in building knowledge (Kleinsmann & Valkenburg, 2008; Valkenburg & Dorst, 1998) that can cause delay, frustration and create further misunderstanding. In particular organisational and knowledge boundaries represent areas where there are barriers and enablers to creating shared understanding that lead to problems in cooperation, communication and project management (Kleinsmann, 2006; Kleinsmann & Valkenburg, 2008).

To overcome barriers in creating shared understanding, participants are encouraged to effect change on multiple levels (Kleinsmann, 2006; Kleinsmann & Valkenburg, 2008) e.g. individual, project, department and organisation. Shared understanding is also aided by creating a common ground involving cooperation and coordination in a group (Clark, 1992: 257). Badke-Schaub & Frankenberger (1999a) emphasise the importance of cooperation and communication during the entire design process to permit individual perspectives on information to be heard and become less ambiguous over time. Having a common ground prior to interaction is an advantage but a luxury that does not always accompany collaborating across disciplines and organisations; hence this may be why carrying out regular progress reviews are seen as an important factor concerning the process of collaborating (Littler et al., 1995).

2.2.3 Social process of design

Ethnographic studies (Bucciarelli, 1988, 1994) present design as a social process of negotiation and compromise where the final product represents the consensus. The social
process in design is an intersection of object worlds, where no one object world dictates the form of the artefact (Bucciarelli, 1994). Teamwork is a social process (Cross & Clayburn Cross, 1995) and design can no longer be sufficiently conceptualised in terms of individual intelligence (Baird et al., 2000). Other researchers (Harrison & Minneman, 1991; Minneman, 1992) concur showing designs are developed through social processes of argumentation and negotiation.

Social interactions, roles and relationships that occur in small teams during design activities (e.g. a design workshop) are observed to be intricate and interchangeable throughout a task (Cross & Clayburn Cross, 1995). Other empirical studies of engineering design activities through observation and analysis reveal that:

- Thinking aloud interferes with designing (Günther et al., 1996; Lloyd et al., 1996)
- Designing in teams is concurrent in nature i.e. each individual is an independent cognitive and social agent whose actions are intertwined through to develop a group product (Radcliffe, 1996).
- Collaboration is successful from a balance of roles in the group and open negotiation (Brereton et al., 1996).
- Participants were more satisfied when standard project documentation was available to all (e.g. design standards), correspondence and meetings were planned, and participants had prior experience of working together (or opportunities to develop a working relationship) (Thomson et al., 2007).
- Both technical process (problem solving phases, product characteristics etc) and social process (group and decision making processes etc) are recognised and recorded (Günther et al., 1996; Minneman & Harrison, 1998).
- Individual and group prerequisites, external conditions, design task are all involved in creating a design solution (Günther et al., 1996) and influence design productivity (time, cost and quality) in practice (Frankenberger & Badke-Schaub, 1998a).

The latter point is emphasised by Frankenburger & Badke-Schaub (1998a, 1998b) who develop a model of group design processes (see Figure 4) for systematic design. Data were collected from individuals (using diaries, interviews, questionnaires, simulation) and group interaction (observation) in two case studies within one organisation.
Figure 4 – Factors influencing design process and outcomes (Frankenberger & Badke-Schaub, 1998b)

Their model is based on an input-process-outcomes (I-P-O) model to study team effectiveness [see Hackman & Morris (1975)]. Six linked topics (individual prerequisites, group prerequisites, external conditions, task, design process and result) represent relations between influencing factors and critical processes of problem solving in engineering design (e.g. goal analysis, conflict management). Their study reveals that information availability for communication and analysis primarily impacts time, cost and quality of design decision making (Frankenberger & Badke-Schaub, 1998a). Relevant and up to date information is key for design and development (Boston et al., 1998), and decision making is influenced by individual experience, informal power relationships, group organisation and external time pressures (Frankenberger & Badke-Schaub, 1998b).

Researchers (Baird, Bucciarelli, Clayburn Cross, Cross, Harrison, Minneman) concentrate on design as being a collective social process but Eckert et al (2005) remind us of the importance of the role of a designer working independently, communicating with her/himself to learn and develop new ideas. Individual knowledge is introduced to groups through inter-personal communication.

2.2.4 Inter-personal communication

Communication between individuals is recognised as being key to allow a design to develop (Badke-Schaub & Frankenberger, 1999b), as a key factor for successful collaboration across organisational boundaries (Kleinsmann & Valkenburg, 2008; Littler et al., 1995; Maier et al., 2009), and as a mechanism for sharing information and achieving coordination in software development (Kraut & Streeter, 1995). With increases in inter-disciplinary and international projects (ASME, 2008, 2009; Günther et al., 1996; Larsson,
2007; Sonnenwald, 1996) inter-personal communication becomes more important to designing.

Understanding communication though is dependent upon both a speaker’s intention and a recipient’s knowledge (Eckert & Stacey, 2000). Thus a person’s ability and approach to communication may act as a barrier to sharing knowledge in engineering design. Communicating data, information and knowledge presents a high potential for ambiguity in design projects which can be useful in negotiations to discover new ideas by reconciling differences (Minneman & Harrison, 1998). This ambiguity arises from different knowledge bases and different departments or organisations trying to combine expertise. Due to this diversity individuals will often have to create, or at least adapt and maintain, shared understanding to develop and represent a group. This creates inter-personal dependency within a group. If dependencies are not seen as tangible it can easily cause friction through misunderstanding or polarised needs. The use of similarity can explain different perspectives but Eckert et al (2003) caution its use as an effective mode of communication without managing inherent ambiguities between individuals.

There are two notable theoretical communication models in engineering design. Minneman’s framework (1992) consists of facets and trajectories. Facets focus on communication: artefacts, processes or connections. Trajectories emphasise time, considering a design in the present, how it arrived from the past and what it may be in the future. Eckert et al (2005) provide a systemic view of communication involving three theoretical foci: information centred, situation centred and interaction centred. These combine to provide a systemic view of communication as a process.

Furthermore Stempfle & Badke-Schaub (2002) present a two process theory of thinking in design teams from studying communication in three laboratory teams. In the first process, individuals immediately evaluate solution ideas and in the second they analyse solution ideas before evaluation. Changing from the first process to the second is characterised by:

1. Lack of common understanding.
2. Failure of first process.
4. Adopting a methodology.
5. Disagreement and challenging of ideas.
The second thinking process leads to less errors in solving complex problems but takes more time and effort (Stempfe & Badke-Schaub, 2002). This observation and the five characteristics illustrate realities and needs from collaborating in engineering design. They also note that structuring group process in design teams is important as designers spend two thirds of their interaction on task content with the remainder on group process. This recognises clearly the importance of understanding group and design development processes.

Lastly, one factor that significantly influences communication is collaboration. Maier et al (2008) empirically highlight collaboration as being central to influencing (directly and indirectly) 27 factors that affect communication in engineering design. Furthermore Sonnenwald’s (1996) classification of 13 communication roles in four inter-organisational design projects shows there are a number of inter-personal roles that facilitate information and knowledge transfer across organisational boundaries. These points suggests that collaborating and communicating are closely linked social processes that involve knowledge exchange. Research into both processes is hence imperative to understand how engineers design together.

**2.2.5 Informal networks**

Social links are important in retaining and promoting knowledge sharing and also functional expertise. These links create informal networks that can foster creative aims, transfer information, provide contextual knowledge about individuals (e.g. logic they use), enable personal trust to be determined (Baird et al., 2000; Larsson, 2007) and provide support beyond project, department or organisation boundaries.

A number of empirical studies examine an individual’s perspective on knowledge. Larsson (2007) in particular emphasises the role of inter-personal relationships to enable individuals to discover who knows what. Thus through inter-personal relationships participants learn about individual capabilities and to what extent individuals can be trusted to fulfil their plans. Studying 65 projects in one large software development organisation, Kraut & Streeter (1995) found that networks of inter-personal relationships were more valuable to individuals as the degree of uncertainty in completing design tasks increased. Through inter-personal networks, participants were likely to be more informed and coordinated which Marsh (1997) and Brookes et al (2001) corroborate in recording the importance of personal experience and informal networks of contacts in sharing information.
In Lave and Wenger’s (1991) Communities of Practice (CoP) model it is proposed that learning is a social process in groups describing individuals’ ability to handle unstructured problems and share knowledge beyond traditional structural boundaries (Wenger, 1998). Brown and Duguid (2000: 143) note CoP allows highly productive and creative work to develop collaboratively from a ‘network in practice’ at Xerox’s Paulo Alto Research Centre. McMahon et al (2004) note these communities are important links for individuals completing similar tasks to share valuable information and tacit knowledge. Court et al (1996) support this by emphasising the importance of colleagues and a designer’s own memory as sources of design information, however this informal knowledge sharing is typically not accounted for (Baird et al., 2000).

2.2.6 Review

In this section research on group processes relating to collaborating in engineering design has been reviewed. This focuses on various social processes and has outlined that sharing understanding is an inherent requirement to current product design. Social processes are influenced by both design processes and group processes – building a shared understanding, synchronising individuals’ activity and maintaining inter-personal relationships in a group are often completed at the same time (Harrison, 1993; Minneman, 1992). Yet there is limited knowledge about how participants in practice recognise, establish and maintain shared understanding in design projects.

In engineering design both design and group development processes are recognised e.g. Frankenberger & Badke-Schaub (1998a, 1998b) introduce a model illustrating individual and group prerequisites and external conditions that affect design outcomes. Yet there is a prevalence of studies concentrating on one or two social processes [e.g. communication – Eckert et al (2005), Maier et al (2008), Minneman (1992)], and little on how the process of collaborating or how the type of project (e.g. original designs) influences designers’ behaviour. Furthermore empirical case studies on group processes centre on groups within one organisation (Badke-Schaub & Frankenberger, 1999a; Baird et al., 2000; Bucciarelli, 1988, 1994; Dougherty, 1992; Frankenberger & Badke-Schaub, 1998a, 1998b; Kleinmann, 2006; Kleinmann et al., 2005, 2010; Kleinmann & Valkenburg, 2003, 2008; Kraut & Streeter, 1995; Larsson, 2007; Maier et al., 2008; Maier et al., 2009; Minneman & Harrison, 1998; Perry & Sanderson, 1998; Stempfle & Badke-Schaub, 2002; Thomson et al., 2007; Törlind et al., 2005). A small number have looked at designers interacting between organisations: Littler et al (1995) derive factors from engineers general experience in collaborative new product development; Sonnenwald (1996) investigates specific
completed design projects from industry; whilst others focus on single and relatively short experimental design activities (Cross et al., 1996; Harrison & Minneman, 1991; Minneman, 1992). Thus gaps remains in current literature regarding how the process of collaborating in engineering design is understood or how participants adapt during a design project.

2.3 Design collaboration tools

Research in engineering design under collaboration typically focuses on technological developments and tools to aid engineers perform their tasks. Two themes are outlined in a review of design collaboration tools: codifying and managing knowledge, and facilitating group work.

2.3.1 Codifying and managing knowledge

Knowledge management has a range of topics focusing on standard products that codify and classify knowledge for retrieval. This codification strategy (McMahon et al., 2004) incorporates Knowledge Based Engineering (KBE), data mining, classifications and ontologies, and information systems focusing on design processes.

KBE originated in Computer-Aided Design (CAD) to integrate the computational aspects of engineering design including Computer Aided engineering (CAE), Computer Aided Manufacturing (CAM), and Product Life Management (PLM). This aims to automate all or part of design processes by capturing and modelling product and process information. A complete design process can be represented and interdependencies identified through software interfaces reflecting knowledge requirements from differing design aspects.

Data mining, also termed knowledge discovery, extracts high-level knowledge from a low-level data (Simoff & Maher, 2000) automatically searching through large amounts of data for patterns defined by rules and retrieving explicit information for individuals. This method has been used with text analysis to evaluate group participation in virtual environments (Simoff & Maher, 2000) assessing individual contribution with synchronous communication and the extent of collaborating through asynchronous communication. Collaborating is described by interaction and development between individuals through asynchronous communication content.

Classifications develop semantic, statistic, and key word based tools to capture and store knowledge in engineering design. This has included annotation and mark-up of models (e.g. Ding et al., 2009a; Liu et al., 2008a; Liu et al., 2008b) with Ding et al (2009b)
focusing on component based records to organise aspects of design development processes. Huet et al (2007) provide an example where the design content of review meetings are evaluated to produce a knowledge orientated strategy to record design evolution. Campbell et al (2007) present a data capture method to record the relative importance of documents for individuals and groups in different settings highlighting the need to consider context whilst others (e.g. Conway et al., 2009; Giess et al., 2008a) outline the importance to capture both synchronous and asynchronous data.

Standardisation of systems is required to establish a consistent input into tools but each user classifies knowledge differently. One approach that seeks to encompass multiple perspectives in categorising data is facet classification. However there are still difficulties addressing how bodies of information change over time, that facet analysis may not lead to repeatable results due to participants’ preconceptions (Giess et al., 2008b), there is limited methodological guidance and confusion between facet analysis and classification (Wild et al., 2009).

It is hence not simple for different users to retrieve knowledge that is relevant to them. To overcome this, ontologies define domains (based on relevant concepts) to interlink each piece of information and can use software platforms, e.g. Protégé (2010c), to provide virtual environments to communicate and exchange information in groups. Information systems represent infrastructure for facilities (e.g. a library or common virtual work space) for engineers to store, retrieve and exchange information. These can improve the visibility of data (Hie Tikko & Rajan Iemi, 2000) but keeping product and project data up to date can be challenging.

2.3.2 Facilitating group work

Overlapping with knowledge management in engineering design are technological tools that facilitate group work supporting individuals interaction with each other. These software based tools emphasise a personalisation strategy (McMahon et al., 2004) with unique product solutions known as Groupware, Collaborative Computing, Computer Supported Cooperation Work (CSCW) where ‘Cooperation’ is sometimes replaced with ‘Collaborative’. Each has a similar definition to Groupware defined by Ellis et al (1991: 40) as “computer based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment”.

CSCW tools are based on information sharing in projects to support communication and learning in design groups. Empirical research by Chiu (2002) shows CSCW tools enhanced design communication and contributed to effective decision making. CSCW tools can also
support project planning (Flanagan et al., 2003) by following parameter inter-dependencies to recognise trade-offs and give designers an improved overall representation of a project.

Internet and hardware developments have encouraged synchronised virtual offices and allowed individual companies [e.g. BIW technologies (2010a)] to provide infrastructure and systems to support group work. There is a greater reliance on communication working in distributed design teams (Ion et al., 2004; Sclater et al., 2001) with different technical and organisational systems yet less frequent ‘natural’ communication [i.e. informal communication, brainstorming etc (Törlind et al., 2005)]. This highlights a major challenge to creating technologies that support information exchange (Perry & Sanderson, 1998; Törlind et al., 2005). A further challenge is promoting creation of social connections for individuals to develop an awareness of processes (organisational and design) and participants behind the information (Törlind et al., 2005).

Early research by Dong & Vande Moere (2005) develops software tools to assess teamwork dynamics in very large design teams by quantifying design team conversations through rules. At present findings are limited – the approach is feasible albeit modelling a small team with further rule definition is required; yet this illustrates the relevance of current research to develop understanding about how a team performs by considering participants’ behaviour and its’ influence on a project.

Academics in engineering design are interested in encouraging learning in groups but have to contend with different abilities and multiple needs from those using software. At the University of Strathclyde research on shared working spaces in distributed teams over the last 15 years [see Ion et al (2004) amongst others] has focused on understanding technical requirements for codifying and managing knowledge (see previous section) and implications for pedagogy (e.g. Breslin et al., 2007; Grierson et al., 2008; Ion et al., 2004; McGill et al., 2005; Simoff & Maher, 2000). Online approaches teach computing design (Maher et al., 1997; Simoff & Maher, 2000) with Stanford and Strathclyde engineering departments pioneering LauLima (2010b). LauLima is structured around the product design dynamic process and uses web-based groupware to aid students working together by having a tool to store, organise, and share information. This technology is also a new factor that can impede group contributions and interaction if poorly designed (Craig & Zimring, 2000). To develop tools and address learning Wu et al (2003) compare individual and group learning recommending that tools provide:

- Mechanisms for knowledge sharing (e.g. via communication).
- Methods to transform input knowledge into output knowledge.
- Ways to capture learning stimuli.
- An area for collective knowledge.
Individuals can improve their ability in using a collaboration tool through learning, but this also can limit the functionality of a tool (Eckert et al., 2001). A less apparent limiting factor on the functionality of a tool and group is an individual’s ability to work in a group.

CSCW has limitations producing a satisfactory alternative to face-to-face communication only for routine work (Kunz et al., 1998; McGregor et al., 2004) and technology does not determine design quality (Chiu, 2002). For critical processes (e.g. goal/solution analysis, conflict management) face-to-face communication is still preferred.

2.3.3 Review

Knowledge management collaboration tools emphasise requirements for clear classification, structuring and presentation of design information or knowledge; group collaboration tools support communication, coordination and learning in design groups. Both aim to support and facilitate knowledge exchange between individuals, departments and organisations yet both show little interest in capturing what understanding is shared between participants or how individuals collaborate. Combining the two sets of tools increases designers awareness of interdependencies between design and group development processes and gives further understanding about collaborating in engineering design.

Present tools however predominately develop their structure from design methods and approaches focusing on design process i.e. engineering solutions for social problems (Minneman & Harrison, 1998).

Understanding the influence of and on group dynamic processes in collaborating design teams may help to improve design collaboration tools. Tools themselves present problems for social process in engineering design that stem from a reduction in inter-personal interaction, relationships being depersonalised, and rich informal and varied communication being limited (Perry & Sanderson, 1998). Technology itself does not determine quality but requires social initiatives to support thinking and communication (Baird et al., 2000).

2.4 Summary

Overall in this chapter engineering literature is classified under three themes: Design processes, Group processes and Design collaboration tools. In critiquing literature the following points are made:
Literature on engineering design

- The choice of design process or design type influences how engineers design.
- There is a need for descriptive analysis to aid developing design methodology (Blessing et al., 1998).
- Design collaboration tools aim to support knowledge management (storage and retrieval of information) and promote communication, coordination and learning in design but fail to capture how shared understanding is developed and maintained.
- Design collaboration tools address influences from design dynamic processes but fail to recognise that they may be “engineering solutions for social problems” (Minneman & Harrison, 1998: 32).
- To design collaboratively in groups it is key to share knowledge.
- Empirical case studies looking at social process predominately cover design projects that are within an organisation.
- Few investigate how design type influences how participants achieve their task(s), consider how participants design by collaborating in pairs, or how collaborating influences participants.

There is a broad range of topics investigated in engineering design related to collaborating. In this research the author focuses on the social process of engineering design during a projects’ lifetime building on research in sections 2.1 & 2.2. Research investigating tools for collaboration (section 2.3) are acknowledged and are valuable to illustrate how findings may be applied in practice. Particular interest for the author lies in providing a descriptive understanding of social processes (e.g. building trust, communication) in engineering design through investigating how individuals manage to cross organisational and knowledge boundaries to design together. This is to recognise that successful product development is increasingly based on collaborating between multiple organisations (ASME, 2008, 2009; Günther et al., 1996; Sonnenwald, 1996) and that design type influences the process of designing (Frankenberger & Badke-Schaub, 1998b: 156; Ostergaard & Summers, 2009). Social aspects are recognised in engineering design literature but few describe how they change and interact during a project, i.e. over time, or how they influence participants. In the next chapter research in engineering design is complemented by introducing literature on groups focusing on human behaviour over time i.e. social process (Pettigrew, 1973: 1).
3 Literature on groups

In this chapter a synopsis and critique of current literature associated with groups and collaborations is presented. Primarily this addresses established models and theories to understand group dynamics and behaviour to outline previous work, gaps, and develop (or adopt) a conceptual framework for this research. Initially key aspects to a group are presented (3.1) including what is a group, individual and group productivity and social process in pairs and a group. This is followed with research on group development models (3.2) and shared cognition (3.3). Collaborating and groups is then presented (3.4) covering how collaborating is defined, key social themes in collaboration and collaboration models. Specific gaps in research on collaborating are then outlined (3.5) before concluding with a summary (3.6).

3.1 Key aspects to a group

Literature on groups is reviewed focusing on small groups [typically Tuckman’s work (1965) was based on a maximum of 15 individuals] to understand theories of group behaviour appropriate to a design project group. This starts by considering what is a group (3.1.1), then highlights effects of a group on individual and group productivity (3.1.2) before covering the behaviour of individuals (social process) in pairs and groups (3.1.3).

3.1.1 What is a group?

Groups are formed to complete what individuals alone cannot. This concept may seem simple but in reality it is not trivial as dysfunctional groups are common. A group can be expressed as individuals that are placed, classified or are physically together (an aggregate), however the number involved can be conscientiously vague. Schein (1980) refines this definition to any number of people who interact with one another, are psychologically aware of one another or perceive themselves to be a group; hence individuals are often in groups. In this research a group is defined as three or more individuals to distinguish it from phenomena relating to a pair of individuals.

A group incorporates two types of processes: task and affective (or socio-emotional). Task processes are orientated around accomplishing group tasks and goals (including problem solving) with examples of task processes being communication and coordination. Affective processes concern building and maintaining relationships amongst group members to develop an effective working unit e.g. building trust or developing commitment to each other. This research encapsulates both task and affective processes under the term social processes (see Definitions p. xii, sections 3.1.3 & 3.4.2 for details).
3.1.2 Individual and group productivity

The relevance of understanding groups in organisations was first discovered in the early twentieth century while studying the optimum level of lighting for productivity on an assembly line in the Hawthorne experiments (Roethlisberger & Dickson, 1939). They presented three main findings:

1. Lighting was not a factor in productivity.
2. Inadvertently the special attention given to workers illustrated strong motivational aspects for a group to perform well. This relates to a groups’ normal working values (norms) illustrating how these can be more powerful than extrinsic benefits to influence productivity.
3. Informal groups defined working norm standards and hence productivity was related to motivation of a social unit instead of an individual.

This description of group behaviour focused on homogenous groups where each individual performed identical functions – the lack of task interdependency may denote behaviour as a group instead of behaviour within a group. Essentially, these studies diverge from Taylor’s scientific management approach by highlighting the influence of social processes in work environments that led to human relations management theories. These findings highlight that groups are not only powerful entities in what they can achieve, but on how they affect participants – a group can instil conformity on members (Anzieu, 1984; Bion, 1961; Gibb, 1964) such that group members will balance relationships and their esteem for others and may hesitate to voice alternative opinions. The strength of being in a group can also increase the risks a group is willing to take. Janis (1972) noted this effect and termed it ‘group think’ which relates particularly to delusions of invulnerability created by a group although this process of invulnerability does not affect weak willed or easily influenced individuals.

This is complemented by research concluded by Belbin (1981) known as the Apollo syndrome. In this Belbin describes that balanced heterogeneous groups perform better than a group of similar high intellect individuals due to excessive internal competition and poor negotiation. This illustrates an old adage that ‘too many cooks spoil the broth’ but it is also clear that an Apollo group is not a precursor to poor performance, they can perform though a team is likely to lack creativity (Belbin, 1981).
Belbin (1993) further defined the balance of individuals required to perform in a team and divided them into roles (Plant, Resource Investigator, Coordinator, Shaper, Monitor-evaluator, Team-worker, Implementer, Completer, Specialist) using human characteristics (e.g. creative, extrovert). This categorisation is based upon observations and measurements of team inputs from self reporting psychometric tests (personality, outlook and reasoning ability) and aims to help practitioners select balanced teams. There is some uncertainty whether there is any advance in defining individuals by functions or by roles. Both techniques can cause stereotyping and limit individual input in group activities to their perceived role or function, when participants may perform a number of roles to accomplish their tasks. These categories are useful to consider individual roles in a group and can contribute to an initial understanding of a group; however they are limited in interpreting how and why individuals interact and behave or how context influences work teams.

Sundstron et al (1990) develop the link between a group and its context by proposing an ecological framework for analysing effectiveness in work teams. The outputs of performance (meeting customers’ needs, quantity, quality, time) and viability (group cohesion, shared purpose, commitment) define team effectiveness as shown in Figure 5.

![Ecological Framework for analysing work team effectiveness](image)

**Figure 5 – Ecological Framework for analysing work team effectiveness (Sundstrom et al., 1990)**

Thirteen cases were reviewed considering internal aspects of a team when individuals have intervened to improve team effectiveness. They state that a lack of ecological perspectives (organisational context) explains why intervention success rates are low in these cases. This recognises the significance of considering the effect of organisational context on participants and group effectiveness.
3.1.3 Social process in pairs and groups

Social process is recognised as an influence on individual and group productivity and more generally is described “the behaviour of people over time” (Pettigrew, 1973: 1). In this research it covers task based processes (e.g. communication) and affective processes (e.g. building commitment) that involve or relate to people. Thus behaviour in a pair (e.g. dyadic processes, inter-personal relationships), or behaviour in a group (e.g. inter-personal processes or group processes) are both considered as social process.

Research under dyads or inter-personal relationships in social psychology focuses on close personal relationships to understand affiliation, affection and friendship between people. Inter-personal relationships are when two people coordinate with each other so that their action, evaluation or thought, and affect are complementary (Fiske, 1998) or are mutually and causally interconnected (Kelley et al., 1983). Relationships are hence patterns of coordination among people and are not properties of individuals (Fiske, 1998). This promotes conceptualising links between two individuals in terms of ongoing connections of mutual influence.

Typically three analysis approaches are used on studying relationships: an individual, a dyad or a systemic level (Sarason et al., 1995). A systemic level of analysis aims to understand how others in a social network or group are influenced by a pair (Sarason et al., 1995) and is seldom used in social psychology (Berscheid & Reis, 1998: 197). Thus, relevant contributions to this research from literature on inter-personal relationships in social psychology are predominately informative in defining and understanding what happens to an individual or dyad in close relationships. This also highlights a gap in research on how pairs of individuals influence groups.

Studying inter-personal processes or group processes provokes a divide in social psychology that represents two approaches to understanding behaviour in groups. Some researchers [individualists e.g. Allport (1924); Latané (1981)] consider group processes simply as inter-personal processes between a number of people i.e. people’s behaviour is similar in groups, pairs or on their own. Others [collectivists e.g. McDougall (1920); Sherif (1936); Tajfel & Turner (1979)] see behaviour in groups as a unique social process that is influenced by socially constructed group norms i.e. people alter their behaviour because they are in a group. Along this divide recent debate illustrates that social psychologists are unresolved about whether research on groups should include that of pairs / dyads (Moreland, 2010; Williams, 2010). There is a consensus that pairs are not groups
(Moreland, 2010; Williams, 2010) – pairs are more transient, exhibit stronger emotions, and are simpler as some group phenomena cannot occur in groups (Moreland, 2010). Yet any group phenomena that can by understood through social impact theory (Latané, 1981), an individualist approach, can be studied in pairs, e.g. conformity, social inhibition, cooperation, competition – dynamic exchange is all that is required (Williams, 2010).

There are methodological hurdles. Researchers need to be careful when generalising from pairs to groups and vice versa; they should consider how to capture data on both pairs and a group, and literature on both already have their own separate research domains (Moreland, 2010). These are hurdles to understanding both pairs and a group and should not presented as a reason to not study both pairs and group. Phenomena occurring in both groups and pairs are different (Moreland, 2010) yet as they are studied independently to each other, knowledge about how general phenomena (e.g. collaborating) are different or similar in pairs and group is still illusive. Excluding the study of pairs in groups is short sighted (Williams, 2010) highlighting a gap in current research particularly where phenomena can involve both pairs and groups e.g. collaborating in design teams.

3.2 Group development models

The behaviour of people over time (social process) in a group and their performance is influenced by shared (or not shared) group experiences and group development (Mennecke et al., 1992). Group development models illustrate phases / stages that a group progresses through over time and are classified into three broad categories – progressive, cyclical, and non sequential (Chang et al., 2006; Chidambaram & Bostrom, 1996; Chidambaram et al., 1991; Mennecke et al., 1992) with Chang et al (2006) introducing a multi dimensional approach to model selection. These three model categories are outlined next to consider how groups and inter-personal relationships are viewed.

3.2.1 Progressive models

Progressive models are typified by Tuckman’s research (1965) based on his experience and a review of 50 articles on group behaviour in three settings: group therapy, natural groups and laboratory group settings. This led to creating a model to understand how task entity (task activity) and social entity (social activity) develop in small groups. Proposed initially in four linear stages (forming, storming, norming, performing) and adding a fifth (adjourning) later on (Tuckman & Jensen, 1977) and shown in Figure 6.
Figure 6 – Tuckman’s group dynamics model [adapted from (Tuckman, 1965; Tuckman & Jensen, 1977)]

A group first establishes boundaries and inter-personal relationships; followed with conflict over ideas and leadership; to a synergy of values and trust; fourthly with a focus and clear cohesion in functions and roles; then finally with closure and separation. This model is reinforced by a number of similar models from other social psychologists [e.g. Corey & Corey (1987); Peck (1987), Zinker & Kepner (1980)]. Progress from one stage to the next in this model is not guaranteed, some groups may never reach the ideal ‘performing stage’ and potentially there is transition both forward (white arrow) and backward (grey arrow) through stages.

Guirdham (2002) introduces into Tuckman’s model the consideration of group and individual perspectives in each stage with three factors:

1. Individual needs.
2. Group needs.
3. Task needs.

Each stage has its own relative dominant factor changing progressively from individual to task over the first four stages. This model has received much attention in both academic and practitioner application in representing small group development with a linear path. This linearity though presents its’ limitation in absorbing variety and change that occurs in group development.

Two models are outlined that take into account links between individuals and a group. First Moreland & Levine (1982) introduce a progressive model that describes connections between an individual and group over a group’s lifetime – group socialization (see Figure 7). This is based on literature from a number of academic domains (e.g. political participation, social movements, professional and organizational socialization etc) and focuses on small autonomous groups whose members regularly interact.
There are three processes: developing commitment, role transition, evaluation (group vs. individual strategy) and five phases in the model: investigation, socialisation, maintenance, re-socialisation, remembrance. Individual commitment is depicted as increasing through the first two phases as an individual joins a group (Entry Commitment) and is accepted (Acceptance Commitment), peaking during maintenance, and decreasing through re-socialization (Divergence Commitment) to remembrance (Exit Commitment). Characterising each phase in role is prospective member, new member, full member, marginal member and ex member. Similarly group and individual strategies across the five phases are recruitment/ reconnaissance, accommodation/ assimilation, role negotiation, accommodation/ assimilation, tradition/ reminiscence. This is an idealised representation and does not account for sudden changes to individual or group commitment, or if individual and group strategies are based on the same criteria – where there are differences conflict is likely.

Secondly Worchel and Coutant (2001) suggest that group dynamics have inter-personal and intergroup components that should be included when studying the links between individual and a group. They put forward an identity development model (Worchel & Coutant, 2001) illustrating how individual roles and identity are influenced by changes in group identity [in contrast to Moreland & Levine (1982)]. This model shows individual membership of a group is temporal and it is important to maintain a group identity for a productive group where salient components of individual identity change during group development. Thus in addition to creating a project group identity a number of group
identities will exist that reflect participants’ associations with other groups (e.g. discipline, organisation). This illustrates that in defining and maintaining a group identity in a project it is important to recognise participants’ different attributes to motivate individuals to be part of a group.

### 3.2.2 Cyclical models

The second set of models (e.g. Bales, Bion, Homans) propose that a group develops in iterative cycles and they focus on the changing nature of work and emotions in a group. Bion (1961) developed a model from extensive psychotherapeutic work noting two levels in group behaviour:

1. *Common task* (or the work group).
2. *Common feeling* (or the basic assumption group – the combined hidden agendas of group members).

These two levels relate to the external and internal (respectively) focus of a group. There is often a tension between the two when individuals try to learn to balance their need to belong to the group and express their individuality. Bion secondly recorded that individuals in a group are combined instantly and involuntarily (‘group mentality’), and conflict occurs between individuals and group mentality (‘group culture’). Further insight into group mentality is recorded in Bion’s affective states of a group relating three basic assumptions:

1. Dependence.
2. Fight flight (a sign of group cohesion).
3. Pairing (groups or pairs develop due to the 2nd basic assumption).

Only one of the three basic assumptions can appear at any given moment. Basic refers to the survival motivation of a group and assumption is the collective projections of group members (that are based on neither fact nor reality). Bion’s work, in addition to that from Klein, forms the basis for the Tavistock method (Astrachan, 1975) noting that when individuals become conscious of their interdependency (e.g. due to an external threat) they behave like a system with a primary aim to survive. This is a powerful mechanism to bind individuals together in a group though often it is hidden. The Tavistock method also provides a framework to analyse group behaviour and is useful to consider individual actions that illustrate conflict between group cultures.
Bales’ equilibrium model is derived from studying interaction and behaviour in numerous laboratory groups (Bales, 1950, 1966a; Bales & Strodbeck, 1951) and explains that a group will go through three task phases:

1. Orientation (asking for and receiving information).
2. Evaluation (asking for and receiving options).
3. Control (through norms to guide group).

At the same time a group will exhibit Positive and Negative affective reactions. During orientation instrumental acts are greatest and at their lowest in control. Expressive acts show the inverse pattern and status struggle, shown by negative intra group acts, is most significant during evaluation (Bales, 1966a; Bales & Strodbeck, 1951).

This seems like a progressive model but there is iteration through phases as a group divides its efforts to balance task and affective reactions. In a group each function is recognised as a specialist role of equal and complementary importance (Bales, 1966b) that can be performed by one or more participants.

Homans presents a group as a system of connections where each individual is interlinked and mutually dependent to survive in an environment (Homans, 1955: 107). Cases from social studies [e.g. The Hawthorne experiments (Roethlisberger & Dickson, 1939)] are used to develop a group model (Homans, 1955: 19-21) of two systems: external and internal. External refers to task concerns (i.e. for survival), internal to inter-personal relationships (Homans, 1955: 110) and the term ‘system’ is used to emphasise that group members are mutually dependent. The two systems complement each other but require interdependence and balancing as the internal system simultaneously arises from the external system and acts upon it (Homans, 1955: 109). Both are defined as having:

- Activity (what people do as part of a group).
- Sentiment (wants, wishes, values, ideology).
- Interaction (when people are brought into relationships with each another).

Mutual dependence occurs between activity sentiment and interaction in an internal system. External systems do not have dependence between interaction and sentiment characteristics.

Bales and Homans argue that inter-personal relationships are developed through role differentiation that depends on group consensus (e.g. shared aims, needs etc) where individuals play particular parts in a group’s life. Both progressive and cyclic models offer
representation of groups at different points in their existence but do not address any causes of change mechanisms or define how long a group is in each stage.

### 3.2.3 Non sequential models

Non sequential models (Gersick, 1988, 1989; McGrath, 1991) present a third option primarily aiming to explain underlying change mechanisms in groups. Gersick’s punctuated equilibrium model is taken as an example and focuses on task activities of group development appreciating time as a mechanism to encourage change. This involved a grounded theory study of eight organisational working groups (Gersick, 1988) observing long static periods in work direction punctuated by focused radical periods of significant change, and complemented by studies of eight student groups (Gersick, 1989). Three periods describe the model:

- **Phase 1** – An initial period of small advances in direction. A group’s first meeting defines this pattern and continues until Transition
- **Transition** – This is a major step in progress characterised by:
  a. A project’s midpoint in time – midpoint progress is atypical.
  b. Expressed urgency.
  c. New contact between team and organisations.
  d. New agreements on ultimate direction.
- **Phase 2** – Second period of small advances following direction identified at Transition. Again as the final meeting approaches there is a major step in progress as a group accelerates to complete work.

This clearly details the impact of time on task function but does not consider the influence of social function. Considering this function may enlighten further the periods of small advancement in phases 1&2 and provide a comprehensive picture of group development.

The three types of models illustrate a variety of approaches to describe small group development. Each highlights different interests that are relevant to some groups and less so to others illustrating that there is no universally preferred or accepted model. The sequential models (progressive and cyclic) can be viewed as being preoccupied with developmental patterns and non sequential with developmental processes (Chidambaram & Bostrom, 1996). Common throughout group development models presented is a recognition of *task* and *affective* aspects [entities – Tuckman (1965); common – Bion (1961); functions – Bales (1950, 1966a; Bales & Strodbeck, 1951); systems – Homans
(1955); activity – Gersick (1988, 1989)]. These two aspects in group development complement each other and illustrate a duality in how inter-personal relationships are perceived to develop in group life (Radley, 1991: 38). Appreciating both task and affective aspects is key to understand a group, and generalised results may be misleading when observations are limited to just one aspect.

Two progressive models outline connections between individuals and a group highlighting links between group membership and group performance. Moreland & Levine (1982) record how individual commitment changes as their membership in a group alters, whilst Worchel & Coutant (2001) recognise how changes in group identity alter individuals’ association with a group.

Lastly the environment in which a group is set influences inter-personal relationships. Individuals may tend towards attitudes and expectations brought from peer groups or gender identities [e.g. male - task activity, female – social activity (Bales, 1966b: 443; Radley, 1991: 44)], and an environment’s formality may bias affective or task aspects e.g. towards friendship or safety of a group respectively, illustrating links to Bion’s (1961) research.

### 3.3 Sharing cognition: mental models and understanding

In this section research under the term shared cognition is presented to build on the importance of group consensus in role differentiation and developing relationships (see 3.2.2). People simply cannot talk together without appealing to a common ground – a type of shared information covering the sum of mutual knowledge, beliefs and suppositions between two people (Clark, 1992: 2). A number of terms have been introduced by collectivists (see section 3.1.3) to describe sense making in groups e.g. cognitive maps (Axelrod, 1976), mental models (Rouse & Morris, 1986), collective mind (Weick & Roberts, 1993). These terms, and shared cognition as a concept, indicate that individuals in effective teams have accurate and similar knowledge to guide their actions (Cannon-Bowers & Salas, 2001; Cannon-Bowers et al., 1993; Cooke et al., 2003; Klimoski & Mohammed, 1994; Stout et al., 1999). Literature presented next focuses on the term mental models as it is prevalent in management and engineering design fields of research.

Mental models are used to explain how knowledge and information are represented in the mind (Klimoski & Mohammed, 1994) and can provide a conceptual framework for describing and explaining future cognitive states (Rouse & Morris, 1986). Mental models represent assumptions and beliefs about how tasks are performed and how people are likely to behave providing a structure and source to interpreting information (Badke-
Schaub et al., 2007). Sharing mental models involves conscious and explicit negotiation and agreement between those involved (Fiol, 1994; Klimoski & Mohammed, 1994; Levine et al., 1993). Those who have a shared mental model are able to anticipate each others actions, needs and consequently adapt their behaviour (Cannon-Bowers et al., 1993; Klimoski & Mohammed, 1994). Not all aspects of individual mental models are critical to shared understanding, however learning some knowledge collectively is required to achieve a high level of team effectiveness (Mohammed & Dumville, 2001).

The term sharing can mean having in common, dividing up, overlapping (Klimoski & Mohammed, 1994) or that members hold compatible mental models that lead to complementary expectations (Cannon-Bowers & Salas, 2001). The content of what is shared in mental models can be split into four or two categories. Analysing literature Mohammed & Dumville (2001) identify four categories:

1. Task-specific knowledge.
2. Task-related knowledge e.g. team work.
3. Knowledge of teammates e.g. transactive memory.
4. Attitudes/beliefs e.g. similar work approaches.

Mathieu et al (2005; 2000) reduce these into two categories – Task (e.g. design procedures, scenarios, strategies etc – pts 1&2) and Team (roles, participant capabilities, attitudes, beliefs, behaviour etc – pts 3&4). Interestingly this highlights two categories that are similar to the two aspects noted in group development models – task and affective aspects (section 3.2 p31).

Researchers predominantly use a game simulation to collect data on shared mental models of two people (e.g. Mathieu et al., 2005; Mathieu et al., 2000) or of small groups – three or four people (e.g. Bierhals et al., 2007a; Bierhals et al., 2007b; Stout et al., 1999). Methods to construct a team mental model include cognitive mapping (Klimoski & Mohammed, 1994) and similarity ratings where further methods for measuring cognitive structures are recorded in Mohammed and Dumville (2001).

Team mental models have been applied to group decision making and group performance with Figure 8 illustrating a framework to explain team mental models and team performance. The framework highlights factors that influence team performance presenting factors in numerical order similar to a flow chart. In this case an individual’s mental model would include their cognition (knowing) about performance and could be synthesised with other members cognition to build up a team mental model (number 5 in Figure 7) to develop their shared understanding of performance.
Empirical studies show that similarity in shared mental models positively affects team performance (Mathieu et al., 2005; Mathieu et al., 2000; Stout et al., 1999). Matheiu et al. (2000) show that team processes (leadership, assertiveness, decision making/analysis, adaptability, situation awareness, communication) are positively influenced by both shared understanding of Task mental models and Team mental models, and team processes positively influence team performance. Bierhals et al. (2007b) note that shared knowledge reduced the amount of explicit communication and that Team mental models were a stronger predictor of performance than Task ones. Furthermore Bierhals et al. (2007a) show that shared knowledge in setting design process goals positively influences team performance.

The concept of shared cognition can explain team performance as participants of effective teams have compatible knowledge that they use to guide their behaviour. It can also be used to consider how participants share understanding (similar, overlapping, distributed, complementary) and what is shared (Task or Team). Empirical studies have focused on pairs or small groups, and have yet to consider how pairs influence a group.

### 3.4 Collaborating and collaborations

In this section research is presented and reviewed focusing on collaborations and collaborating primarily drawing on literature under Inter-Organizational Relations (IOR) in management academic disciplines. First what is collaborating is considered (3.4.1), then key themes and challenges are outlined (3.4.2) before finishing with models of collaboration (3.4.3).
3.4.1 What is collaborating?

Collaboration and collaborating are terms that are used about phenomena involving individuals and groups working together across knowledge and organisational structures. Current interest stems from professional associations (e.g. ASME, 2008, 2009) and governments promoting collaborating with it being frequently central to an organisation’s strategy (Huxham & Vangen, 2005: 7). People collaborate to create a competitive advantage (under the guise of innovation) and solve complex problems (Trist, 1983) by sharing resources and risks (Bozeman & Corley, 2004; Jassawalla & Sashittal, 1998; Katz & Martin, 1997; Littler et al., 1995; Schilling & Hill, 1998; Tidd et al., 2005) or because collaborating is the only way to address a problem (Huxham & Vangen, 2005: 7; Malhotra et al., 2001).

Collaboration is a relational construct between at least two parties. It involves interactions between individuals (Huxham, 1993; Jeffrey, 2003) that may sometimes be new within or beyond a collaborations boundaries (Lawrence et al., 1999). Collaborating itself is a process that derives a solution going beyond the individual components (Gray, 1998), creating new value together (Kanter, 1994) and is not a pragmatic alliance (Jeffrey, 2003). Collaborating hence takes place over a period of time encouraging individuals to work together with their combined effort greater than separate components.

Interacting and combining individual attributes over a period of time draws attention to inter-personal relationships. Collaboration is seen as involving informal, cooperative inter-personal relationships through which shared visions and mutual understanding are created (Jassawalla & Sashittal, 1998) with inter-organisational relationships being free from “market or hierarchical mechanisms of control” (Phillips et al., 2000: 24). Gray (1998) sums up five critical aspects about collaboration:

1. Stakeholders are interdependent.
2. Solutions emerge from constructively dealing with differences.
   a. Search for information.
   b. Mutually agreed solution.
   c. Ratification and plan to implement.
3. Joint ownership of decisions.
5. Collaboration is an emergent process.
Collaborating is hence possible in pairs, a group or a team. Working collaboratively encourages participants to develop ideas and solutions together combining individual expertise and producing outcomes that are greater than the sum of separate components. This also requires collective responsibility and care needs to be taken to allow individuals to express personal limitations (knowledge and time) particularly in unfamiliar environments or in a group. Collaborating is hence viewed as a pinnacle of interactive work where outcomes are highly reliant on combining participants’ abilities.

In observing collaborations over 15 years Huxham and Vangen (2004) present two key concepts to understanding collaboration in practice. Firstly collaborative advantage is “to gain real advantage from collaboration, something has to be achieved that could not have been achieved by any one of the organisations acting alone” (2004: 191). Secondly collaborative inertia is when “output from a collaborative arrangement is negligible, the rate of output is extremely slow, or stories of pain and hard grind are integral to successes achieved” (2004: 191). The first reinforces the notion that in collaborating output is greater than the sum of participants, yet the second reminds participants that collaborating is intricate and requires attention, patience and hard work for success.

3.4.2 Key social themes and challenges in collaborating

Involvement, commitment, trust and control are key social themes in collaboration as participants work across boundaries defined by geography, organisations and knowledge. In these circumstances, the study of social processes becomes more relevant to understand how participants collaborate and achieve their activities (Cullen et al., 2000; Gulati, 1995; Kanter, 1994; Larson, 1992; Littler et al., 1995; Ring & Van de Ven, 1989) as they confront a number of paradoxes and challenges. For broader reviews that include economic processes and Inter-Organizational Relations see Bachmann & Zaheer (2008) amongst others. Empirical evidence outlining these themes and challenges is presented next (definitions of each theme recorded in Definitions p. xii).

Social themes

Collaborating across discipline and organisational boundaries (even within one organisation) participants are less likely to be co-located. There is concern that without co-location individuals can become less involved and disillusioned with a collaborative project as selective perceptions reinforce different perspectives and broad synergies on paper fail to occur (Kanter, 1994). Hardy et al (2003) in a study of eight collaborations of a nongovernmental organisation highlight that involvement and embeddedness describe
knowledge creation, strategic and political effects. Collaborations where participants are both involved and embedded are more likely to be associated with knowledge creation effects; those that are only involved are more likely to be associated with strategic effects with those that are only embedded are more likely to be associated with political effects.

Other research notes that working across discipline boundaries is influenced by participants’ dedication to achieve their activities (Jeffrey, 2003). A survey on risks and benefits of collaborative product development in UK Information and Communication Technology products highlighted that commitment from all involved at all levels was seen as the most important people factor (Littler et al., 1995). Commitment has been linked to participants’ communication patterns and trust – Maznevski & Chudoba (2000) in a study of group dynamics and effectiveness in three global teams (inter-organisational) describe that teams who fit communication patterns to their activities creating a rhythm of face to face communication combined with remote communication reflected teams with high commitment or high group cohesion. In addition to commitment Cullen et al (2000) call for individuals to pick partners with trust in mind and to identify a level of trust and commitment appropriate for a collaborations strategic goals. From two large empirical studies (Cullen et al., 2000) participants are recommended to understand each others’ behaviours and interactions to discern trust or commitment signals and gradually reveal long and short term goals.

Trust is required in collaborations to deliver their potential strategic or economic payoff (Madhok & Tallman, 1998). Studies specifically looking at trust in collaborations identify different types of trust. Two types of trust (Cullen et al., 2000; Das & Teng, 1998) outline a benevolent or goodwill trust that covers individual ability to take initiatives for mutual benefit, and secondly a credibility or reliability trust that includes expectations about partners intent and ability to meet obligations. Sako (2000) splits this latter type into two with contractual trust focusing on shared norms of honesty and intent, and competence trust on ability.

Malhousa et al (2001) from an empirical case study of radical innovation in engineering observed that strategy setting was important for creating trust and this was also a reason why some firms don’t put time into a collaboration due to it being a low priority for them (Larson, 1992). Trust itself can help individuals select prospective partners based on previous relationships and reduce initial collaboration setup costs (Gulati, 1995). There is also empirical evidence that trust aids participants to move beyond initial roles and redefine them together as collaborations develop (Doz, 1996), getting agreement to
implement new working practices (Sako, 2000), incrementally developing mutual trust (Larson, 1992), and moving from contracting to working practices that are less prescriptive (Gulati, 1995).

Sako (2000) comments that trust can act as a governance structure; it can also affect organisations’ confidence in cooperation (Das & Teng, 1998). In a detailed literature review Das & Teng (1998) present four propositions that describe links between trust and control in collaborations:

1. Confidence in participant cooperation is dependant on a combination of trust and control.
2. Trust between participants is reduced when formal control mechanisms are used (e.g. contracts).
3. Trust between participants is increased through social control mechanisms (e.g. understanding and predicting participants’ behaviour).
4. Trust in a collaboration facilitates the impact of control mechanisms (goal setting, shared values & norms, rules & regulations).

Thus it is unlikely that collaborations can be controlled solely by formal mechanisms (e.g. contracts). Instead inter-personal relationships and internal infrastructures are required to facilitate participants learning how to collaborate (Kanter, 1994).

Ring and Van de Ven (1989) highlight that inter-personal relationships across organisational boundaries establish formal and social control mechanisms to manage exchanges. In a study of seven pairs of collaborating entrepreneurial firms Larson (1992) outlined a dependence on social control mechanisms instead of formal contracts in forming and maintaining collaborations. Multiple exchanges and a high amount of cooperation and collaboration define settled and sustained inter-personal relationships through which participants establish and maintain norms of trust and reciprocity (Larson, 1992). Inter-personal relationships that are seen as cooperative are those that are free from “market or hierarchical mechanisms of control” (Phillips et al., 2000: 24).

Furthermore Macaulay (1963) in an empirical study of exchanges between manufacturers highlighted that as close inter-personal relationships emerge across organisational boundaries they create pressures for individuals to conform to expectations. Simply being able to influence an individual though does not guarantee influencing an institutional field; effecting change at this level requires inter-personal relationships within the institutional field (Phillips et al., 2000).
Challenges in collaborating

Research on themes of involvement, commitment, trust and control have been highlighted to describe key social themes to collaborating. These also bring challenges to learning, managing and being flexible about how to collaborate as individuals become more dependent on less defined social processes instead of established formal procedures.

First participants are challenged to learn how to work together when collaborating (Kanter, 1994). Innovation is likely to be located in learning networks rather than individual organisations (Powell & Brantley, 1992) and Hardy et al (2003) highlight that strong flows of information are important to produce learning in collaborations with Doz (1996) emphasising that successful collaborations go through a sequence of learning, re-evaluation and readjustment cycles.

The content of what participants learn revolves around recognising, establishing and maintaining shared values. There are calls for early creation of shared work norms and working practices (Malhotra et al., 2001), and normalising information to participants (Cramton, 2001) to allow participants to work independently of each other (O'Sullivan, 2003). O’Sullivan (2003) notes that establishing standards in product design rules depends on social interaction and shared understanding and is facilitated by similar backgrounds. Learning about shared values relates to a paradox in strategic alliances: participants are encouraged to follow their own interests yet simultaneously are required to limit this approach to make an alliance work (Das & Teng, 1998). In order to assess individual expectations with those of a group, participants have to learn how to balance competition and cooperation to make a collaboration successful (Teece, 1992).

Managing social interaction and relationships in a collaboration is also a challenge (Maznevski & Chudoba, 2000). Some organisations spend more finances on partner selection than managing a collaboration (Kanter, 1994), yet collaborations fail to produce innovative solutions, be mutually successful (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005) or meet participants’ expectations (Killing, 1982; Ring & Van de Ven, 1989). In particular participants have to recognise how to share control with Killing (1982) suggesting that this should only be shared when all involved are critical to a collaborations success. Littler et al (1995) from a survey on risks and benefits of collaborative product development concluded that managing these projects involves balancing four challenges:

1. Establishing initial standards and responsibilities vs. being flexible to changes.
2. Creating boundaries around knowledge vs. building trust.
3. Managing a collaboration vs. awareness of market factors.
4. Evaluating outcomes to objectives vs. less tangible benefits and wider impact of outcomes.

This also highlights calls for participants to be flexible throughout the duration of a project (Doz, 1996; Killing, 1982). Participants need to be patient in developing trust and commitment (Cullen et al., 2000) with collaborative projects requiring participants with both technical and social skills (Jassawalla & Sashittal, 1998) and investment in cross-cultural training (Cullen et al., 2000). Partner cooperation although required to collaborate may not be easy to achieve (Das & Teng, 1998) and a major challenge as collaborating takes significant time and effort (Gray, 1998: 479; Huxham & Vangen, 2004).

This leaves certain topics and approaches that are more relevant to the study of collaborating. First, studies highlight the importance of social analysis in addition to economic analysis to understanding collaboration phenomena (Cullen et al., 2000; Gulati, 1995; Kanter, 1994; Larson, 1992; Littler et al., 1995; Ring & Van de Ven, 1989). Trust, commitment, control, involvement are all aspects of relationship capital illustrating the relevance of research on the topic of inter-personal relationships. Inter-personal relationships influence how individuals learn (Doz, 1996), yet there is limited research on how pair-wise relations in a collaboration influence group relations, individual participants or the process of collaborating.

Considering approaches Hardy et al (2003) call for a more holistic approach to consider different types of collaborations and different outcomes. Specifically O’Sullivan (2003) appeals for research to look at functional and organisational backgrounds and how these are related to project innovation type. Additionally, as there is an emphasis on inter-personal relationships and process [e.g. (Doz, 1996; Gulati, 1995; Larson, 1992)] there is a gap for longitudinal studies to capture how social themes and their relevance may change as collaborations evolve.

The design of a collaboration is also important (Bloedon & Stokes, 1994; Das & Teng, 1998; Malhotra et al., 2001; O'Sullivan, 2003; Penny et al., 2000) and in the next section a selection of conceptual frameworks about collaborations from IOR literature are described.

### 3.4.3 Collaboration models

Pitsis et al (2004) look at the design of a collaboration and define ten building blocks in the synthesis of inter-organisational relationships IORs) (shown in Figure 9).
Literature on groups

Figure 9 – Building blocks of inter organisational synthesis (Pitsis et al., 2004)

This concentrates on synthesis between organisations participating in a collaboration. Synthesis is described as “what happens between parties, the processes that connect them, the practices that divide them and the routines that lock them together” (Pitsis et al., 2004: 51) but does not have to mean harmony. Each theme presented is essential for successful inter-organisational synthesis and should be taken into account when designing and managing inter-organisational relationships. Many of the themes are related to each other and show clear requirements to build and maintain a balanced relationships for successful collaboration. This demonstrates that collaboration design is quite intricate. Although the framework centres on organisational relationships, it could equally be applied to individual relations within a collaboration and conveys some similar themes observed by Huxham and Vangen (2005) e.g. trust, leadership (see below). However, this model only presents critical topics for synthesis and does not establish a process to achieve synthesis.

Ring and Van de Ven (1994) present an insightful framework about developing cooperative inter-organisational relationships (see Figure 10).

Figure 10 – Process framework of the development of cooperative inter-organisational relationships
(Ring & Van de Ven, 1994)
Crucially they believe developing IORs to be iterative and cyclical moving between negotiating, committing to and execution of the task. Each stage is assessed through equity defined as fair dealing (equivalence of benefits and sociological meaning of indebtedness) and efficiency (economic exchange). This assumes that there is a formal agreement and illustrates that collaborating across organisations may be synonymous to the development of inter-organisational relationships. Furthermore Ring & Van de Ven propose that inter-organisational relationships develop, evolve and grow as a consequence of individual activities; if personal relationships fail over time to support formal role relationships, then the possible severity of conflicts between role specialists of each organisation will increase (Ring & Van de Ven, 1994). They also note that collaborations can be formal or informal with the latter exhibiting a greater dependency on trust defined as confidence in another’s goodwill (Ring & Van de Ven, 1994). Collaborating is presented as a process, dynamic, occurring over time. To observe and understand collaborating in this form research needs to capture data that can illustrate developments or how changes occur.

Huxham and Vangen’s (2005) present research is specific to a collaboration and focuses on creating a theoretical framework for practical use in understanding collaborations. There is no ‘recipe’ for individuals to follow just a descriptive theory that allows practitioners to analyse and influence practice. The structure of a collaboration should also be seen as ambiguous, complex and dynamic (Huxham & Vangen, 2000) to recognise a more contextualist and dynamic view of knowing (Pettigrew, 2001). The theoretical framework is formed from appreciating the multiple perspectives involved in a collaboration (see Figure 11).

![Diagram](image.jpg)

**Figure 11 – Types of themes in collaboration practice [Figure 3.1 in (Huxham & Vangen, 2005)]**
Literature on groups

In the framework, 18 themes are observed in collaborations but six are focused upon:

1. Managing aims and negotiating purpose.
2. Membership structures and dynamics.
3. Coping with trust.
4. Using power.
5. Identity.

Each theme includes techniques founded in action research to help represent and understand individual behaviour in a collaboration. Focusing on understanding the individual as part of a group develops from group theory and forms a framework to look at a group. Combined with theoretical concepts (collaborative advantage and collaborative inertia see section 3.4.1) this research provides a robust method grounded in practice to help dissect group complexities in a collaboration. This theoretical framework is developed from a range of collaborations and predominantly is used within the public service delivery domain. This presents limitations in accepted use and practical experience outside this knowledge domain. Furthermore, results of action research are highly context based and when applying elsewhere possible differences need to be recognised.

Research in engineering design and in particular new product development investigates approaches to selecting partners (Emden et al., 2006). Emden et al propose a conceptual model for selecting a partner with the most potential to create value based on narratives from four dyad case studies in co-development alliances. Co-development alliances are defined as “non equity-based relationships in which each party contributes a significant portion of the end solution” (Emden et al., 2006: 331) and note that individuals are interdependent and competitive. The process aims at pairing two compatible organisations to meet new product development demands through alignment of technological aspects (technical ability, resources, knowledge bases), strategic aspects (motives & goals) and relational aspects (culture, ability to change, long term orientation). This framework provides an understanding of desired characteristics for co-development alliances but its applicability is limited to strategic planning and there is little to help understand social process or group development during product development.

3.5 Collaborating, pair-wise and group relations, and context

In this literature review gaps are highlighted in knowledge about collaborating in engineering design that call for empirical research about 1. the process of collaborating, 2.
how pair-wise and group relations influence each other, and 3. how participants are affected by context in design projects.

Collaborating is characterised as a process that takes place over a period of time that derives a solution going beyond the individual components (Gray, 1998). Few capture empirical based understanding about this process [e.g. Doz (1996); Gulati (1995); Larson (1992)] with research in engineering design (see chapter 2) focussing on factors, barriers and enablers [e.g. Kleinsmann (2006); Maier et al (2008)]. This highlights a requirement for longitudinal empirical research to capture the complexity of social processes in project teams over time and recognise that social reality is dynamic (Pettigrew, 1997).

Collaborating is also distinguished as a relational concept (involving at least two parties) emphasising that it is important to consider social process in pairs and in a group to understand collaborating. Current research on collaborating centres on group effectiveness [e.g. Bierhals et al (2007b)], one or two social processes [e.g. control and trust (Das & Teng, 1998)], and deals with either inter-personal relationships [e.g. Larson (1992)] or a collaboration [e.g. Hardy et al (2003)]. Thus it is clear that there remain gaps in current research to investigate how pair-wise relations in a collaboration influence group relations, individual participants or the process of collaborating. In considering both pair-wise relations and group relations the aim is to develop understanding to explain why collaborations fail to produce innovative solutions, be mutually successful (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005) or meet participants’ expectations (Killing, 1982; Ring & Van de Ven, 1989).

It is also shown that group behaviour is affected by a project’s environment (Sundstrom et al., 1990) and how individuals clarify concepts or requirements is influenced by the novelty of a task (Frankenberger & Badke-Schaub, 1998b: 156; Ostergaard & Summers, 2009). However, current empirical studies focus on specific contexts i.e. either within one organisation [e.g. Brown, J.S. & Duguid (2000); Frankenberger & Badke-Schaub (1998a, 1998b)], across organisations [e.g. Huxham & Vangen (2005); Littler (1995)], and only consider one design type [e.g. Eisenhardt & Tabrizi (1995); McMahon (1994)]. Thus, comparative empirical research is needed to recognise how contextual factors influence collaborating in engineering design.

3.6 Summary

From literature presented on groups there are a number of important observations:

- Research on inter-personal relationships and group processes in social psychology have distinct separate fields though share some common approaches.
Literature on groups

- Task and Affective aspects are complementary and interdependent in describing group development.
- There is an inherent conflict between an individual and a group (and the representation of each) with group membership being temporal and changes in group identity influencing individual roles and identity.
- Hidden influences (i.e. needs, processes etc) exist in a group on multiple levels (i.e. individual, group, organisation and context).
- Shared cognition can highlight consensus and effective performance in pairs and groups through compatible knowledge outlining what and how understanding is shared.
- Sharing Task and Team cognition highlights similar topics to those outlined by Task and Affective aspects of group development.

Specifically looking at collaborating and collaborations, studies show:

- Three aspects describe research on collaborating: antecedents, structure, and as a process over time.
- Collaborating implies an increased interdependency of participants’, collective responsibility and output that is greater than the sum of components.
- Collaborating is a relational construct occurring in pairs and in groups.
- Study of social processes (e.g. developing trust, involvement, control, commitment) in addition to economic analysis, are key to understand collaborating across organisational boundaries.
- Empirical research focuses on one or two social processes, either a group or inter-personal relationships, and on project performance outcomes.
- Collaborating is challenging.

A broad range of topics from management, social psychology, sociology and engineering design academic disciplines have been described in this literature review. These have been narrowed to illustrate the importance of considering the process of collaborating, pair-wise and group relations and context in engineering design. In the next chapter, methods and approaches are described to outline how the researcher investigated the phenomena of collaborating in engineering design.
4 Methodology

In this chapter the aim of this research and how it is investigated is outlined. The literature review and critique provide foundations to define objectives and a Research Question (4.1). The philosophical approach of this research is presented next in section 4.2 emphasising suitable choices to study phenomena through coherent epistemology, ontology, methodology and methods. In research design (4.3) selected methods are detailed describing case method, how cases were identified, data collection and data organisation. Next, how data were analysed and interpreted is described in section 4.4. Research reliability, validity, and ethics (4.5) is consider by looking at the authenticity of data, analysis, and reflections on ethics before concluding with a summary (4.6).

4.1 Research Question and Objectives

There is one Research Question and six objectives in this thesis (previously stated in section 1.3):

Research Question: How do pair-wise relations influences group relations and outcomes in collaborating engineering design teams?

Objective 1: To review relevant literature and develop, or adopt, a framework of concepts to investigate engineering design teams, groups and collaboration.

Objective 2: To design and conduct a longitudinal cross-case comparison of engineering design projects.

Objective 3: To describe influences on the process of collaborating in design project teams.

Objective 4: To analyse how pair-wise relations influence collaborating in design project teams.

Objective 5: To develop existing or new (if applicable) concepts and theories based on empirical findings about how pair-wise relations influence collaborating in engineering design.

Objective 6: To develop implications for practice of collaborating in engineering design based on empirical findings.

This question and objectives emphasise that this research is looking at the process of collaborating, where process is defined as “a category of concepts of individual and organizational actions” (Van de Ven, 1992: 170). Collaborating is hence seen as being
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observable through fixed entities or variables here considered in three conceptual constructs: pair-wise relations, group relations, and outcomes.

A Research Question is used to concentrate analysis on understanding one particular aspect in collaborating design teams. There are three conceptual constructs: 1. Pair-wise relations, 2. Group relations, and 3. Outcomes (illustrated in Figure 12). Pair-wise relations cover interaction and understanding between two individuals. Interaction is any form of action or behaviour between two individuals, in essence it is what a pair of individuals do. This can be asynchronous e.g. email or synchronous e.g. telephone, and co-located e.g. face to face or distributed e.g. via video conference facilities. Interaction is broader than the term communication by including behaviour to recognise how interaction is conducted e.g. when telephone calls are made, or how openly participants express themselves. Understanding in pairs is based on the concept of shared understanding where individuals show an awareness about how tasks, behaviour and events are interpreted including being able to anticipate each others’ actions, needs, and adapting their behaviour (Klimoski & Mohammed, 1994) to develop common or complementary expectations (Cannon-Bowers & Salas, 2001). Shared understanding is split into two aspects: knowledge about Task (e.g. design procedures, scenarios, strategies etc) and Team (e.g. participant capabilities, attitudes, beliefs etc) – see section 3.3 p37 for literature.

![Figure 12 – Constructs of Research Question](image)

Group relations includes the same content as pair-wise relations, i.e. patterns of coordination, interaction and shared understanding, but is expanded to consider the project group. The third construct outcomes is defined as observable consequences of process covering project events (e.g. a finished product), interim events (e.g. revisions to designs) and participants’ affective reactions (e.g. establishing commitment to other participants). Affective reactions focus on how individuals’ adjusted to achieve their activities when project expectations were challenged i.e. when there were changes to project participation, delays, design revisions, or requirements for additional resources (finances or individual
effort). These three constructs are considered only within an engineering design context and a record of terminology used in this research is included in Definitions p. xii.

Responding to this question the researcher will present empirical findings that describe and explain the practice of collaborating in an engineering design project team (see chapters 6 & 7), and set out implications of these findings for practitioners (see chapter 8). Typically in engineering design, implications for practitioners would first be assessed in practice, however the aim of this research is to first understand and describe relevant themes to collaborating in engineering design. Implications for practice are a product of this understanding.

Choice of appropriate approach and methods to capture the dynamics of collaborating is described next. First the philosophical approach is described (4.2) followed by research design (4.3). Subsequently explanations are provided in section 4.4 of how the researcher systematically analysed data and developed findings to address the Research Question.

4.2 Research approach

There is a multitude of research approaches and choosing a particular approach outlines how a researcher considers the phenomena in question and what is acceptable knowledge. Each research approach includes an epistemology (nature and scope of acceptable knowledge about phenomena), ontology (assumptions about the nature of the phenomena), methodology (techniques for enquiry) and methods (techniques for data collection and analysis); however not all epistemologies, ontologies, methodologies and methods are compatible with each other to develop accepted knowledge. It is thus imperative that a research approach is clear and consistent as failure to consider these philosophical issues can “seriously affect the quality of the research” (Easterby-Smith et al., 2002: 27).

In the next two sections (4.2.1 & 4.2.2) an overview to research approaches is presented to outline differences between how the nature of phenomena are traditionally viewed in engineering design (positivism, objective nature, quantitative data) and how they are considered in this research (interpretivism, subjective nature, qualitative data).

4.2.1 Epistemology and ontology

A subjective-objective dimension is used to contrast assumptions about the nature of social science (Burrell & Morgan, 1979: 3) and understand how types of epistemology and ontology are related. To illustrate this, a variety of epistemologies (theories or perspectives) are represented on a continuous spectrum from subjectivist to objectivist approaches in Figure 13. Two contrasting sets of epistemologies are shown – interpretivism and positivism. Interpretivism represent a number of subjectivist approaches emphasising that
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worlds exist through meaning, language, reflective thought and interaction between individuals. In contrast positivism typifies objectivist approaches emphasising that a world exists externally through objects or external factors.

![Diagram of epistemologies](Diagram.png)

Figure 13 – A selection of epistemologies to give an indication of subjective-objective ontological positions [developed from (Benton & Craib, 2001; Burrell & Morgan, 1979; Denzin & Lincoln, 2003; Easterby-Smith et al., 2002; Lincoln & Guba, 2003)]

Traditionally, empiricists in engineering design focus on investigating how objects/artefacts (e.g. equipment, components, systems, processes) function. This follows a more positivist epistemology i.e. researchers look for causality, laws, results verified by statistics; and in general take an objective nature on the ontology of phenomena where facts are concrete (Easterby-Smith et al., 2002: 33), researchers are excluded from phenomena and quantitative analysis is prevalent in methodologies.

The author though sees ‘collaborating in engineering design’ as a social process based on the interaction of individuals developing shared understanding to achieve group outcomes that without their joint efforts would otherwise not be possible (see 1.4 p5 and Definitions p. xii). As the author focuses on human interaction in engineering design, the unpredictability of human behaviour (Benton & Craib, 2001: 28) become more prominent in the phenomena and choice of suitable research approaches moves away from traditional engineering ones (positivist, objective nature, quantitative data).

The author believes that adhering to an interpretivist epistemology, taking a subjective nature on ontology and qualitative analysis in methodology is appropriate to understand this process of collaborating and address the Research Question. In contrast to positivism, researchers following an interpretivist epistemology seek understanding, explanations of social phenomena, and findings supported by theoretical abstraction. Researchers are likely to take a subjective ontology where facts are human creations (Easterby-Smith et al., 2002: 33).
33), an individuals’ reality is sensitive to language and is produced as they interact, negotiate and make sense of their experience (Hatch & Cunliffe, 2006).

In particular an interpretivist epistemology is used to investigate social constructions and meaning that individuals place on their environment (Benton & Craib, 2001; Easterby-Smith et al., 2002) i.e. what collaborating means to individuals in engineering design. The strengths of an interpretive perspective are numerous (Burrell & Morgan, 1979; Denzin & Lincoln, 2003; Easterby-Smith et al., 2002; Lincoln & Guba, 2003), specifically interpretive approaches are particularly suitable to address this Research Question as they can be used to capture process changes over time, what events mean to an individual, and are adaptable as new issues emerge. Suitable methodology and methods to achieve this are presented next.

### 4.2.2 Methodology and methods

The researcher’s position on epistemology and ontology influences suitable choices of methodology and method. Easterby-Smith et al (2002: 34) record implications (Table 2) comparing positivism and social constructionism as examples of objectivist and subjectivist approaches (respectively). The term ‘social construction’ has come to denote different interpretations of the world (Benton & Craib, 2001: 85) and this epistemology is considered as one of a number under the broad classification of interpretivism (see also Figure 13).

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<th>Elements of Methods</th>
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</tbody>
</table>

Table 2 – Methodological implications of different epistemologies [adapted from Easterby-Smith et al (2002: 34)]

A positivist epistemology, i.e. traditional engineering, implies selecting quantitative methods and collecting data through experiments and surveys to test, measure and verify results to show causality. In contrast an interpretivist epistemology tends to selecting qualitative methods and collecting data through interviews and participant observation to capture, record and make sense of findings to show understanding of phenomena in the social world (Van Maanen, 1979b). There are hence two distinct types of methods to
collect data – qualitative and quantitative. Qualitative methods are used in this research to provide an in depth understanding of context, actions and emotional experiences of individuals fitting with the interpretivist epistemology and subjective ontology. Challenges in taking an interpretivist epistemology are specifically that data collection can be exhausting (time and resources) and analysis and interpretation can be difficult. How these challenges are overcome and the process of analysis and interpretation are detailed in section 4.4.

Data collection techniques in qualitative research are dominated by interviews and observation (Easterby-Smith et al., 2002: 85) with many researchers [e.g. Easterby-Smith & Malina (1999); Eisenhardt & Tabrizi (1995); Mintzberg (1979); Pettigrew (1979); Van Maanen (1979a)] using formal archival documentation to add to their understanding of phenomena. These three methods were used to capture an individual’s perspective and build a picture of an entire collaborating project:

1. Semi-structured interviews with individuals were held to gain individual insight into inter-personal relationships. These encourage individuals to express their opinions and feelings freely about collaborating in engineering design. Subsequently individual interviews were combined to develop a holistic representation of the Unit of Analysis (a project) and look for patterns and underlying causes to events over time. To consider time and process, interviews questions covered past and present events, and future intentions, expectations and predictions (Knight & Pye, 2007). Questions started on task based events to allow a relationship to develop between researcher and interviewee before addressing topics related to social interactions (Knight & Pye, 2007).

2. Project meetings were observed to record interactions and group dynamics. This allows the author to use the “culture of the setting (the socially acquired and shared knowledge available to participants or members of the setting) to account for the observed patterns of human activity” (Van Maanen, 1979a: 539). Observing individuals’ interaction complements interviews allowing the author to capture each individual’s responses in a group and is an established approach to studying a time sequence of inter-personal events (Whyte, 1955: 358). Bales’ interaction process analysis (Bales, 1950) was used to organise interactions (recoding task and socio-emotional aspects) and then summarised into short documents per meeting for analysis.
3. Copies of formal records of the project process were obtained where available. It is important to be aware, as Pettigrew (1990: 277) notes, that formal records are susceptible to “selective deposit and survival” hence they need to be considered as another perspective of events.

The researcher focused on using interviews (method 1) with observations and documentation (methods 2&3) for supporting evidence. This follows an iterative process of triangulation – using multiple methods to develop findings inductively (Denzin, 1978; Jick, 1979; Pettigrew, 1990). In using triangulation the validity of research is checked by considering the Research Question from a number of directions and employing redundancy in data collection (Denzin, 1978). For example, observation and documentation provide a method to cross-check, contextualise and contrast against individual interpretations (method 1) (Dawson, 1997). In particular a temporal dimension was used to study the influence of pair-wise relations and observe if and how they change. How longitudinal research design was achieved is described next.

4.3 Research design: longitudinal cross-case comparison

A comparative longitudinal case study strategy is used in this research to address the Research Question. Individual members are studied to develop a representation of pair-wise relations and consequently construct a holistic picture of a project. This involves understanding context and emotional experiences of individuals and group. In four sections the author covers why case studies are used (4.3.1), what a case study is – including case selection (4.3.2), how data were collected (4.3.3) and organised (4.3.4).

4.3.1 Case method

There are a number of research methods that are suitable from an interpretivist, subjective, qualitative position e.g. narrative methods, action research, cooperative enquiry, ethnography, grounded research and case method (Easterby-Smith et al., 2002: 57). A case method is used as it is popular in process and processual literature, there is flexibility in research design and data collection, detailed examination is possible and case studies aid theory building (Eisenhardt, 1989; Gummesson, 2000).

In this research a comparative case analysis is used to look at “how and why variability in context may influence the pace, timing, and direction of change processes” (Pettigrew, 1987: 667) through uncovering “systematic relationships” (Wolcott, 1994: 183). Longitudinal case studies are used to capture the complexity of social processes in project teams over time and to recognise that social reality is dynamic (Pettigrew, 1997).
Combining processual analysis with a comparative method uncovers further patterns in process to isolate key mechanisms and underlying causes that may be generalisable to other organisational systems (Ferlie & McNulty, 1997).

The quantity of case studies depends on research aims and approach. On one side, Stake (2006: 22) suggests anywhere between 4-15 cases is suitable for comparison – anything smaller can struggle to provide enough interaction between cases and their situations and anything greater may have more uniqueness of interaction than researchers can acknowledge. In contrast, Wolcott (1994: 180-185) advocates a single case approach to focus on depth in understanding the phenomena in question and to compare when it is not possible to get to “the heart of the matter”. Suitability of approach (few vs. many cases) depends on what a researcher is studying and what s/he is trying to achieve. In processual research the number of cases tends to be low. This is to allow researchers to focus beyond the surface of data to uncover patterns that cross a number of levels of analysis and are able to draw a realistic interpretation of a complex reality (Pettigrew, 1990) looking for correlations between cases (Ragin & Becker, 1992: 5). Subsequently the number of case studies is kept low, five including a Pilot Study, to achieve a rich and complex description and understanding.

The Pilot Study was a valuable opportunity to explore proposed objectives, the Research Question and the choice of methods and methodology. The Pilot Study highlighted topics that resurfaced in the four case studies, e.g. patterns of interaction and task dependency, familiarity of tasks, individuals and sharing perspectives, and setting standards for methods and working practices. Initial findings described an array of general group phenomena. The theme of identity highlighted a temporal dimension to participants’ individual and group perspectives about collaborating. In particular temporal variations were observed in how pair-wise relations first reinforce task-based group processes yet individuals develop pair-wise relations due to task dependency. Furthermore it was clear that both pair-wise relations and group relations changed independently as events occurred (e.g. milestones were passed) yet could be used for similar tasks e.g. transferring information. The Pilot Study was hence useful to develop skills in linking ideas and concerns outlined by participants to current concepts and theory and develop fresh ideas through memo writing.

Analysis confirmed that the conceptual framework (see section 4.3.4) was suitable to capture a broad range of data about the research phenomena. The three methods chosen for data collection were recognised as being complementary and upon reflection the researcher decided to focus on interviews with observations and documentation supporting or
contrasting interview data. Furthermore a more simplified method to coding was developed to facilitate analysis across relevant themes.

In conclusion the Pilot Study was useful to develop the researcher’s skills in data collection and analysis, evaluate the selected conceptual framework and research design, and use initial empirical findings as sensitizing concepts (Blumer, 1954) in further data collection.

4.3.2 Identifying cases

Boundaries are established to first define what a case is and to ensure that research is practical and feasible before describing how investigated cases were selected. A case was defined by three criteria: unit of analysis, product design, and size. The unit of analysis (Miles & Huberman, 1994: 25) is a project restricting research to events occurring in a project team. Specifically projects involving interdisciplinary product design were investigated to acknowledge that individuals from different disciplines are increasingly bridging gaps across knowledge domains occurring within (intra) and between (inter) organisations (Günther et al., 1996). The final criteria is the size of a project – this was limited to projects involving up to five disciplines and between 10 to 25 participants. The minimum number of participants ensures dynamic group processes as studying pair-wise relations may result in static processes if there is significant power imbalance; the maximum number of participants limits the level complexity in each case.

Secondly, selection of cases is critical if comparison is desired and a researcher needs to consider the type and quantity of cases. Using a case study approach Yin (2003b: 53-54) notes three options to case selection:

i. To fill theoretical categories to extend emerging theory.
ii. To replicate previous case(s) to test emerging theory.
iii. To contrast with a polar opposite case to extend emerging theory.

The aim of this research is to extend theory (i.) and create a replication strategy (ii.) by selecting appropriate cases and considering the same phenomena in each. Selection was facilitated by each potential case being categorised on two aspects:

**Design type.** New or established principles / solutions may be used in designing a product. In this research cases are classified using Pahl & Beitz’ (1984) distinction between original and adaptive design to note that familiarity of design development procedures may influence how a design team collaborates. A modification on an existing design using a known solution principle to create a new model is classified
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as adaptive design; in contrast original design is one based on new solution principles unrelated to previous products or designs.

**Design setting.** Increasingly individuals are designing across organisational boundaries. This aspect is used to acknowledge that there is potentially an added layer of complexity in designing between organisations (inter) than within an organisation (intra). A typical intra-organisational project is one where the product is designed in one organisation and may involve external suppliers producing components. An inter-organisational project brings together organisations with different design expertise to design a product together.

The purpose of these two aspects is first to address calls to look at varying levels of innovativeness in design projects (Malhotra et al., 2001); secondly to recognise the diversity of potential engineering design projects; and thirdly to classify them to establish how cases may be analysed together. From a list of potential cases four were selected. The choice of four was to add confidence to research findings through similarity and contrasting cases (Eisenhardt, 1989; Miles & Huberman, 1994: 254). Similarity is considered through a consistent methodology and by selecting more than one case in each design setting and design type. Contrast is achieved through comparing cases across the two aspects (i.e. inter vs. intra and adaptive vs. original), and noting that each case has different design aims. Cases selected are illustrated in Figure 14 with corresponding case names and case background [size of organisation(s) involved, product area and engineering sector].

![Cases categorised on design type and setting including background information.](image)

These cases are not uniquely adaptive or original design types. Instead they exist on a spectrum of originality i.e. Medical (novel product: new technology, new problem & solution) is more ‘original’ than Engine (new product: new design methods, new dimensions, existing solution), which is more original than Wing (existing product, new arrangement of components / materials, same dimensions, new analysis technique, existing
solution) and Probe (next generation of product, new arrangement of components / materials / dimensions, existing technology, existing solution). Hence, comparisons can be made between cases based on their design type originality. After identifying suitable cases, data collection started and methods used to achieve this are outlined in the next section.

4.3.3 Collecting data

Longitudinal data collection took place over the last scheduled 6 months of a projects duration and involved two sets of interviews: one set 6 months before the expected end date and one nearing the end of the project (illustrated in Figure 15).

![Data collection timeframe (interaction of design and group development processes)](image)

Figure 15 – Data collection timeframe (interaction of design and group development processes)

In both sets of interviews a similar approach was taken to encourage participants to talk about topics relevant to understanding collaborating in engineering design. Questions were framed openly to allow interviewees to give meaning to project experiences rather than impose other perspectives (Rubin & Rubin, 2005: 36) and capture data on past, present, and anticipated future events (Knight & Pye, 2007). The first set of interviews was used to build a retrospective representation of the project (processes and outcomes) from individual perspectives. First the interviewer outlined their background and purpose of the interview. This led to talking about each project covering timescales and history, and then about individual roles including experience, aims, and approaches for working with other participants. This finished with investigating the future of their role and project covering individual perspectives on progress, potential challenges, satisfaction and how roles/tasks/individuals may influence each other.

In the second interview the evolution of a project was investigated (processes and outcomes) to study changes in, and influences of social relationships. In this interview, there was a brief summary of where the last interview concluded and a reminder of the interview purpose. This allowed an interviewee to provide an update on the project and their role. This interview covered the same themes (project, individual and time) and
probed for how things had progressed, how expectations had turned out, what (if anything) had changed and how participants coped.

In both interviews questions related to subjects in individual and group productivity (e.g. team composition, see section 3.1), group development (e.g. roles, see section 3.2), shared understanding (e.g. approaches to group work, see section 3.3), and collaborating (e.g. different aims, see section 3.4). In particular, the researcher pursued topics relating to the conceptual framework or Research Question without explicitly suggesting them. Topics were used as orientation to explore and describe parameters and dynamics of the social setting (Miles & Huberman, 1994: 35) drawing out nuance, detail and depth through a series of main questions, follow-up questions and probes (Rubin & Rubin, 2005: 129-37). This was done by leading individuals through their experience of working on the project and with other participants. When individuals talked about issues relating to conceptual themes or Research Question e.g. recognising what individual behaviour meant (learning, identity, trust), the researcher then pursued these topics through follow up questions and probes to gain a deeper understanding of individual experiences. Templates of both interview instruments are included in the Appendix (p227). They were not followed prescriptively but were used as a guide to remind and prompt the interviewer to cover topics relevant to understanding the process of collaborating in engineering design.

Data collection of formal project documentation and observations of meetings started prior to the first series of interviews and continued until after the second set of interviews. Data collection for all four cases took 10 months starting in September 2007 and ending mid 2008 (illustrated in Figure 16).

![Figure 16 – Case data collection](image)

Introduction to Probe started through a series of meetings with a metrology organisation (MetOrg). Then two sets of interviews were carried out with a representative sample of project members (7 in total) suggested by the researcher and agreed by project coordinator.
This reflected the variety of expertise involved in both technical and management roles from different departments. A 1st round of interviews was completed on the 18th and 23rd January 2008 with a second and final set on 19th and 20th March 2008. Between the two sets of interviews there were weekly scheduled meetings for this project of which four meetings were attended (11th, 18th January, 22nd February, and 14th March 2008).

Introduction to Engine began on October 17th 2007 by attending a weekly design meeting at an aerospace organisation (AeroOrg). Subsequently design meetings were attended on 31st October, 21st November, 5th December 2007 and 16th January 2008. Additionally a project management meeting was attended on 5th December 2007. Two sets of interviews were carried out with a representative sample of project members (7 in total) suggested by the head designer. This reflected the variety of expertise involved in both technical and management roles from different departments. A 1st round of interviews were completed on 25th and 31st October 2007 with a second and final set on 31st January and 5th February 2008.

Introduction to Wing started after authorisation from a second aerospace organisation (Aero2Org). This project involved three organisations: Aerospace Organisation (Aero2Org), Research Organisation (ResOrg) and Design Organisation (DesOrg). Subsequently two sets of interviews were carried out with a representative sample of project members (5 in total) suggested by the project manager. This reflected the variety of expertise involved in both technical and management roles from different departments and organisations. A 1st round of interviews were completed on 26th, 28th November and 6th December 2007 with a second and final set on 29th, 30th April, 6th and 14th May 2008. Between these two sets of interviews there were no planned project meetings. This was unexpected and due to delays in progress of this project. To gain an appreciation of what was happening and how participants were interacting during this period, emails from this project were reviewed to complement regular updates via phone with the project manager. Post completing the interviews one meeting (15th May 2008) and a day of prototype testing (3rd July 2008) was attended to view group interaction.

Introduction to Medical began through contacting representatives from five organisations: new spinout organisation (NewSpinOrg), scientific research organisation (SciResOrg), a industrial design organisation (IndDesOrg), product design organisation (ProdDesOrg) and a marketing and distribution organisation (MarketOrg). NewSpinOrg remained connected to a host organisation (HostOrg) through funding and senior board
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members. Subsequently two sets of interviews were carried out with a representative sample of project members (5 in total) suggested by the marketing manager in NewSpinOrg. This reflected the variety of expertise involved in both technical and management roles from different departments and organisations. A 1st round of interviews was completed on 5th, 8th and 23rd October 2007 with a second and final set on 17th, 18th and 23rd April 2008. Between the two sets of interviews there were few scheduled meetings for this project with only one meeting being attended. This was due to unexpected delays in project progress, a prevalence of ad hoc meetings between small sub sets of participants and difficulties arising from participants’ diverse geographical locations. To gain an appreciation of what was happening and how participants were interacting during this period, meeting notes were reviewed in conjunction with regular updates via telephone with NewSpinOrg.

Multiple points of data collection are desirable when addressing temporal research questions (Van de Ven, 1992) and it was prudent to find out about opportunities in advance to capture data (Yin, 2003a). The researcher looked for opportunities for informal interaction with project members to enhance understanding in each case. It was not considered as a further interview and it was important to record the context (location, attendees, intentions etc) of informal situations to assess received information. This information was recorded in a short description providing further data in a similar format to transcribed interviews to organise for subsequent case analysis and interpretation. Memos (i.e. documents) were also kept for each case to record research, theoretical and methodological insights that occurred whilst collecting, organising and analysing data.

4.3.4 Organising data – a conceptual framework

A conceptual framework is used as an analytical tool to organise data under topics, ideas, concepts or themes that are relevant to understanding the phenomena and Research Question. Subsequent to literature presented in chapters 2 and 3 a suitable framework was adopted from Huxham and Vangen’s (2005) research on collaboration practice. Their collection of 18 themes relevant to collaboration practice is the result of 15 years collecting data in twelve projects to systematically study collaboration activity in areas ranging from social welfare, to pharmaceuticals and engineering (Huxham & Vangen, 2005). This lasting experience of collaborations is used to build a conceptual framework.

In this research all 18 interdependent analytical themes from their research are used in a conceptual framework (see Figure 17) acknowledging that this is not a finalised list, but is Huxham and Vangen’s current thinking. This conceptual framework acts as a template of
themes to make sense of collaborating in engineering design forming the basis to design interview structures and for initial coding (see 4.4.2 for further information) and then refined to recognise relevant themes from empirical data.

This framework is suitable for this research as it is relevant, flexible and holistic. First it is relevant as it is established from observations of collaborating and it provides pertinent themes that can act as a point of departure in making sense of events. This framework is flexible as it doesn’t impose causality or relationships between themes allowing data to induce findings; it allows further categories to be added if events or findings evoke them; it can include data from different points in time; it can show both affective and task aspects of a group. This framework is holistic in two ways – it brings together multiple topics currently being considered individually in engineering design [e.g. communication (Eckert et al., 2005), compromise (Minneman & Harrison, 1998), leadership etc.] and it can include a number of levels of analysis (e.g. individual, group and context).

![Diagram of analytic themes in collaboration practice](image)

**Figure 17 – Analytic themes in collaboration practice [adapted from Figure 1.1 and Figure 3.1 (Huxham & Vangen, 2005: 12, 38)]**

Analysis and interpretations started as data were collected and organised. This process is outlined in the next section on research analysis (4.4), before describing research validity including ethics (4.5) and a summary in section 4.6.

### 4.4 Research analysis and interpretation

Analysis started when data collection started and involved building on initial interpretations to develop a clear understanding of phenomena. Taking a processual analysis approach the researcher started by investigating events and chronologies to tell a history of events searching for patterns (process analysis) and added a second analytical capability by giving meaning to underlying causes that shape observed patterns (Pettigrew, 1997). Carrying out processual analysis aims to recognise calls to focus on real-time
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change processes to understand how organisations can transform themselves into more effective cooperation partners (Hillebrand & Biemans, 2004).

Data analysis consisted of three overlapping and progressive stages: 1. Developing individual case summaries; 2. Coding and clustering data; 3. Discussing and developing conclusions (see Figure 18). The methodology for each stage is described next in sections 4.4.1, 4.4.2 and 4.4.3 (respectively) with output from data analysis presented in chapters 5, 6, and 7 (respectively).

![Figure 18 – Three stages of analysis](image)

### 4.4.1 Developing individual case summaries

In the first stage of analysis, data in each case was organised to create a project history from all collected data (i.e. interviews, informal conversations, observations and documentation). From this data a chronological description (Yin, 2003b: 119) for each case was constructed describing who was involved, how it started, and what happened. The aim was to record the sequence of events in each case to then investigate underlying significance and meaning of events (Pettigrew, 1990). These descriptions were verified by a contact in each case to ensure that the reproduction of events was accurate and are presented in chapter 5.

### 4.4.2 Coding and clustering data

In the second stage of analysis qualitative data was tagged to themes in the conceptual framework (Figure 17) using codes. The conceptual framework acts as a flexible analytic template to organise data and then coding can be developed inductively to bring out
relevant concepts in case data (Berg, 2004: 266; Miles & Huberman, 1994: 65). The process of coding condenses information in the data to allow systematic analysis of each case and across cases (Miles & Huberman, 1994: 56). Coding developed from the first case to the last and definitions of themes are included in Definitions (p. xii). It is important that codes are unambiguous and close to terms they describe (Miles & Huberman, 1994: 65) thus codes were reviewed and updated during analysis and reflected upon when reporting findings.

When coding, both manifest and latent levels (Berg, 2004: 269) of data are recorded in each case. The manifest level relates to meanings described explicitly by the text. Coding at the latent level develops an understanding of deeper meanings inferred from messages in the text and different data sources (e.g. interview and observation). This started with individual cases and then data from each case was combined for cross-case analysis to develop findings. In cross-case analysis each case was systematically compared through coded data to begin to understand emerging themes and with increasing abstraction build a picture of topics and findings applicable to collaborating design projects.

There were three phases in the second stage coding and clustering analysis (shown in Figure 19). All collected data (interview transcripts, informal conversations, observations, memos, documentation) were reviewed and organised into codes that described aspects of the text using NVivo data analysis software (2008). This involved highlighting paragraphs of text and tagging them to themes in the conceptual framework, research question constructs or new conceptual categories. An example of this process is shown in Table 3.

![Figure 19 – Three phases of stage two cross-case analysis](image)

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Table 3 – Processing data: an example of how interview transcripts were coded

<table>
<thead>
<tr>
<th>Transcript extract</th>
<th>Specific data</th>
<th>Codes: theme(s) &amp; conceptual categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I think it is good to build up a bit of a rapport. And like having the face to</td>
<td>“I think it is good to build up a bit of a rapport”</td>
<td>Pair-wise relations, learning, social capital</td>
</tr>
<tr>
<td>face meetings over lunch you do discuss work but you also discuss what people did</td>
<td></td>
<td></td>
</tr>
<tr>
<td>at the weekend and if you know people went away diving it is just nice to say did</td>
<td></td>
<td></td>
</tr>
<tr>
<td>you have a good trip, just to have that bit of sort of informal relationship, yeah</td>
<td></td>
<td></td>
</tr>
<tr>
<td>you are both there for a reason to do the work, but that doesn’t mean that you are</td>
<td>“And like having the face to face meetings over lunch you do discuss work, but</td>
<td>Pair-wise relations: task understanding, opportunity, communication &amp; language,</td>
</tr>
<tr>
<td>heartless and don’t talk about anything else and you get to know, get to know</td>
<td>you also discuss what people did at the weekend”</td>
<td>working practices</td>
</tr>
<tr>
<td>what makes that person tick. Because f you learn something about their past time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>and f you can build up a familiarity or something that you both enjoy certain</td>
<td>“but you also discuss what people did at the weekend and if you know people</td>
<td>Pair-wise relations: team understanding, identity, learning</td>
</tr>
<tr>
<td>thing, I think you are more likely to work better, if you can have a kind of</td>
<td>went away diving it is just nice to say did you have a good trip, just to</td>
<td></td>
</tr>
<tr>
<td>common ground about things”</td>
<td>have that bit of sort of informal relationship”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“that doesn’t mean that you are heartless and don’t talk about anything else</td>
<td>Pair-wise relations: team understanding, identity, learning</td>
</tr>
<tr>
<td></td>
<td>and you get to know, get to know what makes that person tick”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“Because f you learn something about their past time and f you can build up</td>
<td>Pair-wise relations: team understanding, commitment &amp; determination, culture,</td>
</tr>
<tr>
<td></td>
<td>a familiarity or something that you both enjoy certain thing, I think you are</td>
<td>identity, learning, social capital</td>
</tr>
<tr>
<td></td>
<td>more likely to work better, if you can have a kind of common ground about</td>
<td></td>
</tr>
<tr>
<td></td>
<td>things”</td>
<td></td>
</tr>
</tbody>
</table>

Analysis of coding started in each case after the first set of interviews were transcribed\(^1\). In Phase 1, initial coding analysis focused on searching for patterns using the conceptual framework (Figure 17). This involved producing coding summary reports of all data (interviews, informal conversations, observations, documentation) for each theme to identify issues, patterns of events and influences on collaborating in each case. Ideas and initial insights resulting from this were compiled in a separate table for each case including information from research memos (see 4.3.3). This was repeated as soon as data collection was complete in each case. Subsequently individual case summaries were developed (see 4.4.1) and coding analysis was used to reveal prominent and background themes from the conceptual framework (see Figure 17) in each case. Prominent and background themes were then contrasted across the four cases to search for patterns and relationships relevant to engineering design projects (findings in section 6.1).

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\(^1\) Full interview transcripts are not included in this thesis to ensure that data provided by project participants is treated with strict confidentiality and anonymity.
In parallel in Phase 1, analysis of coding in each case was carried out using all 18 themes of the conceptual framework focusing on process and outcomes. This was achieved by first producing one coding summary report of all the themes for each case including all sources (interview, informal conversations, observations, documentation). Data in this report was limited by filtering to only include data that was also tagged to an ‘outcomes’ code. An outcomes was defined as observable consequences of process covering project events (e.g. a finished product), interim events (e.g. revisions to designs) and participants’ affective reactions (e.g. establishing commitment to other participants). It has a broad definition to capture all potential events. Each piece of data in this document was analysed and data relevant to the Research Question reduced into short summaries, or ideas, and clustered into similar topics within each theme noting potential links to other themes. This refined document for each case was then combined into one table with data from each case colour coded to aid cross-case analysis. This provided a cross-case table to compare, contrast and develop insights and findings from data representing 18 themes and four cases.

The second phase involved two different approaches to analyse cross-case insights:

i. To uncover patterns in data relating to the RQ using insights from the ten prominent themes in the conceptual framework and cross-case insights on process and outcomes.

ii. To uncover patterns in data by re-coding cross-case insights on process and outcomes to each construct of the RQ (i.e. pair-wise relations, group relations, outcomes).

The aim of both approaches was to develop findings inductively through clustering insights to explain patterns across cases and address the RQ. This involved recognising new and separate patterns that emerged from working between data, research memos, insights, Research Question and conceptual framework. Themes from the conceptual framework were used as sensitizing concepts – a set of general concepts that provide ideas to look at whilst acting as a starting point for a researcher to develop, rather than limit, ideas and analysis (Blumer, 1954). At the end of Phase 2 the second approach was more successful in developing clearer patterns to provide findings to answer the Research Question.

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2 The first approach was stopped before phase three in this analysis (moving between selected themes from the conceptual framework, data and ideas); however the researcher gained valuable insights across a range of themes that informed development of new conceptual categories under the second approach (depicted by vertical dashed arrows from i. to ii. in Figure 19).
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In the third phase of stage two analysis, clustered insights from Phase 2 were used to develop four new feature categories (Opportunity, Dependence, Results and Adjustments) relating to the individual constructs of the Research Question i.e. pair-wise relations, group relations, and outcomes. Secondly, clustered insights were developed about how Research Question constructs influenced each other, also producing three new mechanism categories (Familiarising, Associating, Regulating). Opportunity, Dependence, Results and Adjustments categories are introduced in section 6.1 and are used to organise findings in sections 6.2 to 6.5 with Familiarising, Associating, and Regulating structuring findings in section 6.6. Following Miles and Huberman (1994: 172-206) cross-case tables are used to display differences and similarities between cases in these categories (see chapter 6).

Three of the seven new conceptual categories are mechanisms (Familiarising, Associating, Regulating). A mechanism describes the act something does to something else, or simply they describe what makes things happen (Huxham & Vangen, 2004). There are various citations of mechanisms that denote them as something that can create, maintain (Pettigrew, 1990), change, lead to (Knight & Pye, 2007; Pettigrew, 1990), transform (Pettigrew, 1990), drive (Langley, 1999; Pettigrew, 1990) or propel something from one stage to the next (Abbott, 1990). Mechanisms are hence particularly suited to describe findings in processual research.

4.4.3 Discussing and developing conclusions

In the third and final stage of data analysis, findings from cross-case comparison were related to current theories and literature on collaborating (see chapters 2 & 3).

In interpretive approaches there is a focus on investigation and exploration of cultural meanings (Coffey & Atkinson, 1996: 144-145) through a process of abduction. This involves moving from specific phenomena i.e. cross-case findings about the RQ in engineering design, to broader categories e.g. collaboration, inter-organisational relationships etc. Abduction started by considering findings and going beyond data to understand a particular finding, e.g. an unexpected one (Coffey & Atkinson, 1996: 156), in the studied phenomena. Starting with a particular finding, the researcher expanded it to a set of wider ideas or concepts. Then findings are presented that are specific to the evidence and issues at hand to answer the research question working through the relation of ideas to evidence (Ragin & Becker, 1992: 6). Using this evidence the author linked different research strands into a more holistic picture to develop conclusions. This followed an iterative loop between theory, patterns, themes and observations from this study. In
presenting findings the author also notes where themes from the conceptual framework (see 4.3.4) appear and how findings contribute to research in that theme.

To evaluate and develop findings a number of aspects were investigated. Representativeness was checked by considering sampling choices. Effects on the data due to the researcher were understood by comparing data with and without the researchers presence (e.g. comparing outcomes of attended meetings to those when absent); contradicting evidence in the data is sought; data is investigated for outliers to understand their meaning; and alternative conclusions from them were evaluated (Miles & Huberman, 1994: 263-276).

In the final part of the third stage of data analysis, the Research Question was addressed with the author’s interpretation using description to explain patterns and findings in cross-case analysis. This is specific to engineering design and outlines some of the challenges to collaborating in engineering design projects.

The contribution of research findings is presented to two audiences: academic and practitioner. Firstly the academic contribution is a descriptive understanding of collaborating in engineering design (chapters 5, 6 & 7). This includes an empirically developed conceptual framework (sections 7.1.1-7.1.4) and a descriptive response to the Research Question (section 7.1.5). Furthermore, direction is given on suitable themes to develop existing research on collaborating in engineering design. Secondly implications for practice are described (chapter 8) providing suggestions to improve participants’ understanding of topics relevant to collaborating in engineering design. Implications are aimed at individuals who hope to improve the success of future design projects by understanding events, patterns and outcomes of previous projects.

**4.5 Reliability, validity and ethics of research**

High quality process research has high levels of reliability and validity (Ferlie & McNulty, 1997) and the concepts of each are used to substantiate the quality of knowledge produced in this research.

Reliability refers to rigour in choice of theoretical, methodological and empirical bases in research design, to establish that it is consistent and reliable over time (Miles & Huberman, 1994: 278) and there is there transparency in how sense was made (Easterby-Smith et al., 2002: 53). The author has outlined the choice of research approach, design and analysis through selection of compatible epistemology, ontology, methodology and methods (sections 4.2- 4.4). This informs the reader of how the research phenomena (and
knowledge produced) is viewed, captured and analysed and illustrates a number of methods and explicitness which is key for reliability and validity (Hinings, 1997).

There are two types of validity—internal and external. Internal validity is gained if the produced knowledge makes sense, is credible to others (Miles & Huberman, 1994: 278), or the experiences of those studied have been clearly accessed (Easterby-Smith et al., 2002: 53). This can be achieved by involving participants in reviewing research output (Knight & Pye, 2007) via workshops, seminars or feedback. In this research internal validity has been gained by providing a presentation post data collection in one case study (Engine) and gaining feedback from each case regarding case descriptions (see 4.4.1).

In external validity the researcher considers if findings or concepts are relevant beyond the research setting (Easterby-Smith et al., 2002: 53; Miles & Huberman, 1994: 279). External validity is provided by the third stage of data analysis – discussing and developing conclusions (see 4.4.3). This provides analysis to demonstrate where and how knowledge produced from this research compares to the existing understanding of the phenomena (collaborating) beyond engineering design projects.

Ethics are considered by reflecting upon three interlinked aspects: researcher, participants and research phenomena. In taking an ethical approach, the researcher aimed to gain confidence and openness from participants to understand the research phenomena in parallel to responsibly limiting detrimental effects on participants whilst being able to observe phenomena (Easterby-Smith et al., 2002: 75-77; Miles & Huberman, 1994: 288-297). It was thus important to advocate privacy and anonymity by ensuring that observations and interactions with participants were impartial, in confidence, and that information received was not passed on to third parties (Easterby-Smith et al., 2002: 77; Miles & Huberman, 1994: 293). Agreements to publishing rights and use and implementation of research were established through a interactive process with those involved where necessary. The researcher also outlined to participants the purpose of the study (research phenomena) and what was expected from participants (in terms of time) for all to be aware of what was involved in the study (Miles & Huberman, 1994: 291-2). Furthermore a clear description about the implications of findings for participants is provided (see chapter 8) to give guidance on how the researcher expects participants to use, rather than misuse, findings (Miles & Huberman, 1994: 295).

Lastly the researcher was independent from the process and outcome of each project but in observing and interviewing was not independent to each case study. To recognise this the researcher was honest yet vague with participants about his involvement in the research
phenomena to not invalidate the study (Easterby-Smith et al., 2002: 76) and limit the influence of the relationship between researcher and participant on the research phenomena (Miles & Huberman, 1994: 292).

4.6 Methodology summary

In this chapter, five sections are presented to outline how the topic of ‘collaborating in engineering design’ was investigated. First in 4.1 objectives were set out including a Research Question focussing on pair-wise relations, group relations and outcomes in engineering design teams. Next the researcher explained in section 4.2 how the phenomena in question is viewed. This included an interpretive epistemology to capture constructions and meaning that individuals place on their environment; assumptions based in a subjective ontology and a qualitative methodology comprising of interviews, observation and documentation methods for data collection.

The author has argued in research design (4.3) the suitability of using a comparative longitudinal case study and a processual approach to capture how social processes in design teams change over time and how changes in context influence these processes. Four case studies (Probe, Engine, Wing and Medical) are introduced and classified on design type and design setting. A conceptual framework is also identified via the literature review to organise collected data.

The process for analysing and interpreting collected data is set out in three stages (4.4) involving individual case summaries, coding and clustering of data and relating research findings to existing literature and practice through discussion. In the final section (4.5) the reliability and validity of knowledge produced in this research is presented before describing how ethics have been considered in carrying out and completing this research.
5 Four case studies of collaborating in engineering design

In this chapter descriptions of four individual cases are presented: Probe (5.1), Engine (5.2), Wing (5.3) and Medical (5.4). Each case is described covering what happens as designing advances and culminates in prototype testing (see Figure 2 for typical design process). These descriptions are the first stage of analysis – developing summaries of each individual case (see section 4.4.1). This stage of analysis involves organising data in each case over the project history. A chronological description for each case is constructed describing how it started, when it occurred, who was involved and what happened. This is to record sequences of events in changing relationships and to start to investigate underlying significance and meaning of events (Pettigrew, 1990). Descriptions were verified by a contact in each case to ensure that the account of events was accurate.

Finally a summary (5.5) concludes this chapter highlighting the main points from each individual case descriptions including themes that will be explored in chapter 6 on cross-case analysis.

5.1 Probe

Probe is the first of four cases studies and was categorised as an adaptive design type in an intra organisational setting for this research (see Figure 14 p60 section 4.3.2 for case selection). The aim of Probe was to design and manufacture a measurement probe for machine tool setup based on strain gauge technology – a machine probe (Probe).

5.1.1 Who was involved in Probe

The Probe design project took place in a Metrology Organisation (MetOrg). Core membership of this project team was co-located in one department, DGroup IV, within MTool Division. This covered product design, project coordination, testing, and marketing roles (see Figure 20). Additionally there was input from a number of internal departments providing purchasing, production setup, software, auxiliary testing and verification services. All departments were located on the same site except software design. There were a number of participants performing new tasks or roles in addition to those with extensive experience of their technical roles. The majority of participants had previously worked together.

In MetOrg Projects were carried out concurrently and resources for this project were made available through the organisation structure. MTool department manager is responsible for the availability of individuals for each project in the department. Machinery or equipment was shared with other departments in MetOrg and access to testing
equipment based on project priority in MetOrg. This is decided at an organisational level above MTool department.

![Diagram of MetOrg and Probe](image)

**Figure 20 – Participant technical roles and organisational structure in Probe**

### 5.1.2 How Probe started

It originally started in 2004 but was stopped during concept design due to changing organisational priorities. In May 2007, competition from other products and demands from users led MetOrg to restart product development. DGroup IV picked up the project from another department within MTool division to develop the original concepts into a product for market.

In Probe a design review process defined in MetOrg was used to outline steps in product development. Milestones and requirements were clearly defined guiding participants from concept design to production with three stages: feasibility, testing (split into 2 stages) and product production. Progression from one stage to the next is dependent on the outcome of reviews. Comparing their standard design review process to a typical concurrent design process (see Figure 3 p12): feasibility broadly covers initial design process (task clarification, conceptual, embodiment and detail) before product testing (prototyping) starts and finally moving to product production. Redesign may be required between product testing and production representing embodiment and detail phases resulting in a cyclic approach to achieving a finished design.

### 5.1.3 What happened in Probe

Probe started in May 2007 and data were collected up to July 2008 with the product subsequently on sale in January 2009. A timeline for Probe is shown in Figure 21.
Product design was split between mechanical, electronic and software technical elements which was typical of projects in MetOrg. Work first started with electronic and software aspects in May with participants fulfilling those roles interacting with the DGroup IV manager to review how to implement the existing design (feasibility phases). Interaction between individuals was daily for those co-located in the same room and weekly for those in different departments or locations. The latter was achieved through a weekly project meeting using video conferencing facilities with those active on the project attending.

2007

Participants progressively started to work on Probe with representatives from Production and Testing in June, Mechanical in August and a new project coordinator was gradually introduced in September. This progressive addition of members was principally due to individuals working on other projects at the same time as department and organisational priorities defined participants’ project work. When the Mechanical participant started on the project the first thing that was made clear to the group was that it was not possible to physically include all components for the probe’s required functionality. The project group then started to review design requirements via weekly project meetings to develop a product that was feasible from each technical perspective.
A change of project coordinator was complete in October and subsequently regular documentation of project meetings was produced and supplied to participants. This information updated each participant on a weekly basis via email on project progress and current concerns. The project coordinator subsequently acted as a link between individuals and the project organising what was happening.

Project participation was constant over September and October in the three design elements (Electronic, Software and Mechanical). Unexpected results (trigger squeeze) from initial testing delayed completing the feasibility phase of design process. To transfer from feasibility to testing, design reviews of each element were required. Electronic and Mechanical reviews were satisfactory to progress but Software review was delayed as Software participation was reduced in November due to another project having a higher priority. Reduced participation by the software participant was magnified as this was the only project that the DGroup IV department and software participant were working on together and they had little opportunity for informal interaction as they were on different sites.

During product testing, changes to existing designs tended to be carried out on each technical element. There was an order of preference relating to which technical element to change first if there was a general design problem: Software was seen as the preferred route to adjust product behaviour, followed by Electronics and finally Mechanical. This relates to cost, i.e. it is often quicker to change and test software design than mechanical component design.

Product testing started in November using a general product test plan developed in October. This testing was the first of a two stage product testing where the purpose is to refine existing designs before product release, first in house (stage 1) and then with select customers (stage 2). Stage 1 also focused on ensuring that a product is acceptable to production representatives. Testing started to achieve a working prototype for demonstration at an international trade fair in March 2008.

To manage a decrease in software participation in November the project continued by focusing product testing on Mechanical and Electronic aspects. A Software test plan was also drafted without review of Software. In this instance, the fact that Software review was not complete before testing was started created an increased risk of further testing if
Software was to change. This started a pattern that continued throughout the project as participants were often unavailable to complete their current work by being moved temporarily onto other projects while Probe design development continues in their absence.

Design participants that were co-located and full time on the project achieved progress: Electronic design reviews raised changes that were resolved in September (removing components), with test results prompting changes in November (component layout) and December (component layout); Mechanical design evolves in December as components are changed to resolve problems (cap) from testing. There were ongoing concerns with component (Centre Guide [CG]) redesign. This unexpected performance was addressed through individual work and complemented by informal group discussion in the department and weekly project meetings.

2008

The general Test plan was continued from December to January. Delays to completing testing became evident when other projects in MetOrg with a higher priority claimed access to machines. Additionally projects within DGroup IV diverted Test individuals to participate on other projects throughout December, January and February limiting their time on Probe. At first this reduced participation seemed a similar situation to when Software design participation was reduced, however testing participants were co-located and this allowed informal conversation and awareness to be passed to and from the Probe project.

The Software participant returned to Probe in January when Software validation became a high priority. A test plan was created and approved by the end of February with new modifications and a new software version issued mid March. Software involvement included co-location to review and update code with supporting participants in the project group.

Considering Electronic and Mechanical design elements, Electronic components required minor modifications in April (reprogram and general standards) and then the electronic designers’ involvement reduced. Mechanical design started to address production requirements involving more interaction between respective individuals (mechanical design and production).
Where unexpected performance of the prototype in Testing was not specific to one Technical element, project meetings became important to discuss possible causes and solutions. There were three general product concerns by January 2008 1. Temperature variation and 2. combinations of application specific integrated circuits (ASIC) 3. A ‘Squeeze’ concern from August.

Two approaches were used to understand general product concerns and were carried out simultaneously. The first was to use expertise outside of the project but within their organisation for advice or experience of similar problems. This was often via interaction between two colleagues, and frequently involved relevant individuals participating in the weekly group meeting. The second approach was to start technical investigations to understand influential factors on the anomalous behaviour.

Participants performed four investigations (three general design – Squeeze, T, ASIC; and one mechanical design – CG) to evaluate factors on current product performance. In the ASIC investigation different materials were reviewed starting in February and concluding in April involving the Electronic designer and Testing participants. A general understanding of the problem was developed but with no conclusive answers. The Squeeze investigation involved monitoring the product performance in the Testing phase. No changes in behaviour were observed so the project group subsequently considered the performance to be within organisational quality standards. The CG investigation involved the mechanical designer and Testing participants considering a number of different materials. Each created the same problem but to different extents. A final comparison was made with a material used in other current MetOrg products which resulted in the best performance.

In mid March a report for stage one Testing by the testing representative detailed progress. Electronic and Mechanical elements were considered to be satisfactory and were not expecting any problems with the new version of Software. There were improvements in product performance though a number of investigations (ASIC combos, T, CG, Squeeze) had not been concluded. The ASIC, Squeeze and CG investigations were considered to be refinements to current product understanding and individually or cumulatively they did not stop testing progressing to stage two. The main impediment to starting stage two Testing was inconclusive findings from the T investigation.
Four case studies of collaborating in engineering design

This delay in completing stage one Testing led to exhibiting only display models at a trade show in March. Despite only using display models the event was successful in raising awareness of the new product and valuable customer feedback was gained.

In the Testing review, Probe project group suggested further direction to the T investigation. This involved changes to Software and an extension to Testing stage one to understand results. MTool the organisational division above DGroup IV approved this approach and Probe extended stage one Testing. The software designer created a modified software code for Testing. Performance results from this extended Testing stage one were now acceptable for this product and the T investigation was concluded. These modifications to Software then led to a new software verification process which started in April.

Further minor changes to Electronics for component performance were achieved, Mechanical elements approved (cap) and a production process (de-panelling) trialled and modified in March before being validated in June.

Successful results from the T investigation led to potential sites for Testing stage two being reviewed via Marketing in early May. Stage 1 concluded with a report detailing the new results and all Testing in stage 2 is started by mid June. At this point project meetings are reduced from once a week to once a fortnight. This is compounded as participants are again moved off Probe onto other projects and regular attendance in meetings is reduced.

5.1.4 Remarks on Probe

In Probe expertise across MetOrg was combined to design and develop a machine probe. The established design process and clearly divided tasks aided participants to carry out their activities understanding what was expected of them and other individuals.

Projects taking longer than originally planned was seen as a normal occurrence in MetOrg. Inconsistent availability of individuals extended the planned completion time. This was not due to poor individual performance, but created a hurdle to perform as a group. Tasks were completed in parallel and participation in the project group often lacked technical representatives as they were moved onto projects with a higher organisational priority or were not co-located. Specifically the process for modifying technical aspects of product design (i.e. software over electronics over mechanics) was hindered when software participation reduced. However individuals in the group sustained the group as participants
were often active and keen to work together. In particular two aspects helped sharing understanding and maintaining participation in the project group: 1. a project coordinator who created links with participants individually and as a group, 2. a technical individual who had expertise to advise and oversee all tasks in DGroup IV department bringing a perspective on all design aspects to the project group.

5.2 Engine

The second case study, Engine, is an original design type in an intra organisational setting in this research (see Figure 14 p60 for case selection). The aims of this project were to design, build and test a small engine prototype (Engine) as a technology demonstrator in a short period of time (approximately 15 months) and at a more affordable cost (man hours and manufacture cost). Case description is separated into four parts: 1. Who was involved in Engine, 2. How Engine started, 3. What happened in Engine, 4. Remarks on Engine.

5.2.1 Who was involved in Engine

Engine was a design project in one Aerospace Organisation (AeroOrg). A team for this project would typically consist of individuals from eight departments representing different technical roles in design process (e.g. conceptual designers, testing, procurement etc). Three of the eight roles were fulfilled by one department (ATech), three departments (Comb, Cont, Fan) contributed participants as required with the remaining two departments (Trans, Turb) only providing a limited supporting role due to departmental project priorities (this arrangement is shown in Figure 22).

In addition to each department having different expertise, few participants had previous experience of this type of project or had previously worked together. Those that had worked together often were from the same department or in different roles. A number of participants performed new tasks or roles in addition to those with extensive experience of their technical roles.

Approximately a quarter of the project team were in the same office space with the remainder co located on the same site. Most participants worked concurrently on a number of projects whilst a minority worked solely on Engine.

The project itself had resources and a project manager, who requested participants from relevant departments to fill roles in the project group. Departments ultimately decided if they could contribute individual(s) to a project and this commitment changed according to departmental and organisational priorities. Access to and use of equipment and testing facilities was shared within AeroOrg and also influenced by organisational priorities, i.e. a
high priority project for a high profile customer would gain access to resources when they are required by the project members.

![Diagram](image)

**Figure 22** – Participant technical roles and organisational structure in Engine

### 5.2.2 How Engine started

This Engine project developed from a general concept study in ATech. ATech was a department in AeroOrg that developed theoretical concept studies. The aim of this initial study was to look at conceptual designs for low cost design and production of a small engine concluding in Spring 2006 with a standard project review. This concept design review created further interest in AeroOrg as potential option to expand their current engine portfolio to meet future customer demands and resulted in a proposal to develop and test a prototype within the same timeframe.

Design development followed a characteristic concurrent design process (see Figure 3 p12) up to prototyping: task clarification, concept design, embodiment, detail design and prototype manufacture. To achieve project aims participants did not have to follow traditional AeroOrg design and development processes. The design review process was retained with four stages: three design review meetings and lastly a solution review meeting. The first design meeting was used to set out what needs to be achieved and where there are links or interfaces with other tasks; the aim of a second design meeting was to monitor what was happening with a third meeting to ensure that there are no omissions in the final design. Lastly, a solution review meeting is required to approve solution release to a manufacturer. This presented a new opportunity for individuals to carry out their design to their own specification but also for AeroOrg to assess which of their design processes are necessary to make a prototype like this. Consequently, Engine did not start with an explicit and prescribed design process which participants were used to in traditional AeroOrg design projects.
5.2.3 What happened in Engine

Engine started in May 2006 and data were collected up to May 2008. A timeline for Engine is shown in Figure 23.

![Engine Timeline](image)

**Figure 23 – Engine timeline**

2006

Concept design started with a basic General Arrangement (GA) from the theoretical study completed by members of ATech. Responsibility for the project was split between a chief engineer, a chief designer, and a project manager (PM). ATech department provided these three roles with finances allowing one individual (PM) to work solely on Engine from January 2007 onwards. It is worth noting that the head of ATech was also the chief engineer on Engine. To work across departments, each department had a representative – a department lead who was active on the project and responsible for the department’s contribution to the project.

Work carried out between August and November 2006 focused on task clarification and concept design phases. There was a gradual development of architecture and component module design as individuals were assigned to Engine from their department. There were a number of technical design roles that were initially not filled as individuals were not available from some departments. To manage this mixed technical contribution, members of ATech department undertook some of these roles with partial support from a host technical department (e.g. Turb) though a number of roles remained unfilled. In addition to ATech taking on roles, Fan department accepted tasks expanding their involvement in Engine. In
particular, this led Fan participants to work early on with Comb participants considering design concepts suitable for both technical departments. Design development was subsequently gradual and described as an informal process culminating in and passing a formal audit review in November 2006.

Weekly design review meetings were organised by the chief designer to review overall design progress and provide an opportunity for participants to be aware what was happening. Participants were encouraged to attend this meeting though sometimes individuals were unable to due to work commitments from other projects. In addition to weekly meetings there was a monthly meeting arranged by the chief engineer. This meeting involved the project manager, chief designer and department leads to review project progress. Department leads were hence involved in a variety of formal meetings but also actively had to manage their designing between departments and the project – they had to be aware of the overall project and tasks by other departments that could influence their designs. To be able to carry out these different demands some department leads established links on an inter-personal level with relevant individuals (i.e. chief designer, project manager, chief engineer and other department leads). It is also worth noting here that designers in ATech department had no department lead to the project as Engine project manager, chief designer and chief engineer were all from this department. This blurred who was responsible for linking between Engine and technical design being carried out in ATech though existing inter-personal relationships in the department supported this ambiguity.

In contrast to a traditional design process in Engine designers were encouraged to directly liaise with an approved list of manufacturers and an AeroOrg procurement manager. This was to seek out suitable manufactures and involve them early on in design process to reduce the overall design development time. Choice of manufacturers was primarily with new organisations who were unapproved in AeroOrg and facilitated by a procurement role within ATech. This individual set out a list of possible suppliers for designers to find a suitable manufacturer according to preferred designs. This led to a number of possibilities depending on concept selection during the embodiment design phase. The response to interact with potential suppliers varied from designer to designer where some had contact in November 2006 with others interacting with manufacturers later depending on design’s evolution.
2007

Moving from a conceptual phase to embodiment in February 2007, the GA of Engine was divided into 29 solutions to complete designing in modular solutions. The focus in embodiment was to achieve required solution functions by developing a number of concepts and comparing each with initial specifications. Modular solutions are combined together to form the small engine where each solution may involve more than one component part. These solutions and GA broadly represented component dependencies and the overall design to participants.

Representing the design and keeping up to date with progress was carried out through inter-personal interaction. The routine for interaction between Engine members was based on participants carrying out their roles and reporting design progress to the project through weekly design meetings. Awareness of design progress was also facilitated with implementation of a product life cycle management (PLM) system during the embodiment phase. PLM was used to share current drawings but access was often limited to select participants.

Participants working on Engine decreased in May as departmental priorities moved individuals onto other projects. Engine was considered a low priority project in AeroOrg for two reasons: 1. It was a small project in AeroOrg (in terms of man hours and finances) and 2. There was no customer – it is considered a research project with internal funding. This reduction in participation pauses development of certain solutions with others continuing in their absence. The reduction in participation was managed by interaction between individuals – such that those working on other projects would actively interact with the PM and some department leads would actively interact with each other. Additionally if design changes occurred, the chief designer could oversee the complete design and decide whether or not to actively get input from those departments not currently participating.

The GA design was fixed in June 2007 defining concepts that were to be used to achieve Engine design. Fixing the GA permitted fewer alternatives to solve potential problems encouraging a more iterative design approach. Subsequently detail design on each solution started with designers having less concern of major changes from dependent tasks.
A number of long lead solutions were started mid 2007 much later than planned due to two contributing factors. Primarily there was nobody available to undertake the roles from suitable departments so these tasks were put on hold. Secondly there were no participants in the project available to undertake the solutions. As ATech designers in the project started to complete their tasks, the project manager and chief designer recognised their availability to take on these long lead solutions. ATech participants evidently had experience of the project and design concept however they did not have a depth of experience in these specific technical areas. The chief designer and project manager discussed this possibility with ATech designers noting that support, in the form of reviews, was to be provided by other technical departments. ATech designers were positive to continue with Engine yet mindful of their significantly increased workload and relative inexperience in these specific tasks.

Following a reduction in participants’ availability over summer months few solutions had progressed to the final stage of the design review process. Subsequently test installation was delayed and a new date set for the end of the calendar year. Availability of personnel for Engine fluctuated again over August to November. Cont department reduced their contribution until November as an individual leaves the organisation. Fan participants planned to decrease their workload but instead took on extra solutions in October. They were close to completing their role in September and were approached by the chief designer and project manager to take on outstanding design tasks in Engine. This followed a similar pattern to ATech designers taking on long lead solutions in the middle of the year and had similar outcomes. Fan designers were keen to continue but mindful of their relative inexperience on these tasks and also the low technical learning that could be applied in the Fan department. Despite this, the department approved availability of designers and effectively enabled the final solutions to be completed.

Participants from Comb department returned after being unavailable for the project during the summer. Consequently, they are unable to complete analysis of their design before making a decision on final design. In discussion with the chief designer, a decision was made from Comb to allow manufacture to start and aim for an end of year test date. Comb solution parts were ordered to build and test two prototypes – this was different to other solutions where parts are ordered to make four prototypes. This was revised to two prototypes due to expense of the existing design as delays precluded optimising the design through analysis. If further testing was required later designs were to be optimised incorporating results of current design analysis.
Manufacturers were keen to start making components as solutions passed the third stage of review. Moving from the third stage to the fourth stage required all modifications to be complete on the design, for all department leads in the project to be aware of what was being released and also for design drawings to be approved. For drawings to be approved an internal department, Draw, participated in Engine to ensure that AeroOrg drawing standards are maintained. In parallel to third design review meetings dates being accomplished throughout September to December there are concerns with drawing specifications. The first series of third design review meetings raised questions of what was expected on final drawings released to manufacturers as existing solutions did not have a coherent or standard specification. This was because each department liaised with Draw separately, focusing on their own technical areas. These concerns and discrepancies held up final issue of drawings to manufacturers. The delay was resolved over a series of meetings from October to December within the project group. These meetings cover essentially two aspects: awareness of why drawings are in this form (and not the standard AeroOrg form) and subsequently developing a consensus of what was required on drawings. This latter consensus was not straightforward as designers wanted information and instructions on drawings specific to their solutions. Final drawings started to be released in December 2007. Delays to designs being complete and released for manufacture resulted in testing being postponed until the first quarter of 2008. This repetition of delays did cause some informal internal questions from the testing facility to Engine which was brokered by ATech participants.

Some designers minimised this delay to manufacture from drawing specifications by giving verbal approval to a manufacturer to start work. This was enabled through personal relationships with manufacturers (built on this project) and with the chief designer and project participants aware of the decision. Verbal approval of manufacture before sending a final drawing was acceptable for some manufacturers due to the perceived credibility of AeroOrg. This was established through working relationships in developing designs and selected manufacturers were also used to dealing with other organisations where verbal agreements were acceptable and timescales were short.

When components arrived though a further difficulty in some cases was introduced where components were different to issued drawings – due to late verbal changes by designers to manufacturers. When parts were received into AeroOrg they had to undergo a quality check comparing them to issued drawings. All parts were eventually accepted,
some with concession notes delaying access to the component. This acceptance process was facilitated by established personal relationships warning of possible differences with components for Engine. Delays to accepting parts also meant that manufactures would not be paid until the part was accepted and extra work was created for the procurement representative.

All parts for Engine arrived at AeroOrg between November and February 2008. Some parts were slower than others due to three general factors: 1. Part complexity – where a part is complex or novel manufacturers were more cautious in their progress; 2. Some working relationships with manufactures were less established – transfer of information and understanding of parts were less established; 3. Designers had different expectations of what manufacturers should or were able to do. The last two factors are linked and were influenced by designers’ technical skills and previous experience.

2008

In 2008 designers started to reduce their input as designs were completed, parts received and design process and rationale captured. In late January there was an internal open day for staff (and project members) to view the engine layout prior to build (including all components bar three). This was a unique event that seldom occurs prior to testing, and only post testing. Focus shifted from design review and manufacture to test installation and setup. Installation for test progressed through interaction between ATech participants (who were on the project throughout) and Test department. Testing was realised in mid April and results were successful in demonstrating a working prototype.

5.2.4 Remarks on Engine

In Engine expertise from across AeroOrg organisation was combined to develop a novel small engine demonstrator whilst developing an understanding of which current working processes were required to achieve it. A major hurdle to design progress was a varied availability of participants throughout the project. The weekly design review meetings were the only formal focus for the project group to develop an awareness of overall progress. Participants were not always available as this project had a low priority for many departments and fixed low resources. However individuals in the group sustained design and group progress. Participants were motivated by the novelty of the project. The majority of participants committed to work beyond normal expectations e.g. overtime to achieve their tasks on time, taking on extra tasks; and individuals were provided access to experienced designers to develop their own task. There was regular review of traditional
design processes with participants encouraged to question their own design approach and refine it to achieve project aims. Furthermore having a chief designer who could advise on the entire design and a project manager to coordinate with individuals on progress and design changes were both key elements to adapt to unexpected events and maintain relevant standards and aims for the project group.

5.3 Wing

The third of four cases is Wing, an adaptive design type in an inter organisational setting (see Figure 14 p60 for case selection). The aim of Wing was to validate a computational damage prediction model. To accomplish this aim a leading edge (LE) component of a wing was designed and tested for bird strike with measurements from tests compared to a damage prediction model. Case description is separated into four parts: 1. Who was involved in Wing, 2. How Wing started, 3. What happened in Wing, 4. Remarks on Wing.

5.3.1 Who was involved in Wing

Wing was a design project involving three organisations: an Aerospace Organisation (Aero2Org), a Research Organisation (ResOrg) and a Design Organisation (DesOrg). In Wing different expertise is combined from each of the three organisations; Aero2Org is the lead organisation who provided coordination of members and design of a test rig, DesOrg supplied design and manufacture of test specimens and ResOrg contributed computational model simulation (shown in Figure 24). In addition to combining organisational expertise, individuals in each organisation also have different levels of experience of this type of project. Few participants have previously worked together – those that had were often within their own organisation (e.g. within ResOrg or DesOrg). There were also a number of participants performing new tasks or roles in addition to those with extensive experience of their technical roles in all of the organisations involved. Few participants were co-located in the same building even within the same organisation and all of the organisations involved were geographically dispersed in the south of England.
These roles were in accordance with an initial plan for this project established by the three respective organisations in a bid phase for work as part of a large programme of research. These organisational roles also defined available budget to each organisation for this project (e.g. a computational role is smaller and has less budget than design and manufacture), and each organisation was individually paid via reimbursement of quarterly reports on completed work.

5.3.2 How Wing started

Wing was part of a large programme of research and development activities between March 2006 and March 2009 involving 25 organisations. Wing involved three of the participating organisations who combined their overlapping expertise in aerospace engineering.

Initially Wing was scheduled to start in March 2006 but was delayed until late 2006 due to availability of personnel in Aero2Org. Informal discussions about project requirements started in November between a project manager from Aero2Org and a representative from ResOrg. This led to an initial phase of work in Aero2Org where the project manager researched and created a requirements document defining the structure of project work.

All three organisations had different design processes and were responsible for different technical aspects of the project. Each organisational technical aspect had some independence from other organisations but there were links between tasks in each organisation, e.g. the test rig and test specimen were clearly different entities but needed to connect together to achieve testing. There was no defined way for participants to work together, or how their design processes overlap. A series of project objectives (milestones and deliverables) were defined from an initial project proposal but how these were achieved was open; and consequently participants carried out work to their own
organisation working practices. Each project team attended and presented their progress at quarterly meetings for an external funding body to review project progress.

5.3.3 What happened in Wing

Wing started in November 2006 and data were collected up to July 2008 with the project finishing in November 2008. A timeline for Wing is shown in Figure 25.

![Figure 25 – Wing timeline](image)

The Wing project had three aspects of design. Responsibility for each was split between the three participating organisations: design of LE – DesOrg, design test fixture – Aero2Org, and development of computational damage model and testing procedure – ResOrg. All tasks started with LE design.

2007

Wing started as a group project when the project manager from Aero2Org presented a draft of project requirements to a selection of participants from each organisation at a meeting in February 2007. This draft formed an outline to consider testing requirements, LE design (composite choice, structure and core design), and manufacturing processes whilst focusing on minimising weight and cost through new technologies. ResOrg participants suggested further clarification on test requirement sections based on their experience on bird strike testing. The project manager subsequently developed the document and a dialogue was created between the three organisations via group emails. This centred around comments on and contributions to this updated document. As these
comments were incorporated participants subsequently accepted an initial requirements document in March 2007.

Brainstorming on LE design concept started in April and involved participants from each organisation in a group meeting. The initial design parameters (overall size, section of LE to design) were based on an established LE design geometry from Aero2Org and the group brainstorming session developed a number of possible concepts for Wing. DesOrg, who were responsible for LE design, outlined the design process used. This first established possible concepts, then studied LE structural design aspects through computation analysis before final selection of possible material configurations. Once a concept and material were selected then further structural analysis was completed before manufacture started.

As each organisation was responsible for their own contribution where design processes overlapped was not clearly visible. Participants when interacting with each other across organisations didn’t explicitly discuss or define design process. Instead inter-personal interaction allowed individuals to gradually develop awareness of differences in design process. The amount of awareness developed was dependent on individual roles and to some extent personality, e.g. those involved actively in project coordination were more active in understanding differences in design progress.

Subsequent to initial brainstorming the aims and requirements for the project were reviewed to update the requirements document. This update was coordinated by the project manager via email and telephone conversations with participants from ResOrg and DesOrg. Participants subsequently focused on their respective roles. The three designs aspects (LE, software model and test rig) are however not independent of each other. The pivotal design work for the project was the LE, and group interaction focused on discussion and development of this design.

This interaction was first started through emails as ResOrg updated design progress of potential concepts. Early ideas centred on a sandwich concept considering novel materials and new combinations to address the aim of the project. Discussion of possible materials was encouraged by DesOrg giving a concepts outline to the group (via email) before they supplied material properties to ResOrg for their damage model analysis. These concepts revolved around considering skin (carbon vs. glass) and core materials (pinned vs.
unpinned). Aero2Org emphasised that there was a balance between innovation and time on this project and as further work can be carried out later in a theoretical (paper) exercise.

With a variety of possible LE design concepts and different perspectives expressed in emails a meeting was arranged in July to discuss ideas. A way forward was developed in the meeting focusing on material selection, baseline design and analysis, Finite Element analysis and test facilities. Members consolidated ideas expressed through emails and conversations over the previous month from the last meeting in May. In this meeting the initial project group membership was expanded to include designers and stress analysts from DesOrg who were performing the tasks. Expanding the project group placed a greater emphasis on social processes (e.g. building trust, communication and interaction) between participants to share information and understanding.

The majority of inter-personal and group interaction supported information exchange between individuals. The purpose of this exchange was twofold, first for participants to be able to continue their own designs but also for the project group to be aware of what they were doing. Exchange of information was carried out between one contact in each organisation i.e. there were three representatives. Similarly to combining different design processes, a representative for each organisation was established early on based on participants who were active in communicating information to the rest of the group.

Following the meeting in July participants returned to their organisations to carry on their respective work. Stress analysts in DesOrg started preliminary stress calculations considering a number of concepts (different skin and core combinations) and manufacturing engineers started on the mould design to make the LE. Further information from Aero2Org was requested via email and material cost estimations are sourced to provide information for design selection. In August there is a change in tool design in LE manufacture. DesOrg outlined this change via an formal design document that was sent to participants via email. Aero2Org and ResOrg participants accept the change at the following group meeting in August.

At the same time a draft version of the testing document is produced by ResOrg participants, agreed in the subsequent meeting and issued in August as a first version. The damage prediction model underwent development in parallel to LE design and had consistent problems in obtaining material properties. Aero2Org and DesOrg provided assistance in sourcing properties where possible and the first analysis in complete in September 2007.
Four case studies of collaborating in engineering design

From September to November, exchange of information and activity on Wing was on a daily bases and increasingly information was formalised in reports. Representatives from test rig design in Aero2Org join the project to start work in parallel to selection of LE specimen design. In progress meetings objectives are restated as new members join before discussion of relevant issues continued. Progress meetings continue until mid November.

The LE design progressed through concept review as DesOrg designers present the design and assumptions to other participants. Concept choice is based upon cost to manufacture including novel technologies and at the end of concept review a formal report is issued detailing concept and material configurations for manufacture and test. DesOrg engineers also completed LE mould design ordering it in November.

Test rig designers in Aero2Org start in September designing a structure that will hold the specimen and attach it to an existing structure in a Testing House (TestH). This leads to various pair-wise interactions (email and phone) between designers from Aero2Org, DesOrg and TestH on test rig design. These are not one off interactions as LE concept design was confirmed in parallel and solutions were developed as a project group. DesOrg designers commented informally and formally on draft designs in November and subsequently both ResOrg and DesOrg confirmed to AeroOrg2 that test rig design was suitable. These confirmations allow test rig manufacture to start in December.

At the same time the ResOrg participant responsible for modelling and test format started to outline specifically what was required. The participant from ResOrg received data, geometry, material properties from DesOrg (formal documents) and the first damage model results of the chosen design are presented in November. This results in ResOrg proposing changes to the analysis technique to improve modelling of bird behaviour.

In the September group meeting an idea was raised to expand testing from one day to two. The purpose of this was to test two configurations of LE design and gain more data to validate the damage model. The participant from ResOrg who was responsible for their finances was not present and the group wait for a response to see if this is feasible. ResOrg respond to the Wing project group in October stating that their budget is not enough to cover two days of testing. This leaves an option for Aero2Org and DesOrg to co-fund an extra day of testing. Discussions subsequently start between the project manager (Aero2Org) and head designer in DesOrg about what to do and whether they will fund extra testing. The two organisations approve this additional expense to their budgets in November and then request a formal quote for the cost of a 2nd day testing from TestH.
Moving from concept review to manufacture involved producing full stress report based on final LE design. This was released from DesOrg to partners in early December however manufacturing is delayed due to an unexpectedly long lead time in obtaining material for LE manufacture. The year ends with LE design complete and DesOrg waiting for material to arrive to start manufacture. The test rig was designed and manufactured in parallel and the damage modelling was updated using new techniques.

2008

The project manager in Aero2Org and ResOrg software modeller accepted the reasons for this delay and agreed with the DesOrg choice to continue with this material. DesOrg responded by outlining firm dates for completion. The delay in obtaining material combined with designers (DesOrg and Aero2Org) finishing their tasks reduced active membership on Wing. Participants moved onto other projects in their own organisations in early January and contact between each organisation was maintained through email between organisational representatives. Participants all conceded that the delay was unfortunate but was acceptable as there are no was immediate deadline for completing the project and no other projects were dependent on their results.

Test dates are reevaluated as there are delays to manufacturing. This was not straightforward as it was not clear what ResOrg were paying for on the first day of testing and what Aero2Org and DesOrg would pay for on the second. Participants first attempts via email resulted in confusion over costs received by Aero2Org and DesOrg from TestH – they were perceived to be high. Participants had a short meeting at the programme quarterly review in February to discuss what was required and what participants are prepared to pay for. There was agreement in carrying out two days of testing and that two different material configurations would be used (A&B). The ResOrg participant responsible for finances recognised that the project has evolved and agreed to cover the first days costs with DesOrg and AeroOrg covering second. All note that use of a certain equipment would be beneficial and Aero2Org offer to supply their own equipment. Software modelling of the second days testing was also in doubt as ResOrg did not plan finances to carry out this work. This raises concerns by DesOrg and Aero2Org participants over the utility of a second day. Despite this concern a second quote is obtained from TestH in early March though per day costs are not detailed.

In parallel to the debate on testing finances manufacture of the test rig and LE started. The manufacture of the test rig was completed on schedule with some small design
refinements relating to test specimen geometry from DesOrg designers. Test rig tooling was complete in March and interface parts (dummy ribs and trailing edge – to attach the LE specimen to test rig) were sent to DesOrg in April for assembly.

LE mould tool for manufacture arrives in February and a LE manufacture plan and earliest test possible dates sent out from DesOrg to all in a formal document. Delayed material arrives in early March with the first LE complete early April. The contact in DesOrg updates all partners with pictures of the first LE design made. This revitalised project awareness in the group with positive replies from the project manager (in AeroOrg2). All prototype LE designs of the first material configuration (A) are subsequently complete by the end of April. The completion of the first LE allowed verification of interface parts with the test rig to be completed. This was successful and there were no further modifications required to specimens or interface parts.

Before any further manufacturing (LE material B) a meeting was held mid May to confirm the second day testing plan and costs as DesOrg and Aero2Org need further clarification from ResOrg. Participants agree on a final set of instrumentation including who is providing what equipment. A test format is finalised but may be subject to change based on the outcomes of tests on the day. Unfortunately the ResOrg participant responsible for finances didn’t attend and the group were still uncertain of costs for each day. Expectations were that they should at least be equal but the quotes show a greater cost for day two. These concerns are resolved at a further meeting at the programme quarterly review a week later. In this meeting participants settle on what each organisation would contribute. This final agreement allows confirmation to be sent to TestH of dates for testing and for the second LE configuration (B) to be manufactured. Testing of the two configurations of LE were then carried out in early July.

5.3.4 Remarks on Wing

In Wing expertise was combined from three organisations (Aero2Org, DesOrg, ResOrg) within the field of aerospace engineering to design and test a leading edge profile. Each organisation performed a separate function based on their own design processes with some overlap between each organisation. Where there was overlap participants used interaction to discuss potential ideas and solutions. This meant that for progress to occur it was via suggestions to the group, discussion and then approval on selected choices. This may seem protracted but had a number of benefits – possible variations were considered, each organisation had an input, there was visibility on consensus or compromise and an understanding was continually maintained through this process of decision making. This
was made explicit through creating and updating various documents related to each aspect of the project. Consequently completing the design process did take time, it was gradual and required repeated interaction answering questions and concerns. It was also clear that in stopping the monthly review meetings the process of making decisions took longer (and was less satisfying for participants) especially where further work was proposed or additional finances were required.

An external party evaluated the Wing project in quarterly reviews. This involved the whole project and although participants were from different organisations this regular review of project progress reminded individuals to reconsider project standards and produce joint reports. Regular meetings and communication between individuals in the group indicated a lot of activity, participants were motivated, interested in the project and eager to achieve their goals.

5.4 Medical

The last case is Medical, an original design type in an inter organisational setting in this research (see Figure 14 p60 for case selection). The aim of this project was to design and produce a rapid (=10mins) point of care screening (negative) machine for MRSA – a medical device (Medical). Case description is described in four parts: 1. Who was involved in Medical, 2. How Medical started, 3. What happened in Medical, 4. Remarks on Medical.

5.4.1 Who was involved in Medical

Medical was a design project involving five organisations: Spinout Organisation (SpinOutOrg), Industrial Design Organisation (IndDesOrg), Scientific Research Organisation (SciResOrg), Product Design Organisation (ProdDesOrg), Marketing Organisation (MarketOrg). Figure 26 illustrates their roles and the composition of participants in the Medical project. Each organisation had a different field of expertise where few participants have previous experience of this type of project and none had previously worked together. There were a number of participants performing new tasks or roles in addition to those with extensive experience of their technical roles.
SpinOutOrg finance this project providing directors responsible for project management and marketing whilst employing a number of third parties to carry out specific roles. Participants from SciResOrg provided phage technology expertise to develop novel techniques to produce light output from MRSA samples. A second participant from the organisation, SciRes2Org, provided early light output measurement. Note some participants of SciResOrg become members of SpinOutOrg during the project denoted in Figure 26 by dashed lines between the two organisations. IndDesOrg members supplied market research and industrial design expertise (mechanical parts and user interface processes); ProdDesOrg participants provided design expertise in optical sensors to read light output, software implementation and manufacture capabilities; lastly MarketOrg supplied distribution services for the product. All of the organisations were geographically dispersed in the UK, though some (SpinOutOrg and IndDesOrg in England; SciResOrg and ProdDesOrg in Scotland) were close to each other.

### 5.4.2 How Medical started

This product was being developed subsequent to discoveries in phage technology and public interest in detection of MRSA in hospitals. In 2004 SpinOutOrg expanded outside of a parent organisation (ParentOrg) to develop products using phage technology. This decision to expand was established after previous work (2001-2004) developing phage technology research between ParentOrg and SciResOrg. SciResOrg held a scientific patent on the phage technology and ParentOrg bought a license to develop research on non-
clinical applications for a period of time. Research initially focused on a decontamination / cleaning product combining the background of ParentOrg (emulsion technology) with the scientific phage technology from SciResOrg.

A review of work was carried out in 2004 as a new technical director is appointed following the death of a founding member of SpinOutOrg. Subsequently potential applications were considered for marketing of the phage technology and arrangements with SciResOrg were formalised with a contract to develop research on phage technology for a marketable product. To develop a product three other organisations joined Medical between 2004 and 2007: IndDesOrg, ProdDesOrg and MarketOrg. Each organisation was different and there was little overlap of specific design expertise. Similarities exist where SpinOutOrg, IndDesOrg, ProdDesOrg and MarketOrg are commercial organisations with commercial processes e.g. IndDesOrg and ProdDesOrg invoicing costs monthly. MarketOrg have a contract to be paid only once the product is ready for distribution. SciResOrg was an academic institution focusing on developing new research with members denoted here as ‘technologists’. SpinOutOrg had funded SciResOrg participants for three years prior to three members joining SpinOutOrg in 2007; a SciResOrg member also retired but remained part time on the Medical project. There is no change in location or working methods and this group of technologists continue research as before.

### 5.4.3 What happened in Medical

Medical started in June 2004 and data were collected up to May 2008 with the project still active at the time of writing. A timeline for Medical is shown in Figure 27.

![Medical Timeline](image)

**Figure 27 – Medical timeline**
2004

In 2004 as part of the project review in SpinOutOrg participants recognised that new EU directives would result in a longer time to market, and hence a longer time to generate return on investments for a cleaning liquid than a medical device. Subsequently the focus of work in Medical was on developing products for the detection of bacteria strains on patients. In mid 2004 IndDesOrg were introduced into the project to look at product design via a personal relationship in ParentOrg. This complemented a technical research role in SciResOrg and finance and project management roles in SpinOutOrg.

2005

The project followed typical concurrent design practices with participants from IndDesOrg starting with concept feasibility and market research whilst SciResOrg modified their research from cleaning products to detection of bacteria on patients. Work was completed independently by IndDesOrg and SciResOrg based on overall aims and outlines identified and coordinated by SpinOutOrg. Output from market research showed interest in a screening machine at point of care – tests were currently sent to a laboratory. Further market research trials showed a preference for a static machine over a handheld one. IndDesOrg designers developed possible product designs over 2005 with functional requirements of the product increasing (e.g. machine has to be able to analyse a sample and display results). Design work developed involving both individuals from IndDesOrg and SciResOrg2 with the latter focusing on a sensor to read light output from phage technology.

Participants from IndDesOrg, in comparison to SciResOrg, were actively in contact with SpinOutOrg. This is in part due to differences in billing: IndDesOrg have a monthly billing process where they accounted for what they have achieved, SciResOrg had a fixed contract and longer periods between progress review. Secondly participants in IndDesOrg and SpinOutOrg were geographically closer together and had frequent ad hoc meetings to update progress. In contrast SciResOrg participants were used to developing research over a period of time with less frequent updates to those funding the project.

Developing a static product required a method to transport sampled from a patient to the machine. Project participants agreed to suggestions from IndDesOrg designers to use a card. This solution raised considerations about card manufacture so SpinOutOrg managers in conjunction with suggestions from IndDesOrg designers decided to outsource manufacture instead of investing in their own production facility. To address these new
considerations IndDesOrg head designer introduced a product design organisation (ProdDesOrg) specialising in design and manufacture of electronics and software to SpinOutOrg managers. Subsequently ProdDesOrg joined Medical interacting with SciResOrg and SciRes2Org by expanding on their low volume expertise until the involvement of SciRes2Org was phased out at the end of 2005. Technical expertise on optical sensors then shifted from SciResOrg2 to ProdDesOrg and similar working practices (commercial and implementation focus) are emphasised between ProdDesOrg, IndDesOrg and SpinOutOrg.

2006

Development of phage technology advanced and early in 2006 technologists from SciResOrg provided samples of modified bacteria to test components developed by ProdDesOrg and SciRes2Org. This trial of scientific technology resulted in a number of unexpected obstacles in the selected detection method including – high background noise in light output, low levels of light output intensity and slow performance. Subsequently a project review was undertaken by SpinOutOrg first with SciResOrg and then with participants from partnering organisations (SciResOrg, IndDesOrg, ProdDesOrg). SpinOutOrg at this point became more reliant on the other participants for their technical expertise. SpinOutOrg hence decided to bring participants together to collaborate and understand what is happening and develop possible solutions.

Outcomes from this review centred on developing a new technical method proposed by SciResOrg in parallel to developing product design – by IndDesOrg and ProdDesOrg. The project group were convinced this was possible through information provided by each organisation. Changing the scientific detection method influenced work primarily for SciResOrg and ProdDesOrg. ProdDesOrg tasks progressed as planned – an implementation step; but in developing a new method – a research and development step SciResOrg encountered further unexpected problems that delayed achieving their work.

At the end of 2006 there was a project review to consider why participants of SciResOrg had not achieved their new technical method as expected. Project participants looked at developments in both phage technology and product design. Although there are uncertainties, the group still believed it was worthwhile to continue developing both phage technology and product design simultaneously based on information from each of the third party organisations. The group remained optimistic about developing this novel product.
2007

At the start of 2007 there was a number of membership changes. First there was a decision by SpinOutOrg to appoint phage technology advisors to review progress and act as a sounding board. Secondly three of the four members of SciResOrg became employees of SpinOutOrg with the fourth, the original participant with ParentOrg, continuing to provide part time consultancy work to Medical project. There were no changes in location or working approached for the new SpinOutOrg members who continue work as before with the remaining SciResOrg specialist.

ProdDesOrg set out plans for the overall project in early January showing how they were influenced by other participants work. Product design in this phase focused on developing the detection module system and card manufacture. This includes procurement, build and testing in three phases. In parallel IndDesOrg carried out design and manufacture of the product structure and start to develop a user interface process. Phage technology development continued looking at inserting a gene into a phage to produce measurable light output. This method was more complex than foreseen and a deadline of March was exceeded when ProdDesOrg designers required light output information to develop and test their optical sensors. To allow ProdDesOrg designers to continue phage technologists provided estimates of what light output could be.

Product development now was starting to be limited by progress in phage technology. Clinical trials were postponed and a demonstration prototype without a working detection system was built. The technical advisory board supported the methods chosen by the phage technologists and suggested to increase the number of staff. A genetic biologist was subsequently recruited and starts to work specifically on gene insertion in May 2007.

Up to this point, meetings with new participants or reviews had involved individuals from each organisation. From May onwards phage technology representatives no longer attended group meetings. There were two contributing factors: 1. they were only geographically close to ProdDesOrg, 2. Managers in SpinOutOrg wanted them to focus on their tasks as it was limiting product development. There was also further effort by SpinOutOrg such that one of the directors from mid 2007 started to regularly spend one or two days per week with technologists. The purpose of this was to improve communication between technologists and project directors concerning what was happening and increase awareness of the urgency of completing their tasks.
Product development continued in parallel to phage technology development. SpinOutOrg then involved a distribution organisation – MarketOrg. They were keen to be involved and influence product development even though they were not being paid until they started distributing the product. This was achieved as MarketOrg provided early feedback on the current prototype via a meeting with SpinOutOrg, ProdDesOrg and IndDesOrg.

There were a number of subsequent events that cause design requirements to be changed. First a conversation between a SpinOutOrg director and a phage technologist revealed that the test time is temperature dependent, i.e. below a certain temperature the reaction takes much longer than 10 minutes. This introduced a new requirement previously and a meeting in July involving all participants considers the incubation of samples. Secondly design requirements changed as SpinOutOrg wanted to address comments from the review by MarketOrg. This in particular looked at laboratories as a potential market and subsequently IndDesOrg and ProdDesOrg started re-design. IndDesOrg focused on possible incubator designs and redesign of the card. IndDesOrg evaluated how to incorporate the new mechanical designs into the existing internal electronic design.

A complete break through was thought to have been achieved by phage technologists in November 2007. A telephone communication between a technologist and marketing director in SpinOutOrg suggested that the main problem had successfully been overcome. This was verified, but to confirm the complete break through a process of screening work was undertaken to find the inserted gene and phage.

2008

Screening work that analysed how and where a reporter gene had been inserted. This proved that the process had been unsuccessful. Questions were then posed about whether a reporter gene was inserted in bacteria phage or somewhere else. Further approaches were devised with technologists and a new method (genetic insertion) was suggested in April that could take 6 months.

Subsequently all screening work by phage technologists stopped in April with a complete review. The technical advisory board recognised the difficulty in phage technology developments and supported the steps that were being taking. This provided little consolation for other participants. It was taking longer than SciResOrg originally predicted because it was novel research. At the end of April the whole project and
SpinOutOrg were reviewed. SpinOutOrg had been looking for third party investors (since the end of 2007) to take on some of the commercial risk in creating the product. Third party investors were lined up, but without a proof of concept i.e. no working prototype, none were willing to take technological and commercial risks. This delayed injection of cash into the organisation and consequently in April 2008 SpinOutOrg restructure the project. This involved pausing all third party work at convenient point; two members of SpinOutOrg (former SciResOrg) are made redundant and a new genetic biologist was hired to pursue the new approach. The marketing director in SpinOutOrg was moved back into the ParentOrg as a temporary move to also restrict financial spend. All third parties were on hold waiting for progress from the technologists to resume product development.

5.4.4 Remarks on Medical

In Medical participants combined expertise across five organisations (SpinOutOrg, IndDesOrg, SciResOrg, ProdDesOrg, MarketOrg) and multiple disciplines (engineering, microbiology, marketing etc) to develop a rapid screening medical device. This combined a number of different approaches to achieving tasks with similarities existing between each – though there were few aspects common to all. These similarities and diversity epitomise why collaborations exist and in this case provide understanding why there were potential problems in assumptions, terminology, expectations and interaction patterns.

In Medical what may have seemed like similar working practices or similar terminology, often had different meanings. This highlights a significant risk of miscommunication or misunderstanding in transferring information between organisations. This ambiguity was particularly evident when participants expressed the certainty of completing tasks or in explaining the precise level of progress to other participants. Those in implementation roles assumed there was a high certainty of meeting expectations in comparison to those in research roles who recognised that developing novel technology and techniques was uncertain. This illustrated different approaches or different disciplines yet similar terminology used to transfer information. In particular it affected how participants prioritised tasks with decisions taken to simultaneously continue or accelerate product design work based on the misleading impression of major hurdles being overcome.

Initially participants developed confidence in achieving a product within predicted timescales. This was based on group interaction synthesising perspectives with SpinOutOrg collating information and then deciding what to do. Interaction was maintained, though primarily through pair-wise interaction particularly between IndDesOrg, ProdDesOrg, and SpinOutOrg whilst SciResOrg carried out their tasks. This
was because there was a greater inter-dependency of tasks between these organisations with all being reliant on SciResOrg. SciResOrg was relatively independent to other organisations on completing their tasks. Limited resources and a strategy to achieve both product design and technology design simultaneously changed the membership in group participation. This accentuated similarities and differences in the group. It becomes clearer that some participants were performing implementation tasks and others research tasks. This was not initially clear, partly due to similarities in use of language, but also because what participants expected was less explicit – participants assumed and understood what individuals stated primarily within their own working context.

Another difference between organisations was that IndDesOrg and ProdDesOrg billed on monthly contracts in contrast to SciResOrg which had a contract for a fixed length of time. Thus SciResOrg had less incentive to regularly demonstrate what was being achieved.

Participants took other organisations’ predictions for task completion in good faith based on initial openness in group interaction. This changed as delays became more prevalent, participants weren’t present in interactions, and uncertainty on task completion dates increased. Ultimately there was some disillusionment as some participants’ tasks were completed as predicted, and others (e.g. technology development) were repeatedly taking longer and not being achieved as envisaged. Despite high individual interest and motivation for the project to succeed, limited resources resulted in changes to the working approach with implementation tasks being deferred until research based technology tasks were completed.

5.5 Summary of four case studies

In this chapter descriptions of four different cases studies of engineering design have been presented. In each case a description has outlined who was involved, how a project started, what happened including any remarks relevant to each case. This description in particular focuses on the development of a product recognising how individuals and a project group develop and change as they progress from concept ideas to finalising detail designs in preparation for prototype testing. Descriptions highlight both task and affective aspects as participants learn how to judge each other’s contributions.

Participants experienced different events in developing their products for prototype testing yet have faced similar challenges – changes in project participation, delays, design revisions and requests for additional resources. Participants reacted to these challenges by
each reviewing how to achieve their tasks in the project. They considered what was feasible and how participants had performed so far – falling short of, meeting or exceeding expectations. Participants used design procedures, organisational working practices and interaction with other participants (in pairs and groups) to orientate their judgements and expectations.

In each case summary, aspects of cultural and historic context are described e.g. participants’ backgrounds, previous experience, degree of established processes, procedures and values. These highlight differences between participants, organisations, cases, and issues relating to how individuals recognised, established and maintained customs, norms, and shared assumptions. These aspects of culture are hence related to individuals, pairs and groups and are specifically considered under the term ‘understanding’ in analysis of pair-wise relations and group relations Research Question constructs, and under ‘expectations’ in outcomes. Cross-case findings are described in the next chapter focussing on these Research Question constructs.

These individual descriptions provide the groundwork to start cross-case comparison to compare and contrast events, reactions, patterns and causes to develop an understanding of how participants collaborate in engineering design. This is presented next in chapter 6.
6 Cross case findings – a comparison of design case studies

The aim of this chapter is to present findings from cross-case analysis to address the Research Question. This is the second in the three stages of case analysis (see 4.4.2 p66) expanding individual case descriptions in chapter 5 to consider multiple cases. The purpose of cross-case analysis is to describe, analyse and interpret similarities and contrasts between cases to develop findings about collaborating in engineering design. In developing these findings the aim is to explain how pair-wise relations influence group relations and outcomes in design projects.

At the start of this chapter there is a brief description of how seven new conceptual categories have been uncovered through cross-case analysis (6.1). These have emerged from working between data, research question and conceptual framework in carrying out data analysis (also see 4.4.2). Conceptual categories are classified into features and mechanisms. Features include findings on specific Research Question constructs (pair-wise relations, group relations, outcomes); and mechanisms consist of findings about how Research Question constructs influence each other.

Each Research Question construct is described with sample data (6.2) before being individually analysed using the new conceptual categories. Pair-wise relations (6.3) and group relations (6.4) are each split into two features: Opportunity (6.3.1 & 6.4.1) and Dependence (6.3.2 & 6.4.2). Cross-case analysis of these features introduces a dilemma for participants (6.4.3). In the fifth section (6.5) findings on the final Research Question construct, outcomes, are presented. This is split into two features: Results (6.5.1) and Adjustments (6.5.2).

Findings are presented in section 6.6 that describe how constructs influence each other: that is how pair-wise relations influence group relations and outcomes. These are separated into three mechanisms – Familiarising (6.6.1), Associating (6.6.2) and Regulating (6.6.3) to highlight patterns and describe the influence of pair-wise relations in engineering design projects. This concludes with a discussion on how individuals through pair-wise relations are helped and hindered in managing a dilemma (6.6.4).

This chapter concludes with a summary (6.7) of presented findings including how they contribute to answering the Research Question.
6.1 18 themes and seven new categories

Seven new conceptual categories have been empirically derived in completing the three phases in the second stage of cross-case analysis (see section 4.4.2, Figure 19 p67). This has been achieved through searching for patterns and links between the four cases whilst working between data, the Conceptual Framework and Research Question.

In the first phase of cross-case analysis early indications of patterns were evident having coded case data to each of the 18 themes in the conceptual framework and completing individual case descriptions. Figure 28 illustrates early prominent themes in each case and variation across cases using Huxham & Vangen’s themes (2005).

Figure 28 – Comparison of themes from individual cases

In Figure 28 it is clear there are similarities and differences when comparing themes across cases. Ten themes are highlighted (accountability, commitment and determination, communication and language, compromise, learning, membership structure, social capital, resources, risk, working practices) and provide an indication of topics relevant to understanding collaborating in these four engineering design projects. These ten themes in Figure 28 were used as sensitizing concepts to search for patterns across cases as analysis focused on Research Question constructs (see phase 2, Figure 19 p67). This involved clustering data, memos, insights and then developing findings to explain patterns across the four cases and address the RQ (see phase 3, Figure 19 p67). A specific example of this process is included in section 6.3 Table 4. These clusters led to identifying seven new categories shown in Figure 29. These new categories are split into two types: four are denoted as features – Opportunity, Dependence, Results and Adjustments; and three as mechanisms – Familiarising, Associating and Regulating.
Figure 29 – Seven new conceptual categories used to describe patterns across case studies

Pair-wise relations and group relations share two new conceptual categories – Opportunity and Dependence; outcomes has two categories – Results and Adjustments (with three aspects). Secondly there are three categories that are mechanisms which describe how pair-wise relations influence group relations and outcomes in collaborating – Familiarising, Associating and Regulating. Familiarising is depicted as an individual recognising different aspects (separate segments) of a project (oval shape); Associating as an individual establishing their links to certain aspects of a project; and Regulating as an individual maintaining which project standards are prominent. In total seven new conceptual categories have been empirically derived and are used to present and describe cross-cases findings in sections 6.3-6.6. Next Research Question constructs are operationalized.

6.2 Defining and operationalizing Research Question constructs

Definitions and examples of each construct in the Research Question are outlined next to provide a foundation to develop analysis from individual case descriptions (see chapter 5) to cross-case data analysis. Three constructs are used to consider how pair-wise relations influence group relations and outcomes when collaborating in engineering design teams.

6.2.1 Pair-wise relations

The construct of pair-wise relations includes data related to interaction and understanding between two individuals. Interaction is any form of action or behaviour
between two individuals, in essence it is what a pair of individuals do. This can be asynchronous e.g. email, or synchronous e.g. telephone, co-located e.g. face to face, or distributed e.g. via video conference facilities. Interaction is broader than studying communication (i.e. what is intended and interpreted in exchanging information). Interaction deals with “the way people form, maintain and change their relationships with each other” (Radley, 1991: 1). An example of data collected on pair-wise interaction is:

“The guys I interact with, I will often have one to ones with about new parts arriving, come over and see me and say I want this, and once the information comes back I’ll go and see them and we’ll go over the responses that we have from the suppliers” (Probe)

Understanding in pairs is based on the concept of shared understanding specifically focusing on two people. Shared understanding is where individuals show an awareness about how tasks, behaviour and events are interpreted including being able to anticipate each others’ actions, needs, and adapt their behaviour (Klimoski & Mohammed, 1994) to develop common or complementary expectations (Cannon-Bowers & Salas, 2001). Performance together is greater than the sum of their parts as pairs share values, beliefs, assumptions and perceptions about how tasks are performed and how people are likely to behave. This provides a structure to existing knowledge and a source for interpreting new information (Badke-Schaub et al., 2007).

The content of shared understanding is split into two aspects – Task and Team. Task understanding is knowledge about design procedures, scenarios, strategies etc; it sums up understanding about engineering design. Team understanding is knowledge about roles, participant capabilities, attitudes, beliefs, behaviour etc; and is simply understanding about working with people (Mathieu et al., 2005; Mathieu et al., 2000; Mohammed & Dumville, 2001) (section 3.3 p37 for literature). This split presents two topics similar to the two aspects noted in group development models – task and affective aspects (section 3.2 p31 for literature). Data related to pair-wise relations Task understanding is exemplified by:

“I have been on a course to learn how to use Catia… and when I talk to designers… I can understand roughly where they are coming from … I can see why it would take that long… I have a bit more of an understanding of what I do [and] how it affects what they are doing” (Wing)
And on *pair-wise relations* Team understanding:

“You are working definitely with him, you are not really seeing him as AeroOrg2, you are seeing him as someone you know what he is doing, you can understand where he is coming from. And also if you know them better when you do get an email or something from them you can interpret it better because you know that person” (Wing)

These two aspects, Task and Team, are used to specifically describe the content of what is shared in cross-case findings. Examples of data on *group relations* are described next.

### 6.2.2 Group relations

*Group relations* are similar to *pair-wise relations* in that they encompass data on interaction and understanding; however interaction in this construct includes any form of action involving more than two individuals from the project. An example of data collected relating to group interaction is:

“It is quite hard [to organise meetings] because everybody has different commitments, everyone has different work hours and different roles on the project and different aims, to tie people down to get people together” (Wing)

Understanding in a group focuses on data that describes how participants develop complementary expectations involving more than two individuals. Like pair-wise understanding, this is split into two to reflect understanding relating to design procedures, scenarios, strategies etc – Task understanding; and participant capabilities, attitudes, beliefs, behaviour etc – Team understanding. An example of *group relations* data related to group Task understanding is:

“But there are clearly issues that do cut across [the product] especially where you change an interface or there is a potential impact because you change your design without realising implications, and there hasn’t really been a forum other than the weekly meeting – which has been a little erratic and quite often focused on specific detail design clearance rather than as a forum for holistic design agreement” (Engine)

And *group relations* data on group Team understanding aspects:

“Everyone is in the same position – that can work quite well… I think the team of people that we have got are quite out-spoken, they say what they are thinking, they do ask questions” (Wing)
Understanding and interaction are interlinked in both *pair-wise relations* and *group relations* Research Question constructs. Interaction is often a method to develop understanding, and in particular a mutual or shared understanding about Task or Team aspects. Both processes are considered as key to comprehend *collaborating* yet it is not the intention of the author to investigate this connection. Instead, the focus is to observe how both occur in pairs and how they influence participants as a project group and as individuals. As such, *pair-wise relations* and *group relations* are conceptual constructs used to investigate data on interaction and understanding across multiple levels i.e. individual, pairs and groups. Examples of the final construct of the Research Question, *outcomes*, are described next.

**6.2.3 Outcomes**

*Outcomes* is the third construct of the Research Question and is split into Results and Adjustments. Results covers data about project and interim outcomes describing delays, project completion, design changes, project participation and requests for additional resources. An example of results data is:

“We decided to take the hit in terms of the delay to get the material we wanted and that arrived at the end of February” (WingDam)

Adjustments includes data relating to individuals’ affective reactions during a project that focuses on three aspects of individual learning: how to trust each other, how to commit to each other and how to influence each other. Examples of adjustments data on individual affective reactions:

“Yes I have confidence in people that I get to know and who have delivered and some people do it extremely well and others not” (Engine)

or

“I don’t agree with the strategy but that is not an issue, they call the shots, they are paying the money” (Medical)

and

“You have got no control and you have to replicate certain aspects of the way they designed it” (Probe)

This last section concludes examples of how research constructs have been operationalized in this research. Findings from cross-case analysis are detailed next starting with each individual construct (sections 6.3, 6.4, 6.5), and then describing how they influence each other in addressing the Research Question (section 6.6).
6.3 Pair-wise relations

In this section cross-case findings under the construct pair-wise relations are presented. These are based on data collected through interviews, informal conversations, observations and documentation and developed through three phases (see Figure 18 p66) working between data, research memos, insights, Research Question and conceptual framework (CF). An example of this process is presented in Table 4 focusing on one insight from Table 5 (detailed cross-case findings).

<table>
<thead>
<tr>
<th>Data</th>
<th>Data type &amp; CF theme(s)</th>
<th>Memo</th>
<th>Insight</th>
<th>Conceptual category</th>
</tr>
</thead>
<tbody>
<tr>
<td>“The other main draw is I think the certain amount of license we have been given, to do things differently and to break free of the procedures that are there for a good reason”</td>
<td>Interview</td>
<td>Accountability, commitment &amp; determination, working practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“The [organisational] process is designed for you to be able to design a production engine without making any mistakes or quality drop offs... they thought let’s try and cut that down because we are effectively making a rig bit... and there isn’t a quick process to follow, and to some extent you make it up as you go along.”</td>
<td>Interview</td>
<td>Working practices</td>
<td>Standard design procedures adapted by each individual/ department to achieve project aims/ goals</td>
<td></td>
</tr>
<tr>
<td>“very different attitudes depending on what people are like and what their working history has been and some people are very adaptable and go, oh, yeah we can shortcut that process because it’s not applicable here”</td>
<td>Interview</td>
<td>Compromise, compromise, working practices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“I would say it’s not necessary we have different ideas about what we want to do with it. It's we have different ideas on how we should be doing it and from a procedural perspective”</td>
<td>Interview</td>
<td>Common aims, working practices</td>
<td>Modified design procedures used with participants establishing new links between individuals’ tasks</td>
<td></td>
</tr>
<tr>
<td>“we’d like to agree and work out between us what the pros and cons are because it may upset the [component performance]”</td>
<td>Interview</td>
<td>Common aims</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Everyone is different but some people will come and explain things nicely, and other people don’t have a clue”</td>
<td>Interview</td>
<td>Communication &amp; language, working practices</td>
<td>Participants purposefully interact in pairs to identify how to achieve their tasks</td>
<td></td>
</tr>
<tr>
<td>“So we had to make sure that we were liaising with what these designers had in their minds to what is happening in the real world... it is very much a matter of experience and knowing the people involved”</td>
<td>Interview</td>
<td>Compromise, identity, social capital, working practices</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 – From data to insight and new conceptual category (pair-wise relations: dependence)
Cross case findings – a comparison of design case studies

Conceptual categories (e.g. Dependence and Opportunity) under each research construct (e.g. pair-wise relations) were developed through clustering of memos and insights and identifying those that explained cross-case patterns and addressed the Research Question. There was a clear distinction between clusters about how participants interacted in pairs and how they relied on pair-wise understanding to achieve their activities according to design type and design setting (see Table 5 for details). This led to creating two conceptual categories to explain cross-case patterns: Opportunity and Dependence on pair-wise relations.

In carrying out product design and manufacture in a group individuals develop pair-wise relations (unconsciously and consciously) through dividing resources and coordinating how tasks are accomplished together. Pair-wise relations cover interactions in pairs, and Task and Team aspects of understanding shared by a pair of individuals (see section 6.2 for sample quote, recorded in Definitions p. xii). Cross-case findings on pair-wise relations are split into two sections: Opportunity for pair-wise relations (6.3.1), and Dependence on pair-wise relations (6.3.2) (shown in Figure 30).

![Figure 30 – Categories in Pair-wise relations: Opportunity and Dependence](image)

### 6.3.1 Opportunity for pair-wise relations

The conceptual category of Opportunity includes data to describe the prospects participants had for interacting in pairs (recorded in Definitions p. xii). Opportunity for pair wise relations in each case occurred within and across departments and organisations. There was a greater frequency of opportunities for interaction in pairs of project members in intra than inter-organisational projects. Probe & Engine participants interacted with each other on a daily basis; in inter-organisational cases (Wing & Medical) participants were more likely to interact with participants from their own organisation than other organisations on daily basis. When participants did create opportunity for pair-wise interaction and understanding across organisations it was often motivated by the need to acquire information for their tasks:

“They normally send [information], Alex is email but he does phone as well, Chris phones quite a bit. I don’t think Jo has ever phoned me. It has
been that I have had to chase her but then her time on the project is much
less than the rest of us that are on it” (Wing) 3

Where there was a greater frequency of opportunities, participants developed their pair-
wise understanding of how to achieve tasks together (Task & Team aspects). Thus the first
finding is:

Finding 1. Individuals interact with each other more when there are more
opportunities and continue to develop understanding in pairs to achieve their tasks
together. This was more evident in intra-organisational design projects.

A contributing factor to there being a greater frequency of opportunities for relations
within an organisation (all cases) was physical co-location. Comparing cases, not all
participants were co-located, they could be in a different building (Engine) or different
buildings and sites (Probe, Wing & Medical). This suggests that it is not simply whether a
project is intra or inter-organisational that creates opportunities for interaction and
understanding in pairs, but if participants are co-located in the same organisation.
Furthermore co-location was less likely in original than adaptive design cases (Engine &
Medical) as expertise from a number of departments and organisations was used:

“Sometimes the interfaces between them are not talked about enough.
Therefore they don’t get the message of how they should relate to another
part… practically that doesn’t happen so it is about geography” (Engine)

Thus:

Finding 2. When participants are not physically co-located there are fewer
opportunities to develop understanding in pairs about how to collaborate. Participants
were more geographically dispersed in inter-organisational and original design
projects.

There were further opportunities for interaction and shared understanding where
participants worked together on other projects or had previous experience of working
together:

“Yeah, I probably see Sam more than all the other guys. At least 2 or 3
times a week Sam [and I] will sit down for a chat… go through bits and
pieces, not always that project, sometimes other projects that he is working
on” (Probe)

3 Note – participants’ names in all quotes have been changed.
<table>
<thead>
<tr>
<th>Feature</th>
<th>Probe</th>
<th>Engine</th>
<th>Wing</th>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opportunity for pair-wise relations</td>
<td>- Regular frequency (daily)</td>
<td>- Regular frequency (daily)</td>
<td>- Regular frequency (internal – daily, external – as information required)</td>
<td>- Regular frequency (internal – daily, external – as information required)</td>
</tr>
<tr>
<td></td>
<td>- Majority co-located</td>
<td>- Some co-located, particularly those in same department</td>
<td>- Few co-located even in same organisation</td>
<td>- Majority of those in same organisation co-located</td>
</tr>
<tr>
<td></td>
<td>- Majority interact on multiple projects</td>
<td>- Those in same department interact on other projects</td>
<td>- Some from same organisation interact on other projects</td>
<td>- All from same organisation interact on other projects</td>
</tr>
<tr>
<td></td>
<td>- Majority have experience of working together</td>
<td>- Majority have experience of working together</td>
<td>- Majority of those within same organisation have experience of working together</td>
<td>- Those within same organisation have experience of working together</td>
</tr>
<tr>
<td>Dependence on pair-wise relations</td>
<td>- Activities achieved using similar organisation working practices &amp; across overlapping technical disciplines</td>
<td>- Activities achieved using similar organisation working practices &amp; across complementary technical disciplines</td>
<td>- Activities achieved using distributed organisation working practices &amp; across overlapping technical disciplines</td>
<td>- Activities achieved using distributed organisation working practices &amp; across complementary technical disciplines</td>
</tr>
<tr>
<td></td>
<td>- Standard design procedures used to establish links between individuals’ tasks</td>
<td>- Modified design procedures used with participants establishing new links between individuals’ tasks</td>
<td>- Combining standard design procedures with participants establishing new links in individuals’ tasks</td>
<td>- Modified &amp; combined design procedures with participants establishing new links in individuals’ tasks</td>
</tr>
<tr>
<td></td>
<td>- New roles &amp; tasks for some individuals</td>
<td>- New tasks for all, new roles for some</td>
<td>- New tasks for some, new roles for some</td>
<td>- New tasks for all, new roles for some</td>
</tr>
<tr>
<td></td>
<td>- Higher individual stake where role or task new</td>
<td>- Individual stakes high</td>
<td>- Individual stake higher where role or task new</td>
<td>- Individual stakes all medium-high</td>
</tr>
</tbody>
</table>
Joint project work or prior experience of each other was evident in intra-organisational projects but was not universal. Some participants in intra-organisational projects were new to each other and some participants in inter-organisational projects had previously worked together – typically those in the same organisation or those working in a large programme of work.

Considering design type, the nature of original design projects brought together more diverse expertise than those in adaptive cases. Consequently there were fewer original design projects in each organisation and participants in such projects had less experience of working together, either previously or in other current original design projects, than those in adaptive design projects. Summarising:

Finding 3. When participants work together on other projects (current or past) there are additional opportunities for pair-wise interaction and shared understanding. This was more likely in intra-organisational and adaptive design projects.

6.3.2 Dependence on pair-wise relations

The second category from cross-case analysis is Dependence on pair-wise relations. This covers data about the extent an individual requires something from another individual to achieve their aims and activities (recorded in Definitions p. xii). In this research two aspects – activity and reputation, have emerged in considering Dependence on pair-wise relations.

Activity interdependence

To design an artefact involving more than one individual it is divided into component parts or solutions. Tasks are generated to achieve solutions for each component part and to coordinate synthesis of each solutions into a whole product.

“Design is like bringing it all together. It’s bringing together all the aerodynamic, stress work and those sorts of things and bringing it all together and turning that into a physical thing you can touch” (Engine)

This splitting and then unifying of component solutions inherently creates dependence between activities for individuals in a project. Individual recognition of activity dependencies was linked to participants’ technical backgrounds and established organisational working practices. The first finding links dependence on pair-wise relations to how technical expertise was shared. At an individual level in intra-organisational cases participants shared a similar Team understanding of a project through similar organisation working practices – these outlined role dependencies in a project. In comparison, inter-
organisational cases had distributed organisational working practices with few established links e.g. Medical included organisation working practices covering product design, microbiology research, emulsion technology products. Participants themselves identified potential dependencies between each other to plan and achieve their activities in a project.

In adaptive design cases individuals identified dependence through their overlapping understanding of design procedures, potential scenarios etc. In contrast those in original design cases shared complementary understanding, and participants combined their knowledge from independent technical disciplines to design together. Sharing knowledge from complementary disciplines (Engine and Medical) created a high dependence between participants and prompted pair-wise interaction for individuals to understand how to complete their activities together.

“When you meet somebody first of all, you are trying to tune into them on a personal level; and also their expectations, their experience, what will they be assuming what are they not asking, they should be asking, do they understand the concept from the specification” (Medical)

Where participants shared understanding that was similar or overlapping there was a lower dependence on interaction between individuals to complete their activities; participants were more familiar with how expertise and activities combined, hence initiating and sustaining inter-personal interaction was less critical to understand activity dependencies and achieve their own work. Consequently:

**Finding 4.** There was a greater reliance on pair-wise relations to achieve a participant’s activities where individuals shared complementary Task understanding or distributed Team understanding. This was more evident in inter-organisational and original design type projects.

In addition to sharing technical understanding in a variety of ways, the content of what is shared by individuals differs across cases. Design procedures are used to define what is required to achieve a complete design (Task and Team understanding). Where design procedures were fixed, predefined and common to all i.e. in Probe, what activities were required and how they were dependent upon each other was clearly outlined. Where there were modifications to design procedures, i.e. in Engine, or design procedures were combined, i.e. in inter-organisational cases (Wing, Medical), individuals, instead of design procedures, established links and dependence of activities:
“I have made efforts for experienced people to go along side less experienced people to make sure that they understand the review process and the design detail” (Engine)

This expands an individual’s role from following design process to defining and maintaining design procedures. This was more evident in original and inter-organisational cases than adaptive and intra-organisational cases. This also identifies where pair-wise relations is more likely to be required to accomplish an individual’s activities.

**Finding 5.** Participants establish role dependencies and design contingences through pair-wise interaction when design processes are modified or combined. This was more likely in inter-organisational and original design type cases.

**Reputational stake**

In each case, achieving individual activities required information from other participants. In particular, there were links between the novelty of activities for participants and what was at stake for individual reputation i.e. if a project didn’t go as expected. Those performing activities that they were accustomed to or had experience of, were typically content to focus on their own work. In contrast, where activities were new to an individual they were more likely to interact in pairs to achieve their work. In each case there was a variety of both. One explanation for these different approaches is that when activities were new to individuals, the purpose of developing pair-wise relations was to express their own priorities and maintain their own reputation. Participants actively created an impression:

“You pick up how knowledgeable they are, if they ask technical questions or if they are talking rubbish…or how responsive they are to you. For example the main contact Robin… extremely efficient, extremely questioning, and… will answer it pretty much immediately. And asks some pretty pertinent questions as well” (Wing)

Looking at the cases there was relatively more at stake for individual reputation in inter-organisational and original projects where activities were more novel and how to share working methods and procedures was less explicit. This increase in risk to individual reputation relates to a greater individual reward in participating in original and inter-organisational projects as they were less frequent and provided new technical and social challenges. This was illustrated by individuals being active in interacting with other participants to build pair-wise shared understanding of scenarios, role dependency and priorities. Thus:
Finding 6. Individuals maintain their own reputation by actively conveying their project priorities and judging others’ priorities in pairs when activities are novel to them. This was more likely in, but not exclusive to, inter-organisational and original design cases.

Findings have been presented on the first conceptual construct in this research. These findings are extended in section 6.6 considering interaction between each conceptual construct (i.e. pair-wise relations, group relations, outcomes). Next findings on group relations are presented.

6.4 Group relations

In this section cross-case findings for the construct group relations are presented (see Table 6 for details). Group relations include interaction in a project group and both Task and Team aspects of understanding shared by a project group (see section 6.2 for sample quote, recorded in Definitions p. xii). Cross-case findings on group relations are split into two sections: Opportunity for group relations, and Dependence on group relations (shown in Figure 31).

![Group relations: opportunity and dependence categories](image)

Figure 31 – Group relations: opportunity and dependence categories

6.4.1 Opportunity for group relations

The first category of Opportunity for group relations matches the first category in pair-wise relations. This conceptual category covers prospects participants had for interacting as a group (recorded in Definitions p. xii). Contrasting inter and intra-organisational cases it is clear that opportunity for group relations differed. Group interaction in intra-organisational cases was constant in periodicity and trends i.e. regular 1-1.5hrs weekly meetings:

“Because we have a regular Friday meeting the team is aware of the progress, the team is aware of major issues that come up and minor issues too” (Probe)
In comparison group interaction including participants from each organisation in inter-organisational cases was less regular – it was less frequent (monthly at most, quarterly at least), was typically prompted by changes in project progress, and varied between 1 and 5 hrs (see Table 6). It is clear that intra-organisational cases had more frequent opportunity for group relations than inter-organisational cases. All cases had ad hoc meetings in smaller sub-groups but those in inter-organisational cases were less frequent, less likely to be face to face and less likely to involve participants from each technical area involved. As opportunities were fewer and less regular in inter-organisational cases, a project group’s shared understanding of current developments, potential changes, etc was updated less often. This could lead to discrepancies between individuals’ understanding of how a project was progressing. Thus:

**Finding 7.** Opportunities were fewer and less regular for group interaction and reviewing group progress in inter-organisational cases.

How individuals coordinate work in groups is influenced by resourcing practices in each organisation. In each case concurrent design procedures were used and participants worked on a number of projects simultaneously. Participants’ availability for each project frequently changed and influenced membership in, and opportunities for building a group shared understanding (both Task and Team aspects):

“Unfortunately projects do slip and people are unavailable for certain times, and you have to be fairly reactive almost on a daily basis to make sure that those requirements are met” (Wing)

These changes in availability were beyond what was originally predicted when resources were allocated for a project. Intra-organisational cases benefitted over inter-organisational cases as participants were more likely to work together on other projects and so have further opportunities to maintain some shared understanding of how a project was developing albeit in smaller sub-groups. This was influenced by organisational structure – where departments were structured around products (e.g. Probe) there were more opportunities for the same individuals to have other projects in common, than in organisations that defined departments based on technical domains (e.g. Engine):

“We have [department] meetings every Monday morning and get together around the table. Everybody says what he is doing, what he did last week and what he is going to be doing next week. and if there is a particular task that has got a high priority, then we will make that those who need to be involved with that know about it... we basically talk to each other continuously… we also have a [project] meeting every Friday” (Probe)
### Table 6 – Group relations

<table>
<thead>
<tr>
<th>Feature</th>
<th>Probe</th>
<th>Engine</th>
<th>Wing</th>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Opportunity for group relations</strong></td>
<td>- High periodicity &amp; constant trend (1 per week; 1-1.5hrs)</td>
<td>- High periodicity &amp; constant trend (1 per week; 1-1.5hrs)</td>
<td>- Medium periodicity &amp; variable trend (1 per month max, 1 per 3 months min; 1-3hrs)</td>
<td>- Variable periodicity &amp; variable trend (1 per month max, 1 per 5 months min – linked to changes in progress; 1-5hrs)</td>
</tr>
<tr>
<td></td>
<td>- Daily informal interaction in group</td>
<td>- Daily informal interaction as sub groups (e.g. departments)</td>
<td>- Daily informal interaction as sub groups (e.g. within departments and organisations)</td>
<td>- Daily informal interaction as sub groups (e.g. within departments and organisations)</td>
</tr>
<tr>
<td></td>
<td>- Group interaction changes due to individual availability / role</td>
<td>- Group interaction changes due to individual availability / role</td>
<td>- Group interaction changes due to individual availability / role</td>
<td>- Group interaction changes due to individual availability / role</td>
</tr>
<tr>
<td></td>
<td>- Likely to work as group on other projects as product based</td>
<td>- Less likely to work as group on other projects as technical domain</td>
<td>- Unlikely to work as group on other projects as multiple organisations involved</td>
<td>- Unlikely to work as group on other projects as multiple organisations involved</td>
</tr>
<tr>
<td></td>
<td>organisation structure</td>
<td>based organisation structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Dependence on group relations</strong></td>
<td>- Group design constraints &amp; scenarios set via sharing overlapping technical expertise in one market sector &amp; organisation</td>
<td>- Group design constraints &amp; scenarios set via sharing overlapping technical expertise in one market sector &amp; organisation</td>
<td>- Group design constraints &amp; scenarios set via sharing complementary technical expertise in one market sector distributed across multiple organisations</td>
<td>- Group design constraints &amp; scenarios set via sharing complementary technical expertise in three market sectors &amp; distributed across multiple organisations</td>
</tr>
<tr>
<td></td>
<td>- Design constraints &amp; scenarios fixed early in design process</td>
<td>- Design constraints &amp; scenarios evolved as design solutions developed</td>
<td>- Design constraints &amp; scenarios defined early in design process</td>
<td>- Design constraints &amp; scenarios evolved as design solutions developed</td>
</tr>
<tr>
<td></td>
<td>- One design procedure outlines task links</td>
<td>- One design procedure outlines task links; R&amp;D prototype; internal review</td>
<td>- Combining multiple design procedures to outline task links</td>
<td>- Combining multiple design procedures to outline task links</td>
</tr>
<tr>
<td></td>
<td>- Replacement product (1 of many in organisation); normal stake for organisation &amp; departments reputation</td>
<td>- Low stake for organisation reputation</td>
<td>- R&amp;D prototype; external review; Mixed stakes for organisations &amp; departments reputation (low - medium; role dependent)</td>
<td>- Novel product (only one in organisation); external advisory review; mixed stakes for organisations &amp; departments reputation (medium - high; role dependent)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Mixed stakes for departments reputation (low – high; role dependent)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Interestingly, patterns of participants’ availability in adaptive and original design type cases showed no noticeable differences. In summary, participants’ unpredictable change in availability had potentially less impact on a group recognising current progress in intra-organisational cases, leading to the next finding:

**Finding 8.** Unexpected changes to individual availability reduced opportunity for group interaction limiting recognition of current progress. Intra-organisational cases with product domain orientated organisational structures were least affected.

### 6.4.2 Dependence on group relations

The category of Dependence on group relations covers data on the extent to which participants require something from a project group to achieve their aims and activities (recorded in Definitions p. xii). Dependence on group relations has two aspects: activity and reputation.

**Activity interdependence**

In engineering design there is inherently a reliance on participants to function effectively as a group to bring together diverse perspectives in a designed product. Where group relations represented the different levels of interdependence in a project group, individual activities were unified into one product. This is shown by first considering how participants shared understanding about their activities.

In Probe, Engine and Wing participants either shared similar organisation working practices in one market sector (Probe, Engine) or overlapping technical expertise (Probe, Wing). This sharing was apparent in an established group understanding (Task and/or Team) that provided a framework for participants to interpret each other’s behaviour, e.g. what terminology implied (Task), and what each role was for (Team). Sharing similar or overlapping understanding reduced possible misperceptions of events and group interaction. In contrast, where sharing technical expertise was complementary and involved distributed organisation working practices representing multiple market sectors (Medical), design constraints and scenarios from each aspect involved was less likely to be visible to other parties:

“I guess that everybody comes to these things [projects] with different baggage, which is partly cultural and partly commercial and you just have to sift through it and work out an engagement strategy” (Medical)

This placed a greater pressure on a project group to interact and develop their shared understanding to combine their skills effectively. In Medical participants struggled to
maintain group shared understanding as individuals focused on completing their tasks. This led to risks being misunderstood e.g. technology development was planned to be completed in 12 months and participants believed that it was a matter of time to accomplishing it when delays occurred. Instead, there was always a constant risk that the technology itself was not possible and hence the group initially misjudged the extent of their reliance on technology development. Thus:

**Finding 9.** Where participants share complementary technical understanding (original designs) and distributed organisational working practices (inter-organisational cases) there is a greater reliance on a project group to identify design constraints and risks.

The content of what was shared as a group was different in each case. In adaptive design cases, dependence between design activities was typically more predetermined or fixed at an early stage in design phases than in original design cases. For example there was a clear and established group understanding (Task) of how electronic, mechanical and software solutions were constrained by each other from the beginning of the project in Probe. In contrast, Task group understanding of how solutions influenced each other evolved in Engine and Medical as component designs were finalised.

By defining this information earlier in adaptive cases (Probe, Wing) there was a greater visibility and certainty about interdependence between design activities. Participants were subsequently more likely to be aware of who is doing what, when and why. In contrast, original design type cases (Engine, Medical) had to create and maintain a group shared understanding to highlight potential activity interdependence as designs evolved. This dynamic nature of group shared understanding required further effort from individuals to be aware of current project expectations.

Contrasting intra and inter-organisational cases, design procedures were less visible to participants in inter-organisational cases (Wing, Medical). This placed a greater emphasis on group interaction and shared understanding to discover and bring together what participants saw as relevant aspects of each organisational design process.

“I was less clear about that [ResOrg budget for testing] initially. I suppose that is possibly something that I hadn’t appreciated... It was then the second day of testing [new design requirement] that was the sticking point. So that was when things perhaps got a little more clearer about you know what people could contribute to and what people couldn’t” (Wing)

The purpose was to identify individual’s interdependencies (Team) and potential scenarios (Task) for a project group to establish expectations on how to achieve their
activities together. When design requirements changed during the process of designing, updating interdependencies took time and effort and participants struggled to appreciate how each other was affected. Consequently:

**Finding 10.** Where design procedures were less predetermined or more likely to change, role dependencies and design contingencies in the group were less visible and required periodic review. This was more typical in original design and inter-organisational cases.

**Reputational stake**

A second aspect characterising dependence on *group relations* is reputation i.e. detriment to the reputation of departments and organisations involved if a project did not go as expected. In each case these stakes were indicated to participants through their work priorities and hence availability for a project.

In adaptive cases the departments involved all had a similar level of reputation at stake i.e. each department saw this project as not their highest priority and achieving specific timescales was not critical. This meant that participants regularly switched between projects with each project group making alterations. In original design projects there was more variation in how each department’s reputation was affected, i.e. it was more important for some departments than others. This was reflected in individuals’ availability on a project. The lead department (ATech) in Engine had a high reputational stake as they were expanding their traditional domain of work by developing new design processes:

“We are doing hard projects, physical projects, not just paper studies – where the track record of this department is largely 90% of the time, in the past almost 100% of the time” (Engine)

However participants from some departments were not available as expected:

“Most of the designers are pretty constant on the job. Not entirely. And that held us up in combustion, who were going very well, and had actually had pretty important things to attend to. Far more important than this project” (Engine)

An explanation for this lies in looking at organisational stakes in Engine. This project was a prototype for internal research that had little impact outside the organisation; hence even if departments had a high stake in a project, organisational priorities had a more significant influence on participant availability.

Continuing to look at reputation for organisations, both adaptive cases (Probe, Wing) had more at stake than AeroOrg in Engine. Probe was a replacement product for the
organisation so the project group were mindful that they had to achieve the corresponding design quality (organisational reputation) whilst recognising that other projects may have a higher priority. This meant that slow project progress (including delays from participants being unavailable) was acceptable to the group as long as they achieved the required design quality. In Wing, participating organisations maintained their reputation as external parties reviewed the project and all had prior links of working together (organisations). Wing itself was not a high priority and hence participant availability varied. This variation created differences between participants as each organisation had a different amount of reputation at stake – related to their role. This introduced different expectations about how a group should achieve its activities and thus a reliance on group relations to bring together different standards.

This variation in reputational stake for organisations was also evident in Medical yet less visible as SpinOutOrg provided all the finances. External organisations provided staff to the level set out by SpinOutOrg leading to the impression that all were committed to the project in a similar way i.e. had similar stakes. However SpinOutOrg had the highest risk to their reputation. They were developing an original design to address a gap in the market and establish their company. SpinOutOrg was only one of a number of clients for each external organisation who all had no prior history of working together or within the same market sector. This meant that reputations of participating organisations were only linked in developing this product. This variation of reputational stakes was difficult for participants to reflect in their group understanding yet key for individual organisations to decide their priorities and how to achieve their tasks.

There were different amounts of reputation at stake for each department and organisation creating different priorities for participants and potential conflict in a project. In each case it was necessary for a project group to gather these different priorities to understand how to achieve their work together (via group relations), thus:

**Finding 11.** Organisations and departments maintained their own reputation by conveying their priorities and allotting participants’ availability for a project. There was a greater variation of organisational reputation stakes in inter-organisational cases and of departmental reputation stakes in original design cases.

In these findings (Findings 1-11) there are similar challenges for individuals in pair-wise relations and group relations, yet differences in project context (design setting, design type) influence participants’ interaction in pairs and as a project group. This leads to a dilemma in collaborating.
6.4.3 A dilemma in collaborating

Findings presented under features categories Opportunity and Dependence reveal a dilemma for those collaborating in engineering design. As participants were brought together across departments, organisations and disciplines, there were greater hurdles to collaborating (noted even in an adaptive design and intra-organisational case):

“If we are all in the same team, same room, same building it just makes it so much easier, all to do with an immediate response. As I was saying earlier with the development work, you are in control of it yourself. As soon as you have an outside influence, someone else you have to go to get an answer, then things start to take time” (Probe)

As participants took part in more challenging design projects, i.e. inter-organisational or original design cases, there were fewer occasions to interact and share understanding in pair-wise relations (Findings 1-3) and group relations (Findings 7-8); yet a greater reliance on interacting and sharing understanding in pair-wise relations and group relations to achieve individual and group activities (Findings 4-6, & Findings 9-11 respectively).

In particular, participants in inter-organisational cases (Wing, Medical) had less opportunity for collaborating yet a greater reliance on sharing Team understanding to collaborate (pair-wise relations & group relations) than intra-organisational cases. Participants came together from multiples organisations that were geographically and organisationally distributed that reduced possibilities for collaborating. Simultaneously, participants were less aware of each others’ capabilities (individuals, departments and organisations) and hence actively developed their understanding of each other to collaborate.

Furthermore in original design cases (Engine, Medical) participants had fewer occasions for collaborating yet a greater reliance on sharing Task understanding (pair-wise relations & group relations) than adaptive design cases. Participants represented different and sometimes highly specialised technical disciplines that were geographically separated (though sometimes on one site) which limited interaction. At the same time, participants had a greater need to develop their shared understanding of technical expertise involved (scenarios, methods, language) to comprehend how each aspect contributed to their own activities and the overall design.

This presented individuals with a dilemma – how to manage with fewer occasions of interaction yet achieve their activities through a greater reliance on each other? Participants responded to this dilemma by altering their interaction patterns and their awareness of
tasks, behaviour and events. Findings under *pair-wise relations* and *group relations* show that two conceptual features (Opportunity, Dependence) describe similar influences on how participants collaborate in pairs and a group. Interaction and awareness in pairs and a group both reduced as organisational boundaries were crossed or multiple disciplines involved. Notably the balance between *pair-wise relations* and *group relations* altered – participants increased their interaction in pairs when group meetings were less feasible. Collaborating in pairs hence supplemented or substituted *group relations*. Interaction and awareness through *pair-wise relations* presented additional flexibility for individuals e.g. more possibilities to gain information, but created more space for multiple standards and expectations to manifest between participants.

In each case participants had different project expectations, however where fewer boundaries were crossed individuals’ expectations were more aligned. Of specific interest in this research is understanding how participants reacted when plans were not achieved as envisaged – something that occurred in each case. In particular understanding how participants recognised different expectations, defined aligned expectations and maintained them. This is covered next in *outcomes*.

### 6.5 Outcomes

In this section cross-case findings on *outcomes* are presented. *Outcomes* in this research is split into two features – Results (6.5.1) and Adjustments (6.5.2). Results are project and interim events e.g. project completion, project participation. Adjustments are participants’ affective reactions in achieving their activities together and concerns building and maintaining relations with participants to work effectively together (illustrated in Figure 32).

![Outcomes](image)

**Figure 32 – Outcomes: Results; Adjustments in trust, commitment, and control**

#### 6.5.1 Results

Findings under Results cover project completion, project participation, delays, design revisions and requirements for additional resources (see Table 7 for details, section 6.2.3
for sample quote, recorded in Definitions p. xii). Under project results, it is clear that three of the four projects completed product design (MacProb, SmallEng, WingDam) with the fourth still pursuing a developed prototype when data collection finished. This observation itself does little though to highlight patterns across the cases based on design setting or design type. There is also no clear pattern in data on interim results. In each case there were delays, multiple design revisions, changes in project participation and requests for further resources (financial and or individual effort). In sum this presents a complex and mixed picture when contrasting events and patterns across the four cases. Evidently comparisons based on design type and design setting with four cases cannot explain any potential patterns.

6.5.2 Adjustments

Detailed information about cross-case findings on Adjustments are presented in Table 8. Adjustments in this research are participants’ affective reactions in achieving their activities together and concern building and maintaining relations with participants to work effectively together (see section 6.2.3 for sample quote, recorded in Definitions p. xii). This focuses on individuals’ adjustments to achieve their activities when Results challenged their expectations i.e. when there were changes to project participation, delays, design revisions, or requirements for additional resources (finances or individual effort). Reactions are classified into three topics: 1. Trust, 2. Commitment, and 3. Control.

Adjustments in trust

In each case expectations about a project were challenged with participants adjusting how they achieved their activities. To recognise different expectations in a project group, participants identified how to trust each other, that is they developed a confidence in other participants’ abilities to perform their activities. This includes elements that increase participants’ confidence in matching expectations and outcomes (individual or group) covering individual goodwill, honesty and competence in meeting obligations (see Definitions p. xii for ‘trust’ description). This was particularly evident where participants were less familiar with how changes in individual activities affected other tasks, i.e. in inter-organisational or original design cases.
### Table 7 – Outcomes: Results

<table>
<thead>
<tr>
<th>Results</th>
<th>Probe</th>
<th>Engine</th>
<th>Wing</th>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype completion</td>
<td>• Prototype tested, product on sale</td>
<td>• R&amp;D prototype tested</td>
<td>• R&amp;D prototype tested</td>
<td>• Prototype untested (technology in development), product not on sale</td>
</tr>
<tr>
<td>Delays</td>
<td>• Limited access to machines</td>
<td>• Resolving drawing standards delayed accepting components</td>
<td>• Unusually long lead time for materials procurement delays manufacture</td>
<td>• Technology development repeatedly misses deadlines</td>
</tr>
<tr>
<td></td>
<td>• Software solution delayed review and testing program</td>
<td>• Ambitious design targets slipped</td>
<td>• Establishing test format delayed as test date postponed</td>
<td>• Clinical trials postponed</td>
</tr>
<tr>
<td></td>
<td>• Display-only prototype at trade show</td>
<td>• Late starting long lead time design solutions</td>
<td>• Extensions to timescales acceptable</td>
<td>• Extensions to timescales less acceptable to lead NewSpinOrg</td>
</tr>
<tr>
<td></td>
<td>• Extensions to timescales acceptable</td>
<td>• Test date postponed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design revisions</td>
<td>• Procedure for revisions clear and constant to all participants (software, electronics, then mechanical elements)</td>
<td>• Designs approved through modified procedures by departments &amp; project</td>
<td>• Designs approved through monthly group meetings</td>
<td>• EU directives outline long process for liquid product</td>
</tr>
<tr>
<td></td>
<td>• Iterative design process through testing and modifying prototype</td>
<td>• Some designs revisions based on time constraints instead of project aims</td>
<td>• Two concepts selected for testing</td>
<td>• Designs revised as project aims alter, approved by NewSpinOrg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Iterative design revisions prior to testing</td>
<td>• Iterative design revisions post selection of core structure and material</td>
<td>• Iterative design as technology becomes more defined</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Technical advisory board supports steps taken in technology development</td>
</tr>
<tr>
<td>Project participation</td>
<td>• New project team for part-designed prototype</td>
<td>• Project understaffed from start</td>
<td>• All participants worked on multiple projects concurrently</td>
<td>• Most participants worked on multiple projects concurrently</td>
</tr>
<tr>
<td></td>
<td>• Project coordinator changed</td>
<td>• Participants prioritised this project when task/role part of current design phase</td>
<td>• Participants attend project meetings when topics relate to task/role</td>
<td>• Participants prioritised this project</td>
</tr>
<tr>
<td></td>
<td>• All participants worked on multiple projects concurrently</td>
<td>• Most participants worked on multiple projects concurrently</td>
<td>• Group meetings stop when there is no progress to discuss</td>
<td>• Software designer replaced by commercial design organisation</td>
</tr>
<tr>
<td></td>
<td>• Participants often spent their time working on other projects</td>
<td></td>
<td></td>
<td>• Third parties stepped back from project when technology progress not achieved</td>
</tr>
<tr>
<td>Additional resources</td>
<td>• Budget negotiable</td>
<td>• Fixed budget</td>
<td>• Fixed budget</td>
<td>• Budget negotiable</td>
</tr>
<tr>
<td></td>
<td>• Support from other departments when requested</td>
<td>• Supplementary effort and work required to meet deadlines</td>
<td>• Further finances required from two organisations for second days testing</td>
<td>• Multiple organisations were involved as product development progressed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Third parties contributed some of their time without billing for it</td>
</tr>
</tbody>
</table>
### Table 8 – Outcomes: Adjustments

<table>
<thead>
<tr>
<th>Feature</th>
<th>Probes</th>
<th>Engine</th>
<th>Wing</th>
<th>Medical</th>
</tr>
</thead>
</table>
| **Adjustments in trust** | • Individuals’ confidence in completing product design unaffected as delays seen as part of development process  
     • Inherent trust as design revisions within expected working practices  
     • Participants continue project with finances guaranteed to achieve replacement product for organisation | • Delays question confidence in participants finishing tasks on time  
     • Trust in each other evaluated when working practices not applied as expected  
     • Confidence in each other develops as participants achieve activities to required standards despite limited finances | • Individuals need confidence that participants are contributing similar effort during delays  
     • Trust from overlapping technical expertise as design changes seen as acceptable  
     • Confidence in partners questioned as project aims modified and finances available for testing limited | • Individuals’ confidence changes as repeated delays over technology development  
     • Trust in each other reviewed when participants’ progress not as expected – particularly when unfamiliar with working practices  
     • NewSpinOrg supported additional requests for finance based on their confidence in participants |
| **Adjustments in commitment** | • Individuals carried out design changes as expected following normal design processes  
     • Small changes in project membership within normal working practices  
     • Finances available for participants to work on tasks as required | • Design changes required most participants to make additional refinements  
     • Organisational priorities change some participants’ availability during project limiting design analysis  
     • Participants typically finish their activities regardless of finances available | • Design changes altered timescales for individuals to manufacture prototype  
     • Changes in membership as individual tasks are finished reduced project priority for some organisations  
     • Additional testing required individuals to contribute extra finances | • Design changes alter priority of work for participants, who was involved in meetings and active on the project  
     • Participants who were less involved reduced their individual commitment to project  
     • Slow progress limited finances and reduced some individuals’ involvement |
| **Adjustments in control** | • One technical expert oversees design changes to normal design standards  
     • Regular progress updates to all; consistent participation in weekly meetings  
     • Impact of delays on activities managed by project coordinator | • One technical expert oversees design changes based on modified design standards  
     • Participants take on extra work to ensure all design tasks are completed  
     • Impact of delays on activities managed by project manager | • Design changes required discussion with participants from each organisation to maintain group standards  
     • Irregular participant attendance in meetings delayed decision making for testing details  
     • All individuals active in acquiring information to understand impact of delays on individual activities | • Design changes required discussion with participants from each organisation to maintain group standards  
     • Technology specialists attend fewer group meetings at request of NewSpinOrg  
     • Majority active in acquiring information to understand impact of delays on individual activities |
Hence individuals were more active in recognising how to trust each other e.g. in MedDev participants repeatedly used meetings and informal talks to make out how competent other individuals were at their tasks.

Individual confidence was initially based on their own experience and working practices. In intra-organisational cases when there were design changes in prototyping participants developed their confidence in each other’s expertise and how roles fit together from following the same organisational standards and practices:

“I think it is a familiarity with each other, a familiarity with the product. Because at the start of [stage 1] testing you haven’t fully characterised how the product will perform in every situation. At the end of [stage 1] testing you have seen how it performs in every situation and you have certain confidence in the product so that means that you are more generally confident as a team” (Probe)

This was more effort for participants in inter-organisational cases as there were multiple and different organisational standards and more questions were raised:

“Jamie and I will cheerfully say we have to deal with the university, how do we do that? We automatically think that it is a different entity with a different process that we have to work our system around” (Medical)

To cope with and achieve their own activities, participants in inter-organisational cases recognised standards of behaviour through interaction (i.e. social processes). For example when there were delays, individuals checked with each other on their future availability to be confident about how much effort they could expect and should apply themselves:

“I think it is more of a confidence of knowing that everyone is doing their bit. If you are more aware of what is going on, you can foresee if there might be an issue… if there is anything you may need to cover. Because everyone is working in their organisations… you can’t just go over and speak to them. I think it is important to have that visibility to know that you are not slogging your guts out and nobody else is” (Wing)

In adaptive cases when there were design changes, participants placed their confidence in established design procedures and overlapping technical expertise to recognise different design expectations (Task). Participants’ confidence came from identifying this visibility:

“I think with any partnership you do need to have overlapping skills. All of the partners do have what I would call static design capabilities. That is the capability to look at a basic design to see if that is sensible and it will
work… it allows for visibility amongst the group – what people realise is what we are making is actually going to work” (Wing)

In original design cases, it was less established how participants were to use design procedures and share technical expertise. As more finances were required (expectations challenged), participants developed a confidence in each other to recognise what individuals meant and how it may influence their own design activities (Task):

“It is knowing when you can be absolutely straight with somebody and say we can do this for you but the rules have changed, it is going to cost another X thousands pounds. And somebody says we understand that, that is fine. It is a lot to do with money” (Medical)

Thus participants evaluated their confidence in other participants i.e. how to trust them, when they were sharing unfamiliar technical knowledge (Task expectations) or working with unfamiliar people (Team). Consequently:

**Finding 12.** As expectations about a project were challenged (e.g. delays), participants distinguished how to trust each other to recognise different expectations. Individuals in inter-organisational and original design projects were more active in identifying how to trust each other as differences in project expectations were less clear.

**Adjustments in commitment**

Further to building confidence in each other, participants redefined their commitments to a project as it progressed to establish aligned expectations (see Definition for description of ‘commitment’). This was particularly evident when individual expectations were challenged e.g. delays, design modifications, changes in participation or resource requirements. In intra-organisational and adaptive projects, participants were guided by shared working practices with established design procedures; however in inter-organisational and original design cases participants defined aligned expectations through social interaction.

In each project as expectations were challenged individuals re-established their commitment. In intra-organisational cases where there were design changes, organisational working practices outlined participants’ responsibility in establishing a satisfactory decision (aligned Team expectations):
“From a technical managers viewpoint I would give my best opinion of a way forward on this design change, and then that would be discussed with the stakeholders so the ultimate decisions is made with the stakeholders”
(Probe)

Establishing participants’ commitment when expectations were challenged was more effort in inter-organisational cases as multiple working practices were affected by the change. For example, where design aims evolved and additional finances were required, participants were active in outlining their role in a project and what they were obliged to undertake. This was to establish aligned contributions from participants (Team expectations):

“We have really interesting results and we have identified the potential… of coming up with a very good design. But to prove that we would probably have to make three or four [prototypes], where the programme has only budgeted for one. So there is a slight degree of frustration… whether we should cut a bit out of a different program and look to direct more funding into this particular team” (Wing)

In adaptive cases when staff were not available as planned, participants established each other’s responsibility from their overlapping design procedures and technical expertise. Participants hence established acceptable standards for task completion (aligned expectations):

“It is priorities, money – it is everything. So to go down the priorities route, like I said, some of the tooling is taking longer than expected, because obviously Alex’s priorities are elsewhere but at some time he has to design the tooling” (Probe)

In contrast participants in original design cases had less clarity of how each other’s design procedures were combined; hence when there were ideas to change a design (expectations challenged) there was a greater unknown of how each participant was affected. So, individuals sought to involve each other to clarify who was committed to what and agree on a final decisions (aligned Task expectations). This took time as participants tried to be flexible whilst establishing how their commitments were affected:
“In a creative project like this you have to interact in a guided fashion… It is the approach you take where you are involving people in their positions even if you are leading you’re still involving them. You have to be flexible, you have to say that is a good idea, we could do it that way, even if it is not your idea” (Medical)

Thus as participants were challenged, they adjusted by considering how to commit to each other and a project. This was achieved more through social processes when individuals shared diverse technical knowledge (Task expectations) or if individuals had different allegiances (Team expectations). Consequently:

**Finding 13.** When expectations were challenged, participants redefined their commitment to a project and each other to establish aligned expectations. Participants were more active in inter-organisational and original design cases where there was a greater variety of connections between participants.

**Adjustments in control**

Recognising different expectations and establishing aligned expectations are two aspects of how participants adjusted when their project expectations were challenged (e.g. delays, design modifications, changes in project participation, further resources required). Participants also maintained aligned expectations by (sufficiently) controlling how each other’s tasks were achieved (see Definition for ‘control’ description). Those in intra-organisational and adaptive design cases maintained aligned expectations through shared working practices and design procedures; whilst individuals in inter-organisational and original design cases were more likely to maintain aligned expectations through social processes.

In intra-organisational cases individuals were all following the same organisational working practices that was overseen by one individual. This provided clear guidance about how participants were expected to contribute to a project. When there were unforeseen changes to project participation, individuals were all expected to follow the same norms of behaviour, for example if they could help they were expected to:

“We took that [part] on in Fan [department] because we did have some spare resource… there were question marks… but it was ok for us to do given the constraints of the project. And yeah, the acknowledgement that it wouldn’t run unless somebody designed that part” (Engine)
Cross case findings – a comparison of design case studies

In contrast, inter-organisational cases brought together multiple approaches to carrying out tasks that impeded maintaining aligned expectations. When there were delays, individuals exerted their own control over other participants to maintain project progress. For example if participants were delayed by a lack of information they learnt how and who to push to maintain progress:

“When you work with other companies you see what the other people are like and how the relationship develops and stuff. But as AeroOrg2 is the lead, that doesn’t mean that you can just sit back and wait, sometimes you do have to push the lead for the data and push them for stuff. It is not always going to be them pushing you” (Wing)

When there were design changes in adaptive cases, participants’ ability to adjust was derived from established design procedures. Participants hence realised how different aspects of a design influenced their work and could maintain aligned expectations. Understanding the design procedures allowed individuals to continue and complete their work in the knowledge that it would meet group standards:

“Well it [communication] doesn’t influence as much with the work I do because I just know how changes are done here. So you become familiar with the way we do things. Once you know that you do that without thinking much about it” (Probe)

In original design cases, participants were using design procedures that were less prescriptive on how diverse technical expertise was combined. Participants instead developed sufficient control over each other to maintain their own standards for activities (Task expectations). For example when participants applied different approaches to simplify the design process, individuals learnt who they had to manage to maintain aligned expectations with the project group:

“There are certain people you know you have to micro-manage and certain people you don’t. That is just an understanding of characters” (Engine)

When there were challenges to expectations, individuals reviewed how to sufficiently control other participants activities. This was particularly evident through social processes when diverse technical knowledge was shared (Task understanding) or control was split between a number of participants (Team understanding). Consequently:
Finding 14. When expectations were challenged, participants considered how to (sufficiently) control other participants’ activities to maintain aligned expectations. Participants were more active in learning how to share control of activities in inter-organisational and original design cases.

Challenges for individuals having aligned performance expectations came from Results including delays, variation in project participation, design revisions and requirements for additional resources. These all provoked questions about project performance that could elicit different responses and different standards as individuals returned to their own interests, methods, practices and project expectations. Questions about performance were evident in each case, yet individuals in inter-organisational and original design cases were exposed to more unexpected challenges. Individuals reacted by adjusting how to trust, commit to each other and how to share control of activities (Findings 12-14). These reactions highlight a greater individual effort to learn how to achieve their tasks through social processes and based on their own individual interests within a project.

This focus on participants making adjustments to expectations based on individual interests is in contrast to a greater reliance on collective activity to share understanding and sustain group interests (through pair-wise relations and group relations Findings 1-11). This highlights a conflict for participants between individual and group interests as they crossed more discipline and organisational boundaries. Participants hence had to be mindful of their own interests and realise they were reliant on a project group to bring together their tasks. To accomplish this they needed to continually resolve whether to cooperate for group interests or compete for individual interests. Thus this took more time and effort for participants to resolve in inter-organisational and original design cases.

Clearly, individuals perform their activities in the context of a group and ultimately individual and group performance expectations have to be aligned to achieve a product. Yet it is not clear what needs to be aligned in expectations, to what extent and how participants achieve this in practice? These three questions are addressed in the next section by specifying between Task and Team content of shared understanding (about what); looking at patterns between design type and design setting cases (to what extent); and describing the influence of pair-wise relations on group relations and outcomes (how). This outlines how pair-wise relations can both help and hinder individuals and a group to adjust and foster aligned performance expectations.
6.6 Mechanisms: how pair-wise relations influence group relations and outcomes

Up to now findings have focused on each construct of the Research Question. The aim of this research is to consider how pair-wise relations influence group relations and outcomes, i.e. how one construct influences another. In this section the concept of mechanisms (see section 4.4.2 p66) is used to describe cross-case patterns. Three mechanisms are presented – Familiarising (6.6.1), Associating (6.6.2), and Regulating (6.6.3) and shown in Figure 33. Familiarising is depicted as an individual recognising different aspects (separate segments) of a project (oval shape); Associating as an individual establishing their links to certain aspects of a project; and Regulating as an individual maintaining which aspects of project standards are prominent. These three mechanisms are used to present a holistic understanding of collaborating in engineering design projects illustrating how pair-wise relations both help and hinder participants in understanding how to collaborate (6.6.4).

![Figure 33 – Three mechanisms in an engineering design project](image)

In presenting these three mechanisms the aim is to highlight 1. how participants through pair-wise relations familiarise with and combine individual activities recognising different expectations on how to collaborate; 2. how individuals through pair-wise relations associate with project activities and establish aligned expectations for collaborating; and 3. how participants through pair-wise relations regulate what is acceptable in a project and maintain aligned expectations on collaborating.

6.6.1 Familiarising

Familiarising describes how pair-wise relations lead to an increased familiarity with a group’s Task (e.g. design procedures, scenarios etc) and Team (e.g. participant capabilities, behaviour etc) shared understanding [group relations]; and through pair-wise relations individuals recognise what to expect from each other i.e. who knows what and how to trust each other [outcomes]. This is illustrated in Figure 33 as an individual becoming familiar
with different aspects (separate segments) of a project. Detailed information about cross-case findings are presented in Table 9 p141 (recorded in Definitions p. xii).

In *pair-wise relations* individuals became familiar with how to achieve their activities with each other in a project group and who knew what. In recognising how to do this participants developed a confidence in how to trust each other i.e. what they could expect from other participants. This involved creating an approach to work together than included being aware of procedures, potential scenarios and contingencies. This process was often implicit and some participants were more active than others.

Comparing cases across design setting reveals that participants in inter-organisational cases (Wing, Medical) were more active in creating an approach to work together (Team shared understanding) than in intra-organisational cases (Probe, Engine). In crossing organisational boundaries, the absence of one set of organisation working practices, design constraints, and dependencies between roles and organisations required participants to discover who did what and how other people performed their activities in order to collaborate:

“I think the most important thing has been that we have had an open and honest relationship and [that] has allowed the team to move forward. I think it comes back to understanding the people” (Wing)

Considering design type, participants in original design cases active in finding out about each individual to create an approach to design together (Task shared understanding). Participants in original design cases were less familiar with how their own role would be combined with others to produce a functioning product i.e. how different sets of knowledge would be combined; hence individuals were active in pairs to develop individual trust in what was expected by crossing knowledge boundaries:

“You just develop a certain trust that it is ok… they will take care of that bit, they won’t drop that ball or it will crack in the middle… I suppose intuitively you do… you suss out whether they are a tuned to the sort of thing that can happen in this project” (Engine)

This allowed participants to be familiar with how they could trust other participants in their technical capabilities to work together in a group. In adaptive cases there was greater detail and trust between participants from the existing overlap of procedures and expertise. Interaction in pairs was hence used less for recognising what was acceptable than interaction in original design type cases. Consequently:
**Finding 15.** Through *pair-wise relations* participants recognised how their activities (Task & Team) fit into a project group and how to trust other participants’ expectations. Participants were more active distinguishing how activities fit together in inter-organisational and original design cases.

Where there was little existing familiarity between participants, either in pairs or as a group, participants supplemented group interaction with pair-wise interaction to develop their own understanding about group behaviour. This centred around understanding group norms e.g. accepted behaviour and shared beliefs. Increasing individual familiarity of these aspects gave participants information about how to trust what each other did. This trust changed based on how outcomes and events met with initial plans.

In looking across the cases they all have one thing in common – participants actively interacted in pairs to familiarise with a project when they were uncertain of what was required. Where individuals were performing a new role, task, or with new participants, they were likely to actively interact with other participants to recognise what was necessary in that role and project. This meant that previous experience may be misleading:

‘‘I have worked with the guy from Turb [department] before, though I was in a different capacity and he was in a different role – so I had really high hopes for him… He hasn’t been up to my preconceived ideas. Building up a font of knowledge about a person didn’t actually come true. Whereas Jess, who I also worked with before, exceeded [performance] expectations” (Engine)

Standards of behaviour and participants’ knowledge about each other were less clear in inter-organisational or original design cases. In these cases participants actively sought clarification and information from other participants in pairs to understand group behaviour and performance expectations. This allowed them to recognise how to trust other participants’ behaviour in relation to their performance in a group:

‘‘We have had to, I have had to expect a bit of friendly banter shall we say with certain members of the team just because that is how they work and things like that. Because they are doing you a favour, you kind of allow them to rib a bit more than you would otherwise necessarily allow” (Engine)
### Table 9 – Familiarising

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Probe</th>
<th>Engine</th>
<th>Wing</th>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Familiarising</td>
<td>Frequent feedback in pairs to recognise project design standards</td>
<td>Frequent feedback in pairs to recognise what design standards are relevant for project</td>
<td>Feedback in pairs across organisations to recognise differences in working practices</td>
<td>Frequent feedback in pairs across organisations to recognise what design standards are relevant &amp; differences in working practices</td>
</tr>
<tr>
<td></td>
<td>A few participants have unfamiliar tasks or new design constraints so take advice from colleagues in project group and organisation</td>
<td>Most participants have either unfamiliar tasks or new design constraints so take advice from colleagues in project group and organisation</td>
<td>Most participants have either unfamiliar tasks or new design constraints so take advice from colleagues in project group and organisation</td>
<td>Most participants have either unfamiliar tasks or new design constraints so take advice from colleagues in project group and organisation</td>
</tr>
<tr>
<td></td>
<td>Judge confidence in each others’ technical abilities in pairs via recognising how to apply organisational practices</td>
<td>Judge confidence in each others’ technical abilities in pairs via recognising how to apply organisational practices</td>
<td>Judge confidence in each others’ technical abilities in pair-wise interaction via recognising similar approaches</td>
<td>Judge confidence in technical abilities in pair-wise interaction via recognising similar approaches</td>
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<tr>
<td></td>
<td>Participants regularly worked in pairs in same roles &amp; were aware of what was expected from each other</td>
<td>Participants in latter stages of project developed pair-wise understanding to identify the impact of designs on their tasks</td>
<td>Some participants in each organisations worked regularly in pairs &amp; were aware of what was expected from each other</td>
<td>Participants from same organisations regularly worked in pairs &amp; were aware of what was expected from each other</td>
</tr>
<tr>
<td></td>
<td>Minority active in pairs to learn how to trust individual &amp; group behaviour</td>
<td>Minority active in pairs to learn how to trust individual &amp; group behaviour</td>
<td>Minority active in pairs to learn how to trust individual &amp; group behaviour</td>
<td>Minority active in pairs to learn how to trust individual &amp; group behaviour</td>
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<tr>
<td></td>
<td>Minority had new role &amp; were active in pairs to recognise what was relevant to achieve their tasks</td>
<td>Minority had new role &amp; were active in pairs to recognise what was relevant to achieve their tasks</td>
<td>Minority had new roles &amp; were active in pairs to recognise what was relevant to achieve their tasks</td>
<td>Minority had new roles &amp; were active in pairs to recognise what was relevant to achieve their tasks</td>
</tr>
<tr>
<td></td>
<td>Individual aims all recognised in organisational product development process</td>
<td>Limited finances lead participants to interact in pairs to keep up with project progress instead of attending meetings</td>
<td>Different levels of project finances led organisations to exchange information regularly through pair-wise interaction</td>
<td>Recognising how to trust each other in pairs developed at different rates – quicker where expertise was similar</td>
</tr>
<tr>
<td></td>
<td>Greater variety of goals expressed in pairs could obscure group aims</td>
<td>Organisational aims less evident as participants more involved in pair-wise than group interaction</td>
<td>Pair-wise interaction provided extra discussion to support limited group interaction</td>
<td>Pair-wise interaction used to understand why technology development was delayed</td>
</tr>
</tbody>
</table>
Cross case findings – a comparison of design case studies

To collaborate, participants increased their understanding of what was acceptable group behaviour. Individuals were less active in this pursuit when they were more certain of how accomplish their activities. Consequently:

**Finding 16.** Through *pair-wise relations* participants recognise group behaviour and how to trust participants. Participants were active in this when they had new roles, tasks or few occasions for group interaction. This was more typical in inter-organisational and original design projects.

In addition to benefits of interaction in pairs there were limitations. This was more evident in inter-organisational and original design cases when *pair-wise relations* supplemented or replaced group interaction (see dilemma 6.4.3). Where group interaction was irregular, participants’ ability to recognise group standards, changes or progress was limited to information exchanged in pairs. Participants were less likely to recognise the breadth of technical standards and approaches involved through pair-wise interaction. In essence participants could lose sight of the whole project and the connections between each individuals activities. This created problems between individual and group project expectations with participants sometimes believing they had different aims:

“I think the people think they have different goals. And they should be the same the same goal... Had I thought about it earlier. I [now] understand the processes cradle to grave [product development] and that was how it was going to work all the way through. Realising that they needed all that up front, rather than suck it and see approach” (Engine)

Different perceptions of progress were also evident when participants carried out interaction predominantly in pairs:

“To then be told what you have told this person isn’t strictly correct – that is completely at odds with what my understanding was, was just a kind of slap in the face really... when I went sort of back over it, it transpired that this is effectively what has happened... But in my mind and other peoples, like Eddie, it was absolutely categorical that they had achieved [it]” (Medical)

This led to participants questioning how to trust information from each other and whether to continue a project:

“To then being told... we don’t think we are on the home straight. In fact we are not quite sure where we are on the last bend. I think that has been quite de stabilising [for participants]” (Medical)
In sum, awareness through pair-wise understanding can create limitations on how individuals recognise differences in a project. In particular, this posed further questions for participants to identify how to trust each other where group interaction was less regular, and participants shared distributed or complementary expertise. This was more evident in inter-organisational and original design cases. Thus:

**Finding 17.** Familiarising in pairs without group interaction was likely to reduce awareness of group standards, norms, expectations and require participants to recognise how to trust each other. Individual expectations were more likely to differ from group expectations in inter-organisational and original design cases.

Summarising these three findings, participants through *pair-wise relations* improved their familiarity of what was shared (content) and how understanding was shared (process) between pairs and in a group. This allowed individuals to develop an understanding of how to trust each other and be familiar with different sets of expectations within a project group. This was particularly more evident, i.e. participants were more active, in cases that were inter-organisational or original design. Individuals in original design projects had less familiarity of Task aspects of group understanding (e.g. design procedures, scenarios), and participants in inter-organisational projects had less familiarity of Team aspects of group understanding (e.g. individual capabilities) – hence participants placed increased effort in pair-wise interaction to develop their own awareness. Furthermore this shows a shift from a reliance on familiarity with procedures to one that is based on familiarity with participants and groups to recognise how to accomplish tasks in inter-organisational or original design cases.

### 6.6.2 Associating

The second mechanism Associating describes how *pair-wise relations* increase participants’ connections to a group’s Task (e.g. design procedures scenarios etc) and Team (e.g. participant capabilities, behaviour etc) shared understanding [group relations]; and through *pair-wise relations* individuals establish what to expect from each other (e.g. commitment, obligations) [outcomes]. In Figure 33 (p138) Associating is depicted as an individual establishing their connections to certain aspects (separate segments) of a project. Detailed information about cross-case findings are presented in Table 10 p145 (recorded in Definitions p. xii).
Cross case findings – a comparison of design case studies

Participants in each case established a set of standards to clarify what was expected in their project. This ideally reflected each participant’s aims and approaches and led to aligned expectations. In pair-wise interaction individuals developed their own awareness of group norms establishing how standards were similar or different between participants. Individuals hence could make sense of idiosyncratic individual behaviour understanding if it affected them.

Comparing original to adaptive design cases, participants because of the project type had less prescriptive design standards. Consequently individuals were active in pairs to establish together what was similar or different for their project in comparison to their normal approaches. Multiple standards may be apparent in a project group as designs were refined and participants had to define what was acceptable with different people or in different situations:

“It is trying to distil what is important and necessary to do, and then what we normally do but we don’t have to do now… so it is just instilling in people, a set of rules shall we say or values” (Engine)

In inter-organisational cases participants reduced their uncertainty about individuals and organisations commitment to a project through pair-wise relations. Individuals outlined what they were planning to do to achieve their activities so they could establish aligned expectations. For example this involved adjusting to delays and highlighting the consequences of group decisions on individual availability:

“The planning problem becomes exceedingly complicated because I then commit them to other clients. And if these activities for other clients [are] short term activities then the guys will be available when Eddie wants them in the long term. But if they are long term activities then it means that when Eddie wants to kind of put his foot on the accelerator again, it means I can’t respond as quickly as he might want. Now Eddie and I have had these discussions, he is well aware of that” (Medical)

Considering the four cases, group standards and expectations were less established and less similar when participants were brought together across organisational and technical discipline boundaries. To overcome this ambiguity and diversity, participants were more active in defining standards and expectations through pair-wise understanding. Thus:
Table 10 – Associating

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Probe</th>
<th>Engine</th>
<th>Wing</th>
<th>Medical</th>
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<tbody>
<tr>
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<tr>
<td>Associating</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>• Organisational technical standards reiterated in pair-wise interactions</td>
<td>• Through pair-wise interaction similarities and differences about refining design processes were established</td>
<td>• In pairs participants identified overlapping knowledge in design approaches to establish relevant technical standards</td>
<td>• In pairs participants questioned what were relevant working practices</td>
<td></td>
</tr>
<tr>
<td>• All participants reviewed group interactions together in pairs</td>
<td>• Pairs in same departments reflected on group interactions together</td>
<td>• Pairs in same organisations or with similar backgrounds reflected on group interactions together</td>
<td>• Pairs in the same organisation or with similar backgrounds reflected on group interactions together</td>
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<tr>
<td>• Participants contribute more than recorded in financial spend (pair-wise goodwill)</td>
<td>• Participants contribute more than recorded in financial spend (pair-wise goodwill)</td>
<td>• Participants frequently contribute more than recorded in financial spend (pair-wise goodwill)</td>
<td>• In pair-wise interaction participants outlined the impact of changing commitments as progress was delayed</td>
<td></td>
</tr>
<tr>
<td>• Participants follow standards set out in design procedures</td>
<td>• Interaction in pairs with respected experts encouraged participants to adopt new approaches to completing tasks</td>
<td>• Pair-wise understanding encouraged working with people rather than organisation</td>
<td>• Participants frequently contribute more than in recorded financial spend (pair-wise goodwill)</td>
<td></td>
</tr>
<tr>
<td>• Individuals work on project until it meets required organisational quality standards</td>
<td>• Some participants persuaded by core members to take on additional tasks for group to meet deadlines</td>
<td>• Interaction with senior project members helped resolve disagreements</td>
<td>• Without finance from NewSpinOrg 3rd parties only willing to discuss plans as delays continued</td>
<td></td>
</tr>
<tr>
<td>• Pair-wise relations with project manager influence how standards applied when designs changed</td>
<td>• Multiple drawing standards applied from pair-wise interactions across departments</td>
<td>• Long term organisational goodwill towards each other was focus for agreement over test funding</td>
<td>• Divisions between implementation and research approaches were replicated in patterns of pair-wise interaction</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Design changes slow to reach instrumentation and testing participants via pair-wise interaction</td>
<td>• Pair-wise relations unable to influence individual commitment if designs change and finances were limited</td>
<td>• Links of technology specialists to group reduce as attend fewer group meetings at request of NewSpinOrg to limit financial spend</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Repeated delays of technology question reliability of forecasts based on pair-wise interactions</td>
</tr>
</tbody>
</table>
**Finding 18.** Through pair-wise understanding individuals establish how their own standards/perspectives correspond to group norms and other participants. Participants were more active in establishing similarities and differences in expectations in inter-organisational and original design cases.

The need to establish a set of complementary standards differed according to the type of project and participants’ experience. Where participants were knowledgeable of their activities and a product development process was clearly defined, there was less need to establish standards:

“We all have our own way of doing things..., you just know what you want to do and you do it... I just know the process... when I need to do something I come up with a design and I just, just go through the system. We know how it works” (Probe)

Where individuals were less aware of participants or technical disciplines involved there was a greater need to establish aligned group expectations. Participants were likely to form groups around similarities in experience or expertise focussing on people they respected. This was more apparent where individuals had to define their own design procedures (original design cases) or had to work with individuals with unfamiliar working practices (inter-organisational cases). As technical or organisational boundaries were crossed it became more difficult to establish complementary standards as participants would stick to their own ways:

“There are some department groups that... are not taking on enough risk. They haven’t pared down their processes and [are] still feeling too much of a department pull... they are very very rigid” (Engine)

One method for individuals to adopt project norms was evident when core members (e.g. project manager, technical head, recognised expert etc) were involved in pair-wise interaction. Core members evoked characteristics that covered both individual and project needs e.g. similar organisational aims, to establish aligned expectations:

“Theyir boss wasn’t very happy because the work wasn’t related to his directly... But we managed to persuade him to keep going... if you don’t help us out we won’t have a project. Your other parts won’t run either” (Engine)

This meant that core members placed greater effort in being aware of different standards and expectations, thus managing across both technical and organisational boundaries:
“The programme manager trick is that they have to switch between all these different worlds, the way people engage, they might not be expert in all of them but they certainly have got to be aware of them” (Medical)

Through pair-wise relations participants related to a common set of standards about what was necessary to accomplish tasks. Where there were differences in standards, individuals through pair-wise interaction with core members established complementary practices that reflected project standards. Thus:

**Finding 19.** Individuals adopted group standards through pair-wise relations with core members to establish aligned project expectations. Participants adopted project standards through pair-wise interaction more in inter-organisational and original design cases.

Core members interaction in pairs though was limited and individuals unsurprisingly focused on topics and concerns specific to their activities. Where there was pair-wise interaction individuals defined their own expectations regarding what was relevant and appropriate to collaborate. As previously mentioned, these expectations may not always aligned to those set for a project group or indeed with other participants. In particular when there were delays or design revisions (i.e. challenges to individuals’ project expectations) pair-wise relations were not always sufficient to bridge differences between individual and group expectations. This led to participants evaluating their own, and each other’s, commitment to a project.

In both intra and inter-organisational cases pair-wise interaction generated individual social capital; yet this was more limited in inter-organisational cases when participants wanted to increase the scope of the project. For example in Probe participants did not question contributing more time to further testing to improve the quality of a project illustrating established links to each other and a project group. In contrast, participants in Medical and Wing had different budgets, different amounts of flexibility to change, and no matter how established pair-wise relations were, participants had limits to how much they could commit to a project:

“The partners are particularly keen to try and grow the size of the activity over and above what was originally intended. Now this is fine, apart from obviously from a budget perspective – we have a limited budget. So there is a fair amount of discussion in trying to determine what we can achieve with the different budget with what we would like to achieve. And I would say this has probably caused some friction within the partnership” (Wing)
Comparing adaptive and original design cases there were differences in how design changes affected participants’ roles. In particular there was a greater variety of approaches to refine or changes design solutions in original than adaptive cases. For example when there was frequent changes to achieving design technology development (e.g. Medical) individual commitment to a group was reassessed at each point. Despite developing participants’ involvement through extensive pair-wise relations, individuals altered their commitments as deadlines were not met or new directions on solving technical problems required less of their expertise:

“I think the impact on me will be that I will be a lot less involved because I am not a [that type of technical] specialist. And they really have to concentrate on that [technical area]. This is not a strategy problem, it is really a technical problem. Very much a detailed technical problem and I don’t think I could contribute very much” (Medical)

Where design revisions or delays challenged participants’ expectations, pair-wise relations were not always sufficient to bridge differences between individual and group expectations. Thus:

Finding 20. When designs changed and challenged project plans, pair-wise relations were not always sufficient to establish aligned expectations between individuals. Incompatibilities led individuals to reconsider their commitments to each other with greater differences within a group in inter-organisational and original design cases.

Summarising these three findings, participants through pair-wise relations increase their commitment and affiliation to each other based on sharing understanding about Task and Team aspects of a project. Participants explored and defined similar expectations in pairs and group to support, or oppose, commitment to group aims and standards. This involved balancing one set of group expectations with multiple sets of expectations representing different participants (organisations and individuals) to achieve a functioning product. Individuals in intra-organisational cases were more likely to have existing shared understanding on Team and Task aspects to help guide them in balancing these expectations facilitating decision making in pairs. Individuals in adaptive cases also had more autonomy in decision making away from group interaction. Those in inter-organisational cases were likely to experience the greatest differences in Task and Team standards with participants having to establish what was relevant to the project group. They were consequently more exposed to balancing participants’ expectations and commitment to group aims through social processes rather than defined practices or procedures.
6.6.3 Regulating

The third mechanism Regulating describes how pair-wise relations lead to increased control of a group’s Task (e.g. design procedures, scenarios etc) and Team (e.g. participant capabilities, behaviour etc) shared understanding [group relations], and through pair-wise relations individuals maintain what to expect from each other, specifically aligned expectations [outcomes]. In Figure 33 (p138) Regulating is shown as an individual maintaining which aspects (separate segments) of a project are prominent. Detailed information about cross-case findings are presented in Table 11 p150 (recorded in Definitions p. xii).

Participants through pair-wise interaction sought to maintain aligned expectations during a project. This provided individuals with an element of control over how participants carried out their activities in addition to existing procedures and practices. This was particularly useful for individuals when there were multiple organisations or diverse expertise involved in a project.

In intra-organisational projects, participants were guided by one set of working practices that formed the basis of what to expect from each other:

“We have all got guidelines restricting what you are doing, controlling what you are doing” (Probe)

In addition, participants were active in pair-wise interaction to maintain their awareness of progress and if requirements were being met when they worked across departments:

“I have a letter of requirements that I want out of it… it is regular reviews, pop over there and see how he is getting on with the design” (Probe)

This was replicated in inter-organisational projects but participants took a broader approach and also considered how different approaches were brought together:

“I think if you just got involved in your bit you could get a bit narrow minded and as I am looking at what everybody else is doing I am trying to make sure it all works together” (Wing)

Comparing adaptive and original design cases, participants were more active in original design cases in maintaining standards. Participants from different departments and organisations had different approaches and expectations – even in one project some could be doing more routine work than others (identified as execution and discovery modes in Medical). Individuals thus spent time identifying what people were doing to manage them in pairs to reinforce what was expected for the project:
### Table 11 – Regulating

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Probe</th>
<th>Engine</th>
<th>Wing</th>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Fixed design guidelines gives participants outline how to implement product development process</td>
<td>– Group technical awareness maintained by head designer via their links to each participant</td>
<td>– Pair-wise interaction supplements group interaction to maintain group awareness of design developments</td>
<td>– Pair-wise interaction supplements group interaction to maintain group awareness of technical developments</td>
<td></td>
</tr>
<tr>
<td>– Group technical awareness maintained by head designer via their links to each participant</td>
<td>– Those latter in design process active in pairs to influence how new designs impact their role</td>
<td>– Pair-wise understanding provides links between each organisation’s working practices</td>
<td>– All commercial participants active through pairs to influence how new designs impact their role</td>
<td></td>
</tr>
<tr>
<td>– Interdependency of tasks clearly identified in project; pair-wise understanding sufficient to maintain standards &amp; cope with design changes, delays</td>
<td>– Pair-wise interaction reinforce new standards/ methods outside of group interaction</td>
<td>– Some interdependency of tasks across organisations; pair-wise understanding sufficient to maintain standards &amp; cope with design changes, delays</td>
<td>– Pair-wise understanding provides links between research &amp; implementation working practices</td>
<td></td>
</tr>
<tr>
<td>– One individual coordinated group and maintained pair-wise interaction with all participants</td>
<td>– Interdependency of tasks refined during design; pair-wise understanding and group required to maintain standards &amp; cope with design changes, delays</td>
<td>– Contact in each organisation coordinated their tasks with one individual overseeing project</td>
<td>– Interdependency of tasks refined during design; pair-wise understanding and group required to maintain standards &amp; cope with design changes, delays</td>
<td></td>
</tr>
<tr>
<td>– Regular pair-wise interaction by all participants across departments to coordinate their effort</td>
<td>– One individual coordinated group and maintained pair-wise interaction with all participants</td>
<td>– Regular pair-wise interaction across all organisations to coordinate effort</td>
<td>– Coordination of group split between two members of NewSpinOrg - two sets of personal connections required to maintain group standards</td>
<td></td>
</tr>
<tr>
<td>– Regular pair-wise interaction with staff from other departments for advice on similar problems</td>
<td>– Regular pair-wise interaction across departments to solve technical problems and coordinate effort</td>
<td>– Less participation in group interactions led to delays of decisions, implementing changes &amp; overall progress. Pair-wise interaction had little influence to reduce delays.</td>
<td>– Regular pair-wise interaction across some organisations to solve technical problems and coordinate effort</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Less defined working practice allows for more favours via personal relationships</td>
<td></td>
<td>– Changes in meeting membership altered who contributed to maintaining group standards and expectations</td>
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<td></td>
<td>– Participants willing to give goodwill to individuals in expectation that it will be reciprocated in future</td>
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</table>
“It is trying to manage parallel schemes… if two of the streams are in execution mode – we know what we have to do, we know how long it is going to take us to do it – it is easy to manage. Someone who is in discovery mode, and… if it is a particularly complicated discovery… you can’t plan an invention… It is quite tricky to manage” (Medical)

Maintaining standards and aligned expectations was important in each case. These were less maintained in inter-organisational and original design cases and participants through pair-wise relations regulated project norms with individuals being more active where aligned expectations were less clear. Thus:

**Finding 21.** Through pair-wise relations participants maintained control of group standards and individual behaviour. Participants were more active in regulating standards in inter-organisational and original design cases.

When pair-wise understanding was maintained participants were likely to automatically adapt or seek a compromise when changes were required from each other. This was primarily because changes were built on an existing shared understanding that included a common set of potential scenarios. As pairs adapted their designs and approaches there was an increasing risk that standards would change and be less complementary to other participants. This was more problematic and required greater group coordination to seek a compromise where there was a greater choice of suitable methods or approaches.

In adaptive design cases group standards and processes were more defined or institutionalised, and pair-wise understanding was likely to fit within group expectations. For example individuals in Probe all followed the same approach in implementing design changes:

“You can alter quite a few different things that will all have a similar effect. I have tried to keep that clear in terms of a direction, we are just going to go software, evaluated all the options, these are the tasks we are doing” (Probe)

In contrast, those in original design cases had less awareness of each others’ approach to refine their designs. Pair-wise interaction limited individuals to certain aspects of the whole design, hence coordination was required to allow participants input into each others activities and ensure individuals maintained aligned group expectations:
Cross case findings – a comparison of design case studies

“It’s ensuring that you communicate to these individual parties… I think if you just leave it to them to get on with… then it comes to a point where you go ‘Well, actually we would have liked some input there because that’s going to cause us a problem’… it’s a major factor in making sure that everybody is on the right wavelength... and how the project needs to move forward with everybody’s input” (Medical)

Participants in inter-organisational cases combined organisational practices. Individuals adapted their work through pair-wise understanding yet this was only sufficient in maintaining the standards of those involved. This highlights a limitation of using pair-wise relations to maintain project standards as it places a greater emphasis on those managing a project to understand how decisions affect each aspect of a project:

“The communication process and the project management process is one way of making sure that everyone one understands all of the implications of all of the decisions” (Medical)

When participants adapted their designs in pairs, individual standards may not change but they may become less complementary to those set out by a project group. Further discussion and coordination was required to understand the implications of decisions on participants and maintain aligned expectations. Where design procedures and organisational practices were combined or were less defined, further group coordination was required to maintain standards. Thus:

**Finding 22.** As participants intuitively adjusted together through pair-wise understanding to foster aligned expectations, further coordination of the project group was required to maintain complementary individual and group standards. This was more difficult in inter-organisational and original design cases.

In the final finding, patterns across cases relating to access to resources and pair-wise relations are considered. In Probe there was a general standard of sharing information by talking within and across departments. This encouraged participants through contacts or regular inter-department meetings to discuss or ask for information or share concerns to gain further feedback and support. As participants continued to work with each other after this project (same department, organisation) individuals simply continued to use their pair-wise links in order to improve the group understanding (of which they were still part of). In Wing, when one partner was having difficulty in finding information to complete their role, interaction with participants from the other organisations provided support to find
suitable information to help them and the project to meet deadlines. Participants also supported further funding (eventually) as a gesture of goodwill in the knowledge of future work together.

In Engine participants often worked in pairs to gain information on what was happening, and on how designs could influence their work. Outside of the project group, participants used their own contacts within AeroOrg to ask for favours from colleagues to achieve their targets (e.g. being flexible with standard processes, providing extra people):

“[We] both have ex [M] department backgrounds which certainly has engendered a bit of, perhaps a bit more goodwill than you would have expected if it was just a cold call from scratch relationship. So a little bit of favours being done I suppose” (Engine)

This did negatively influence their individual reputation when milestones were not met, although those asked were still likely to offer their goodwill albeit with less confidence but expecting future goodwill in return. In Medical, interaction in pairs was the start of the project, and throughout led to participants and organisations joining to support product design. Participants often gave their time without billing it to NewSpinOrg when they were planning how to adjust to changes to achieve a final product:

“We haven’t been paid a bean... when you talk about IndDesOrg they are getting paid – we are not. We have signed an agreement that we will distribute the product when it is ready. So all this background work we are doing” (Medical)

This continued until a series of milestones were not met and those financing the project (NewSpinOrg) had to stop product design to focus on technology development.

In general participants in inter-organisational and original design cases were more active in pair-wise relations than those intra-organisational and adaptive cases to create and maintain access for group support. In each case this was conditional on meeting expectations, sufficient finances or clear individual benefits. Participants in intra-organisational and adaptive design cases had greater confidence in achieving the required expectations. When expectations were challenged (e.g. delays), participants were more likely to limit their goodwill to other individuals particularly if future interaction or individual benefits were not clear. This was more evident in inter-organisational and original design cases. Thus:
Finding 23. Through pair-wise relations, individuals maintain access to resources to support a project (e.g. information, finance), increasing individual control over how activities were achieved. Changes in participants’ goodwill were more evident in inter-organisational and original design cases.

In summarising these three findings, participants through pair-wise relations increase their control of what and how understanding was shared between individuals and group. Participants influenced each other on what standards were suitable maintaining a closer coherence to group standards when interacting with individuals. Those involved in inter-organisational projects used pair-wise relations to regulate standards more than intra-organisational projects as Team aspects were less guaranteed (e.g. benefits of goodwill). In original cases participants through pair-wise relations developed together what was necessary for their designs (Task) avoiding imposing inappropriate group standards. Overall participants were more active in pair-wise relations to sufficiently control project expectations in inter-organisational and original design cases. This emphasises a greater role for social processes in these cases.

6.6.4 Help & hindrance in managing a dilemma

In these findings three mechanisms are presented that describe how participants through pair-wise relations learn how to achieve their tasks together – i.e. how to collaborate. These mechanisms describe how individuals through pair-wise relations influence group relations: they can recognise, establish and maintain what is acceptable in a group and hence what is expected from participants. Consequently, individuals through pair-wise relations influence outcomes: participants recognise their confidence in, establish their commitments towards, and maintain their control over how participants apply standards.

The four cases illustrate hurdles for participants in sharing both Task and Team understanding in collaborating with a greater ambiguity and uncertainty in inter-organisational (Team understanding) and original (Task understanding) design cases. Participants address this by increasing their certainty through recognising, defining and maintaining aligned expectations about Team and Task standards via pair-wise relations.

Each mechanism is dichotomous such that it outlines how through pair-wise relations individuals are helped and hindered in achieving their tasks. Individuals are helped by developing their understanding of activities and participants, in effect learning how to collaborate with each other to achieve their tasks. Participants are hindered by narrowing individual understanding of a project to topics and interests of two participants; this can
distance participants from a project group or create a false sense of security as individuals are unaware of what other individuals expect or assume their work will fit with other participants. Furthermore it takes time and effort for individuals to understand how to collaborate through social processes.

This provides evidence for what happens when individuals resolve a dilemma of collaborating (see 6.4.3) through altering interaction patterns (pair-wise relations and group relations). To understand how to collaborate, participants supplemented or replaced group relations with pair-wise relations; individuals used pair-wise relations as a proxy for group relations developing aligned performance expectations with certain individuals. Participants had greater opportunities for pair-wise relations than group relations so individuals familiarised with, associated with, and regulated their activities to understand what was acceptable for aligned expectations. This helped to clarify their task and social interdependencies in pair-wise relations yet could be misleading if generalised to a project group. Thus, this was a hindrance where there was greater reliance on sharing Task or Team understanding in a group – typically inter-organisational and original design cases. Specifically this was problematic where there wasn’t one individual responsible for the overall technical design (i.e. in Medical). In these circumstances it was difficult to resolve the dilemma between opportunity and dependence by supplementing group relations with pair-wise relations. Too often participants were unlikely to see the whole picture which led to targets being set based on different expectations (e.g. viewing technical risks as commercial ones).

Pair-wise relations are hence not a solution to this dilemma without problems. Pair-wise relations may be flexible – participants are willing to adjust or shared understanding is less defined; they may be rigid – based on highly prescribed methods or individuals that are committed to one approach. What is most revealing is that pair-wise relations exist in addition to group relations in a project, and making these links visible to participants can highlight potential complications in how individuals collaborate in engineering design projects. In describing pair-wise relations as a help and hindrance to collaborating this emphasises a continual process that takes time and effort to have aligned expectations. Participants assess (and reassess) what is necessary – how much to familiarise, associate and regulate, as the amount of time spent on each aspect may affect their own, or project, performance.
6.7 Summary of cross-case findings

In this chapter analysis has progressed from considering cases individually to comparing cases searching for patterns and relationships to explain events in the four case studies. Seven new conceptual categories (Opportunity, Dependence, Results, Adjustments, Familiarising, Associating, Regulating) have been empirically derived through cross-case analysis (6.1) and findings presented under each of the Research Question constructs – pair-wise relations (6.3), group relations (6.4), and outcomes (6.5) – see Table 12 for summary. A list of specific findings is included in the Appendix p231.

<table>
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<tr>
<th>Table 12 – Summary of cross case categories, patterns and insights</th>
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<td>Category</td>
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Findings in the first two sections illustrated influences on pair-wise relations and group relations in engineering design. Both showed that participants are seldom independent in a design project and rely on individuals and a group to achieve their activities particularly when a project involved unfamiliar task(s) or participants (more likely in inter-organisational & original design cases). This highlighted a dilemma to collaborating such that as participants took part in more challenging design projects there were fewer occasions to collaborate in pair-wise relations and group relations yet a greater reliance on collaborating in pairs and as a group to achieve individual and group activities. In response to this dilemma participants altered their patterns of interaction and awareness of tasks, behaviour and events. Notably the balance between pair-wise relations and group relations
altered – participants increased their interaction in pairs when group meetings were less feasible. Collaborating in pairs hence supplemented or replaced group relations. Interaction and awareness through pair-wise relations presented additional flexibility for individuals e.g. more possibilities to gain information, and yet created more space for multiple standards and expectations to manifest between participants.

In outcomes, Result and Adjustment findings were described. Results covered project and interim outcomes illustrating an unclear and mixed pattern across the four cases when contrasting design setting and design type. Adjustment findings covered participants’ affective reactions when their expectations in a project were challenged. Affective reactions were more evident where activities were less defined or participants were less known – typically in inter-organisational and original design cases. This illustrated that participants recognised different expectations through gaining a confidence in how other participants performed, established aligned project expectations through understanding their commitments towards each other and maintained aligned expectations by controlling how participants applied working standards.

In mechanisms (6.6), findings are presented covering how the construct of pair-wise relations influences group relations and outcomes. Three mechanisms (Familiarising, Associating and Regulating) provide conceptual points to recognise some of the challenges that collaborating implies. Familiarising with a group describes forming expectations on how to trust each other and who knows what in a project. Associating with a project group covers establishing aligned expectations and individual commitment. Regulating group standards describes maintaining aligned expectations and individual involvement. Each mechanism is dichotomous such that they both help and hinder individuals. They describe how through pair-wise relations individuals are helped in understanding how to collaborate and achieve their activities, yet hindered by narrowing individual understanding of a project to topics and interests of a pair rather than a group.

Participants were more active in pair-wise relations to identify Task (original design cases) and Team (inter-organisational) group understanding. Findings illustrated a more established group understanding (Task & Team) in intra-organisational and adaptive design cases with those in inter-organisational and original design cases more susceptible to balancing tensions between different expectations. Lastly participants were more active in pair-wise relations to regulate Team aspects in inter-organisational cases, whilst those carrying out original design were regulated by pair-wise interaction to allow refinement of appropriate standards for each technical discipline involved (Task). These findings show a
Cross case findings – a comparison of design case studies

Shift from reliance on procedures and defined processes to one that is dynamic and more reliant on participants and a group.

In this chapter, findings of this research have been presented. These contribute new conceptual categories and ideas to answer how pair-wise relations influence group relations and outcomes in engineering design teams. A discussion of these findings is presented in the next chapter describing how these findings relate and contribute to current literature.
7 Discussion: influences of pair-wise relations

The purpose of this chapter is to discuss cross-case findings by relating them to current theories and literature in engineering design and management fields. This is the last of three stages of case analysis (see 4.4.3) with the aim to answer how pair-wise relations influence group relations and outcomes in engineering design teams (Research Question).

The first section (7.1) is split into five. In the first three parts cross-case findings are compared to literature for each construct in the Research Question i.e. pair-wise relations, group relations, outcomes (7.1.1-7.1.3). Pair-wise relations and group relations are both described by two features – Opportunity and Dependence; with outcomes illustrated by two features – Results and Adjustments. Findings for three mechanisms (Familiarising, Associating, Regulating) are compared to existing literature in section 7.1.4 focusing on how pair-wise relations influence group relations and outcomes. Findings describe support for current research on social process expanding them by illustrating the influence of pairs, how participants address the conflict between individual and collective interests in collaboration, and contribute how context (design setting, and design type) influences the balance between pair-wise relations and group relations when collaborating in engineering design. In the last section (7.1.5) the Research Question ‘how do pair-wise relations influence group relations and outcomes in engineering design teams’ is answered. This response is based upon the previous four sections outlining how pair-wise relations both help and hinder individuals and a group in how they adjust to foster aligned project expectations.

In the third section reflections on research are described (7.2) outlining what has been achieved and learnt (7.2.1) and limitations of findings (7.2.2). In section 7.3 implications for future research are presented and in the final section (7.4) a summary covers how this research contributes to current literature and the Research Question is answered.

7.1 Pair-wise relations, group relations and outcomes

In chapter 6 cross-case analysis empirically derived two features for pair-wise relations and group relations – Opportunity and Dependence; and two for outcomes – Results and Adjustments (Figure 34).
Discussion: influences of pair-wise relations

Two dimensions were used to classify and compare cases: design type and design setting (see 4.3.2 for case selection). Design type contrasts adaptive design (Probe, Wing) and original design (Engine, Medical) cases, with design setting comparing intra-organisational (Probe, Engine) and inter-organisational cases (Wing, Medical). Next cross-case findings under each feature (Opportunity, Dependence, Results, Adjustments) and mechanism (Familiarising, Associating, Regulating) are compared to current literature to discuss findings.

7.1.1 Opportunity for relations: pairs and group

Opportunity refers to the prospects participants had for interacting and developing understanding in pairs or groups. In the previous chapter cross-case findings described how Opportunity can explain variation across cases. From cross-case findings it is evident that interaction through both pairs and a group are more frequent when participants are co-located (Finding 1, Finding 2, Finding 7), when individuals work together simultaneously on other projects (Finding 3), and individual availability is as planned (Finding 8).

Physical proximity

Physical proximity was closer in intra-organisational cases with no distinctions evident between original and adaptive design cases. This fits with general literature about co-location that describes participants in close proximity of each other as having increasing opportunity for interaction (Monge et al., 1985) and collaboration (Kraut et al., 2002: 141).
This also provides an explanation to why barriers and enablers to creating shared understanding relate to organisational boundaries (Kleinsmann, 2006; Kleinsmann & Valkenburg, 2008) – participants have to create routines to interact as they do not automatically see each other when they are not co-located. In comparison those in close proximity can benefit from an increased frequency of communication, need less individual effort to interact (Kraut et al., 2002: 142) and hence have strong personal links (Kiesler & Cummings, 2002: 87). This also reinforces the idea that “it is only within the first thirty meters that separation has any real effect on the probability of communication” (Allen, 1977: 240). In sum, the frequency of interaction in pairs and groups are equally affected by physical distance created by organisational boundaries.

**Multiple projects**

Concurrent design activities were apparent in each case and influenced the frequency of opportunity for interaction and understanding in pairs (Finding 3). Where participants worked together on a number of projects their opportunities for interaction and understanding increased. This was more likely in intra than inter-organisational projects as there were more projects open to similar groups of individuals. A mitigating factor in inter-organisational projects was when a project was part of a larger programme involving the same organisations (i.e. in Wing). This created informal opportunities for participants to interact and create pair-wise understanding on other projects in the overall programme which alleviated some effects of participants limited physical proximity. This describes how engineers working on multiple projects endeavour to create inter-personal networks to share and coordinate information (Kraut & Streeter, 1995), with there being more opportunity in intra-organisational projects.

Working on multiple projects though is not always beneficial as individuals’ attention may be split between projects (Malhotra et al., 2001). This affects individual effort in performing their activities – participants may interact more often though their efficiency in these interactions on each project can reduce. Finding 3 provides some empirical support for Tomiyama’s view that some advantages of concurrent engineering may be misleading e.g. reduction in overall lead times yet individual activities are not necessarily shortened (Tomiyama, 1998: 178-9), as individual effort to coordinate their own activities through inter-personal relations increases. This highlights that the frequency and quality of interaction in pairs is affected by how many projects individuals work on together.
Discussion: influences of pair-wise relations

Participants’ availability

Individual availability to work on a project altered with work priorities or as roles were completed. These changes in participation influenced how frequent participants could interact as a group (Finding 8). This was less evident in intra-organisational cases particularly where an organisational structure reflected product domains. This notes that where a project is supported by different functional areas (or organisations) there is less opportunity to maintain knowledge as a group than when supported by product domains within one organisation. This builds on McMahon et al’s (2004) concern about individual support from functional environments by highlighting that it is harder to maintain knowledge in a project when there are multiple functional areas involved as there are fewer and less regular opportunities for all to interact together. Overall this highlights that the frequency of opportunity for group relations is affected by a reduction in participants’ availability which can be detrimental to maintaining understanding (Huxham & Vangen, 2005: 74).

Current research recommends creating a rhythm to interaction (Maznevski & Chudoba, 2000; Thomson et al., 2007), though from cross-case analysis it is clear that this is harder in some projects than in others. Whilst a cross-case pattern describes less frequent occasions in inter-organisational and original design cases for both pair-wise relations and group relations, in each case there were fewer occasions for group relations than pair-wise relations. Furthermore the balance between interaction in pairs and groups changed more in inter-organisational and original design cases – it was easier to continue pair-wise interaction than group interaction. Participants used interaction in pairs to supplement or replace group interaction where opportunities were limited. This is a logical finding, yet one that calls into question research about social processes in engineering design i.e. both pairs and groups should be investigated. Acknowledging how participants interact, in pairs or in a group, expands current research on human behaviour in engineering design that traditionally focuses on either an individual designer (e.g. Goldschmidt, 1995) or a group (e.g. Frankenberger & Badke-Schaub, 1998b).

7.1.2 Dependence on relations: pairs and group

Dependence describes essential links between participants for them to perform their work. There are three aspects characterise how individuals relied on understanding from pair-wise or group interaction: 1. Technical expertise, 2. Procedures and practices, and 3. Reputational stakes.
**Technical expertise**

There was a greater variety of technical expertise involved in inter-organisational and original design cases, and hence a greater reliance on interaction and understanding in pairs to achieve individual tasks (Finding 4), and as a group to identify design constraints and risks (Finding 9). In pairs and a group, diverse technical expertise in a project creates a reliance on people to exchange credible information (Larsson, 2007). This recognises collaborating in a project is likely to combine experienced individuals with those bringing new approaches to achieve success (Baird et al., 2000; Broadbent & Cross, 2003). Furthermore each individual needs to be mindful of their own expertise and its limitations in each project, and that for individuals to achieve their tasks they are reliant on sharing technical expertise in pairs and as a project group.

**Procedures and practices**

In inter-organisational and original design cases multiple procedures and practices were combined with participants identifying role dependencies in pairs (Finding 5) and relying upon a project group to manage and update these dependencies as designs became more detailed (Finding 10). This describes how participants integrated each other’s activities to allow themselves to work autonomously (O'Sullivan, 2003) and within project standards. Individuals went beyond existing formal procedures to coordinate their different working practices and establish a suitable level of structure to achieve their activities. This highlights that participants themselves develop structure and working practices via interaction and understanding in pairs or as a project group. This gives further explanation to why Lurey and Raisinghani (2001) describe best practices in virtual teams as not providing enough structured formal process for individuals to perform their work – individuals need to develop appropriate structures and practices themselves.

**Reputational stakes**

Individuals maintained their own reputation in pairs more when activities were novel to them (Finding 6) and there was a greater reliance on a project group to cope with different levels of reputational stakes in inter-organisational and original design cases (Finding 11). Through social exchanges participants build their reputation (Coleman, 1988) and reputational stakes influence how dedicated individuals and organisations were to a project (through participants’ availability). Different levels of commitment, particularly in inter-organisational and original design cases, show that recognising, establishing and maintaining reputational stakes was not straightforward. This concurs with Littler et al
Discussion: influences of pair-wise relations

(1995) who stress that dedication at all levels is one of the most important ‘people factors’ affecting the success of collaborative product development.

These three aspects (technical expertise, procedures and practices, reputational stakes) describe the need for collective action and highlight points in literature on groups – dependence is a basis assumption of a group (Bion, 1961), groups are based on interdependency of fate (Lewin, 1948), participants can be dependent, inter-dependent or independent (Deutsch, 1949), and the degree of dependence increases with the amount of collective action (Wageman, 1995). An increasing reliance on each other as projects cross more barriers may explain some participants concern with less formal control in collaborations (Littler et al., 1995).

Furthermore these three aspects are relevant to both pair-wise relations and group relations. Both constructs are influenced in a similar pattern, i.e. there is greater dependence on them in inter-organisational and original design projects (see Findings 4-6, Findings 9-10). This emphasises that there is more reliance on a group developing its understanding of the project in more complex tasks (Clift & Vandenbosch, 1999) and a reliance on developing pair-wise understanding. Sharing understanding is a social process and hence one that is carried out in pairs and in groups. Collaborating is not simply a group phenomena, it is also key to understand pairs and their role in design teams.

**Resolving a dilemma – balancing pair-wise relations & group relations**

A dilemma from cross-case analysis stated that as participants were involved in more challenging projects, i.e. inter-organisational and original design cases, there were fewer occasions to collaborate, yet a greater need to collaborate.

This dilemma was evident in both pair-wise relations and group relations and is related to what is customarily seen as benefits of collaborating – solving complex problems (Trist, 1983), and sharing resources and risks (Littler et al., 1995; Schilling & Hill, 1998). Based on the previous section (7.1.2), these factors all make participants more reliant upon each other. This reliance on people sharing information, on social ties being a resource to achieve outcomes, demonstrates that social capital is more relevant to collaborating in certain contexts. Cross-case comparison has shown this reliance is rarely equal for participants as there is a greater reliance on pair-wise relations and group relations in inter-organisational and original design cases. At the same time there was a greater physical distance, participants worked on multiple projects and were less available (see 7.1.1) – all factors that reduce interpersonal dependence and interaction that are key for group development (Bion, 1961; Homans, 1955) and social capital (Adler & Kwon, 2002;
Collaborating in engineering design

Coleman, 1990; Nahapiet & Ghoshal, 1998). This dilemma in collaborating poses performance factors against benefits of collaborating and is similar to a paradox introduced by Håkansson and Ford (2002). They note that whilst there are opportunities and hence benefits in being part of a business network, there are also limitations that can be detrimental to individual performance.

The response by individuals was to alter the balance between pair-wise relations and group relations. As there were fewer occasions for interacting in groups participants replaced them with calling each other or sending emails. This allowed both additional flexibility for participants e.g. extra occasions for interaction and understanding, but also created room for multiple standards and expectations to exist e.g. different approaches to working together. Changing the dynamics of how individuals interact and develop their shared understanding reinforces the difficulty of maintaining shared knowledge in a project group (Cramton, 2001) and gives some explanation to why innovative solutions are not always produced when envisaged (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005). Furthermore this required greater efforts as individuals adjusted how they achieved their activities with other participants (particularly those with high stakes). This is considered next in results and adjustments by describing how individuals recognised different expectations, defined aligned expectations and maintained them.

7.1.3 Results and Adjustments

Outcomes in this research are observable consequences of process in engineering design teams and are split into two features: Results and Adjustments. Results are events covering project and interim events e.g. project completion, requirements for additional resources. Cross-case comparison of project Results revealed no clear patterns. A greater sample size may add further meaning to these recorded observations but the four cases and existing comparative aspects presented no patterns. This adds to the ambiguous picture illustrating that collaborating is popular (Huxham & Vangen, 2005: 7; Littler et al., 1995; Schilling & Hill, 1998; Trist, 1983) yet fails to meet participants’ expectations (Gray, 1998: 479; Hardy et al., 2005; Killing, 1982; Ring & Van de Ven, 1989; Tidd et al., 2005) and why researchers recommend avoiding it if possible (Huxham & Vangen, 2005: 37). However moving away from considering Results at a project level to Adjustments at an individual level provides further understanding to current knowledge.

Adjustments focus on individuals’ affective reactions. Research in engineering design studying social processes typically covers group Task outcomes e.g. time, quality, cost (e.g. Frankenberger & Badke-Schaub, 1998a, 1998b), shared understanding (e.g. Bierhals
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et al., 2007a; Kleinsmann, 2006), communication (e.g. Allen, 1977; Eckert et al., 2005), and innovation (e.g. Dougherty, 1992; Eisenhardt & Tabrizi, 1995). Adjustments differs by considering affective outcomes on individuals. It covers individual’s adjustments to achieve their activities focusing on when project expectations were challenged i.e. when there were changes to project participation, delays, design revisions, or requirements for additional resources (finances or individual effort). This is split into adjustments in trust, commitment and control.

**Adjustments in trust**

Challenges to individuals’ expectations led participants to consider how to trust each other and participants questioned each other’s technical expertise more in inter-organisational and original design cases (Finding 12). This relates to a ‘credibility trust’ (Cullen et al., 2000; Das & Teng, 1998) or a ‘competence trust’ (Sako, 2000; Sako & Helper, 1998) – where people evaluate if a person is capable of doing what they say, specifying where this is more likely to happen in engineering design. This also illustrates that inter-personal trust is more fragile where there are more changes (Huxham & Vangen, 2005: 74) and that participants need to continually recognise suitable levels of trust to collaborate (Cullen et al., 2000; Littler et al., 1995).

This builds on Larsson’s (2007) idea that individuals in a distributed design team learn to what extent other participants can be trusted to achieve their activities, by illustrating that participants will actively evaluate their trust in each other when their expectations are challenged. Instead of requiring high levels of trust to collaborate (Crossman & Lee-Kelley, 2004; Jassawalla & Sashittal, 1998; Maier et al., 2008), this suggests it is more important to understand how to trust other participants to recognise how to collaborate. Understanding how to trust other individuals is hence used to reduce the complexity of challenges and develop new expectations (Luhmann, 1979). This was more evident in inter-organisational and original design projects where there were fewer opportunities for interaction and understanding, and a greater dependence on participants collaborating.

**Adjustments in commitment**

In addition to questioning how to trust each other, challenges to individuals’ project expectations in each case prompted individuals to consider their responsibilities and obligations to each other (Finding 13). This was to establish aligned expectations to collaborate and was more evident in original design and inter-organisational cases.

In engineering design organisational structures are typically used to determine participants’ responsibilities in a project (Andreasen & Hein, 1998: 189). This finding
suggests that working across knowledge and organisational boundaries is similar to the idea of self-organising teams as group and individual responsibility is greater than in traditional team structures (Frankenberger et al., 1998: 202). In particular this highlights that as a project progresses participants priorities may change e.g. participants may leave as their tasks are finished, and hence as situations change their obligation and commitment evolves (Crossman & Lee-Kelley, 2004). As expectations were challenged (changing priorities etc), individuals collaborating across organisational or knowledge boundaries had less support from existing practices or procedures as they only represented a fraction of a project. Instead participants had to re-evaluate how to commit their time and effort to achieve their own, and group, activities.

**Adjustments in control**

Lastly, challenges to individual and group expectations provoked questions about how to (sufficiently) control each other to achieve individual tasks (Finding 14). Individuals aimed to maintain aligned expectations between each other and with more adjustments made in inter-organisational and original design cases.

Reaffirming standards to participants was important to ensure individual activities combined successfully permitting individuals to work with some independence (O'Sullivan, 2003). Whilst this may typically be the domain of those managing or coordinating a project, where there were more challenges to expectations, i.e. in inter-organisational and original design cases, each individual had more control of how they achieved their activities. Institutionalising which practices were appropriate was hence not just down certain individuals who had rare or essential resources (Hardy et al., 2003) as each individual had something that was vital to a project. Instead each participant adjusted to manage how other participants’ activities affected their own working beyond formal role definitions. This illustrates how participants coped when they had less overall control of a project (Littler et al., 1995). This also suggests that inter-organisational and original design cases are more prone to poor decision making about design solutions as participants may manage what is acceptable through interpersonal relations rather than a formal hierarchy (Frankenberger & Badke-Schaub, 1998b: 161-2).

Each Adjustment describes how participants react when their expectations are challenged – individuals questioned how they collaborated (i.e. how to trust, be responsible to, and [sufficiently] control other participants). These questions to each participant contribute to explaining why collaborating (e.g. Hardy & Phillips, 1998; Huxham & Vangen, 2005) and designing (e.g. Bucciarelli, 2002; Minneman & Harrison, 1998) are
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associated with conflict, negotiation and compromise as there is no prevailing consensus about how to recognise, define and maintain aligned project expectations. Individuals faced more challenges on how to collaborate in inter-organisational and original cases. This describes a move away from using practices and procedures to recognise how to achieve one’s activities to developing understanding through social processes i.e. through interaction and understanding.

Each participant redefined their own expectations about what was required (Findings 12-14) yet simultaneously a project group defines expectations through social interaction (Coleman, 1988) trying to standardise what was expected from individuals. This captures a conflict between individual and collective interests (Kerr & Park, 2001: 116) and draws strong parallels to a paradox associated with strategic alliances (Das & Teng, 1998): namely that participants are encouraged to follow their own interests yet simultaneously they are required to limit this approach to make an alliance work —participants need to balance competition and cooperation (Teece, 1992). Thus, having to continually resolve this paradox throughout a project provides further insight into why collaborations take significant time and effort (Gray, 1998: 479; Huxham & Vangen, 2004).

Placing greater requirements on individuals to focus on their own needs (Findings 12-14) whilst being part of project group that is unclear about how to combine activities, exacerbates this existing tension between individual and group. Do they compete for their own needs or cooperate with the rest of a group (where there are multiple ideas about what is appropriate)? Multiple identities compete against an ambiguous and changing project group identity. How do participants recognise what is relevant for both themselves and a group? How do they define and maintain aligned expectations to collaborate? A response to these questions is developed next in mechanisms by considering how pair-wise relations influence group relations and outcomes.

7.1.4 Mechanisms

To respond to the Research Question it is key to consider how one construct influences another. To reveal how constructs influence each other three mechanisms have been presented to describe what pair-wise relations ‘make happen’ (Huxham & Vangen, 2004) in design projects. Findings focus on one path through the three constructs – how pair-wise relations influence group relations and outcomes (denoted by curved arrows in Figure 35).
Figure 35 – Three mechanisms and Research Question constructs

Cross-case findings from section 6.6 are developed with literature focussing on these three mechanisms – Familiarising, Associating, and Regulating [denoted by pie chart symbols in Figure 35]. Under each mechanism findings are compared to literature on collaborating to describe what they explain, contradict, support and contribute.

**Familiarising**

Familiarising describes how *pair-wise relations* lead to an increased familiarity with a group’s Task (e.g. design procedures, scenarios etc) and Team (e.g. participant capabilities, behaviour etc) shared understanding [*group relations*]; and through *pair-wise relations* individuals recognise what to expect from each other i.e. who knows what and how to trust each other [*outcomes*].

Participants in inter-organisational and original design cases were more active in pairs recognising how their activities fit into a project group and how to trust individuals’ technical ability (Finding 15). Where participants asked more questions it is likely they were trying to recognise common ground to achieve their activities (Mengis et al., 2009). This stresses the importance of interaction and understanding in pairs for individuals to recognise what was required to achieve their own, and other participants, activities in a project i.e. structuring their work together through their relationships (Ring & Van de Ven, 1994). This links to the notion of *grounding* – a continuous process of developing shared knowledge through common ground in language sufficient to achieve participants current purposes (Clark, 1992: 178). Where Familiarising differs is that it highlights that individuals also recognise how to trust other participants through developing shared
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understanding in pairs – specifically how their activities fit together and what they can expect from them.

Finding 15 also supports Larsson’s (2007) connection between ‘know who’ and technical ‘know how’ in distributed design teams. It emphasises that more effort is spent in pairs to know how to combine expertise when individuals are performing unfamiliar tasks with unknown people. Recognising how activities fit together relates to understanding who knows what in a pair or group – transactive memory (Wegner, 1986). Individuals in pairs or groups can each develop transactive memory of the pair or group, yet this finding (Finding 15) suggests that participants do not have to actively be involved in group interaction to develop their transactive memory of a group i.e. they can recreate aspects of a group’s transactive memory in a pair. This explains how some viewpoints [individual object worlds (Bucciarelli, 1994, 2002), group thought worlds (Dougherty, 1992)] can become more recognised or trusted than others.

Participants through pair-wise interaction and understanding also recognise expectations of group behaviour and distinguish how to trust individual behaviour (Finding 16). This explains how individuals can overcome difficulties in deciphering each others’ intent and knowledge (Eckert & Stacey, 2000) by recognising what individual and group behaviour means through pair-wise relations. Much social interaction is role based which can lead to stereotypical interaction patterns for each role in a relationship (Berscheid & Reis, 1998: 198-9). Gulati (1995) recognises that trust in new projects develops from prior experience of individuals; where this was not possible in these cases participants not only interacted in a group, but they were particularly active in pairs to become familiar with each other. Jassawalla & Sashittal (1998) note that participants were more eager and open when there was high trust and reserved with little initiative in low trust environments; in contrast participants in this research were more active and cautious when they had new roles, tasks or were working with new people (typically in inter-organisational and original design cases). Finding 16 shows that instead of simply recognising high or low levels of trust, participants distinguished how to trust each other to reduce the ambiguity of how to achieve novel aspects of a project.

A drawback of developing common ground in pairs was that participants were less familiar with group standards and placed greater trust in individuals (Finding 17). This was evident where group interaction was more irregular – typically when projects involved multiple disciplines or organisations. This implies that how people recognise project requirements alters between one to one phone calls (pairs) and group meetings over a
projects’ duration. Individuals may carry out their activities being unaware of the overall picture and without group reviews potential problems may be missed. It is understandable to recommend communication and cooperation for the entire design process (Badke-Schaub & Frankenberger, 1999a) yet what is important is having an established rhythm to interaction (Maznevski & Chudoba, 2000; Thomson et al., 2007) for both pairs and group. This furthers knowledge about how participants recognise how to achieve their activities through interaction in pairs and highlights potential difficulties in inter-organisational and original design cases.

In summary, through pair-wise relations participants familiarise with Team and Task group understanding and recognise how to trust individuals. In prior empirical research in engineering design links between the topics of collaboration, mutual trust and recognising different individuals needs have been identified (Maier et al., 2008). Findings here support these links and emphasise that Familiarising is a mechanism that explains some of these links i.e. individuals through pair-wise relations recognise different needs and develop expectations of each other’s motives [i.e. how to trust people (Das & Teng, 1998)]. Individuals learnt how to trust each other and revised their expectations to reduce the complexity of events (Luhmann, 1979). Hence it is not surprising that participants were more active in Familiarising in inter-organisational and original design projects. How participants established aligned expectations through pair-wise relations is set out next in Associating.

**Associating**

Associating describes how pair-wise relations increase participants’ connections to a group’s Task (e.g. design procedures scenarios etc) and Team (e.g. participant capabilities, behaviour etc) shared understanding [group relations]; and through pair-wise relations individuals establish what to expect from each other (e.g. commitment, obligations) [outcomes].

Individuals through pair-wise understanding made links to group norms and established their commitments to each other (Finding 18). Participants were more active in establishing commitments in pairs when they experienced different behaviours or were uncertain of group standards (typically in inter-organisational and original design cases). Thus participants through pair-wise understanding accepted a range of individual behaviours in group discussions to foster aligned expectations legitimising each other’s lack of knowledge about their own work (Mengis et al., 2009).
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As participants established each others’ links to a project group they defined which parts of a project, if any, were important for each person. Prevailing differences in expectations, e.g. individuals driven by high quality against those searching for a quick completion, could lead to stronger connections between members with similar motives. This can represent groups that go beyond organisational boundaries (Brown, J.S. & Duguid, 2000) e.g. engineers, and highlight identities of multiple sub-groups in a project that can cause it to fragment (Adler & Kwon, 2002) rather than have one collective identity.

In addition to reducing individual participants’ uncertainty or inexperience, individuals through pair-wise relations with core members could establish one set of standards for a group and participants adopt aligned expectations (Finding 19). This was evident where there were fewer boundaries (knowledge or organisational) and builds on the notion that shared information or shared identity leads to shared preferences in small groups (Tindale et al., 2001: 21) highlighting the importance of communication with key members (e.g. project manager) in a project group (Huxham & Vangen, 1996).

This is a two-way process and not confined to core members imposing their own standards, hence this creates problems in defining one set of complementary group standards. Where participants spent more time in refining their designs, e.g. original design cases, or refining how to work together, e.g. inter-organisational cases, pair-wise interaction was limited in how it could convey changes to standards from other designs. This illustrates problems participants have in teams that cross organisational or knowledge boundaries as there are limitations of making standardised information available to all participants (Cramton, 2001; Montoya-Weiss et al., 2001) through pair-wise relations.

The last finding describes that when there are design changes or delays pair-wise relations are not always sufficient to establish group standards and that individuals reconsider their commitments when there were differences between individual and group expectations. This was more evident in inter-organisational and original design cases (Finding 20) as pair-wise relations supplemented group relations (see dilemma section 6.4.3). This highlights how changes to participants’ group involvement can limit the information available to other participants and impact on time, cost, or quality of decision making (Frankenberger & Badke-Schaub, 1998a). Gaps in information flow between groups are known as structural holes (Burt, 1992, 2004) and can occur when participants solely focus on their own tasks. This highlights that structural holes are more evident in inter-organisational and original design cases and can highlight where differences in
expectations may occur. Noting where structural holes are, and who makes connections across them, is key to retain commitment to a project group and avoid it splitting (Adler & Kwon, 2002) into its constituent sub groups (departments, disciplines, organisations etc) that emphasises boundaries within a group rather than common identity.

Through *pair-wise relations* participants establish aligned expectations about Team and Task group understanding and define how to commit to each other. Establishing aligned expectations in Associating provides some evidence of how sense making in pairs is used to develop commitment based on inter-personal bonds equivalent to the legal and more formal obligations observed by Ring & Van de Ven (1994). Further to the introduction of the term personalisation in knowledge management (McMahon et al., 2004), which describes a knowledge sharing approach via individuals (or a community), this Associating mechanism identifies commitment or affiliation to a project as an outcome via *pair-wise relations*. It describes how individuals through social relations reinforce identity and social solidarity highlighting potential problems with multiple groups [e.g. fragmentation of a project group (Adler & Kwon, 2002)] and multiple commitments that test the balance between conflict and collaboration. Establishing aligned expectations affects how individuals commit to a project; thus, in addition to noting how and who to trust (Larsson, 2007) participants need to establish how and who are committed to what in a project to mobilise individual social capital.

**Regulating**

Regulating describes how *pair-wise relations* leads to increased control of a group’s Task (e.g. design procedures, scenarios etc) and Team (e.g. participant capabilities, behaviour etc) shared understanding [*group relations*], and through *pair-wise relations* individuals maintain what to expect from each other, specifically aligned expectations [*outcomes*].

Through *pair-wise relations*, participants maintained control of group standards and individual behaviour (Finding 21). This illustrates that individuals enacted communication roles required for collaboration (Sonnenwald, 1996) through personal one to one conversations to maintain aligned expectations. This was evident in each case yet was increasingly time consuming when multiple boundaries were crossed (knowledge / organisational) in a project as no one individual had technical expertise covering all aspects. This ideally is a matter of maintaining status quo; however there is a risk that participants can be impeded from performing by their links to other participants (Smith-
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Doerr & Powell, 2005). Whether participants are impeded is subjective, as a manager may have a different perspective to a designer on what is required to achieve the task. In developing pair-wise relations participants could pressure individuals to conform (Macaulay, 1963) illustrating how participants contended with less overall control of a project (Littler et al., 1995).

As participants adjusted together through pair-wise understanding to foster aligned expectations this required group coordination to maintain complementary individual and group standards (Finding 22). This occurred in each case but coordination needs were greater in inter-organisational and original design cases. This directly supports findings by Kraut & Streeter (1995) that found networks of inter-personal relationships were more valuable to individuals as the degree of uncertainty in completing design tasks increased; adding that there is greater need for group coordination to ensure individuals and group maintain aligned expectations. This also highlights that creating shared understanding in a project group needs to be done across multiple levels (Kleinsmann, 2006; Kleinsmann & Valkenburg, 2008), e.g. as designs are refined by individuals through pair-wise interaction, a group needs to be informed of changes to evaluate potential implications and maintain a coherent representation of the overall design.

Through pair-wise relations, individuals maintain access to resources to support a project group (e.g. information, finance), increasing individual control over how activities were achieved (Finding 23). Individual goodwill was less certain in inter-organisational and original design cases. Participants’ goodwill was forthcoming through pair-wise interaction until expectations were not met and was then reviewed. The use of social networks as an added resource is documented in research focusing on social capital (e.g. see Nahapiet, 2008, amongst others). Individuals who provide access to resources are in brokerage positions (Burt, 2000), with those who control resources that are rare and essential to a project being more likely to institutionalise their practices (Hardy et al., 2003). This finding illustrates, as projects use social relations to achieve their activities control is transferred from formal hierarchies to those in brokerage positions to maintain progress. Thus where there are a number of brokerage positions (e.g. diverse membership), maintaining social capital becomes important to overcoming problems with sustaining shared knowledge (Cramton, 2001)

Through pair-wise relations participants regulate aligned expectations about Team and Task group understanding and maintain how to (sufficiently) control each other.
Maintaining aligned expectations in Regulating highlights that it is not enough to create shared understanding to collaborate. As designs are refined and made less abstract participants continually hone what is required from other participants’ capabilities (Team) and from design solutions (Task). To do this collaboratively participants needed to update and maintain complementary project group standards (and expectations). Regulating demonstrates that through pair-wise relations participants were active in providing direction to ensure that their individual activities were complementary to other participants. This illustrates that through pair-wise relations individuals can enact cooperation and communication for an entire design project (Badke-Schaub & Frankenberger, 1999a) yet this can create brokerage positions (Burt, 2000) and limit a groups’ access to social capital. Maintaining aligned expectations affects how individuals control how to complete their activities in a project; thus, in addition to noting how and who to trust (Larsson, 2007) participants need to maintain their understanding of how and who to (sufficiently) control in a project to retain individual social capital.

7.1.5 How do pair-wise relations influence group relations and outcomes in engineering design teams?

Engineering design is both a social process (Bucciarelli, 1994, 2002) and a process of refining a design problem to a less abstract state (Ullman, 2003). This involves individuals collaborating in pairs and groups that increasingly takes place across technical disciplines, departments and organisations. The influence of pair-wise relations is set out in five parts: 1. Pair-wise relations and context, 2. Pair-wise relations and collaboration success, 3. Pair-wise relations and sharing understanding, 4. Pair-wise relations and group development, and 5. Pair-wise relations, cooperation and competition.

Pair-wise relations and context

Current empirical research in engineering design on human behaviour has focused on one or two social processes in groups [e.g. communication Eckert et al (2005), Maier et al (2008), Minneman (1992)], in projects crossing only departmental boundaries [e.g. Kleinsmann & Valkenburg (2008), Larsson (2007)], and with limited recognition of how the novelty of design tasks may influence designing [e.g. Frankenburger & Badke-Schaub (1998b: 156), Ostergaard & Summers (2009)]. Analysing cases of different design type (original and adaptive) and design setting (intra and inter-organisational) has illustrated three mechanisms: Familiarising, Associating, and Regulating. These capture how through pair-wise interaction and understanding, individuals recognise, establish and maintain how to collaborate in engineering design. In particular, cross-case findings have shown that the
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impact of pair-wise relations varies with design context. Where design type was more abstract (e.g. an original design), participants’ expectations about tasks were less clear (e.g. design procedures, scenarios, contingencies etc). Similarly where design setting was novel to participants (e.g. inter-organisational), individual expectations about each other was less certain (e.g. capabilities, attitude, behaviour etc). This led participants to be more active in learning how to collaborate and solve their design problems through pair-wise relations.

Participants however faced a dilemma: in inter-organisational and original design cases there was greater dependence on, yet less opportunity for, social interaction. To resolve this dilemma, the balance between how participants were active in pair-wise relations and group relations altered. In inter-organisational and original design cases group interaction was substituted with interaction in pairs. This recognises that engineers use inter-personal networks to coordinate their own activities, particularly when they are less certain about how to achieve their tasks (Kraut & Streeter, 1995). However, altering the balance between pair-wise and group interaction changes the rhythm of interactions which influences a team’s efficacy in maintaining standards and managing change (Maznevski & Chudoba, 2000). Thus through pair-wise interaction participants may split into multiple groups that then require greater efforts to coordinate as one group.

Pair-wise relations and collaboration success

Collaborations often fail to produce innovative solutions, be mutually successful (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005), meet participants’ expectations (Killing, 1982; Ring & Van de Ven, 1989) and successful ones take significant time and effort (Gray, 1998: 479; Huxham & Vangen, 2004). Familiarising, Associating, and Regulating each describe adjustments that individuals make through pair-wise relations to help reduce their uncertainty about achieving their activities. Individuals recognised how to trust each other, defined how to commit to each other, and maintained (sufficient) control over each other. Reducing uncertainty was not limited to technical capabilities e.g. how to trust someone’s technical performance (Larsson, 2007); it included social abilities e.g. how to trust what individuals’ behaviour means. These findings suggest that greater individual effort was required in projects due to less knowledge about how to combine diverse technical approaches or knowledge about participants from different organisations. This provides some empirical support for Reilly et al (2002) who suggest that diversity of participants’ personalities is detrimental to group performance in adaptive design and beneficial in original design, highlighting that it is understanding about diversity that is important to recognise, establish and maintain. This increased effort improves individual’s certainty about how to collaborate and provides some insight into why successful
collaborations are perceived to take significant time and effort (Gray, 1998: 479; Huxham & Vangen, 2004).

Furthermore, in aiming for aligned expectations participants are limited in their options of how to collaborate. When individuals’ adjust their goals and activities to collaborate, a project may become less innovative or successful for them. From their perspective, the final design may not live up to expectations or the increased effort makes a project less successful (e.g. financially). Thus what is perceived to be successful or innovative may be radically different from each participant’s viewpoint particularly as design changes are made during a project. This helps to explain to why many collaborations are perceived to fail in producing innovative solutions, be mutually successful (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005) or meet participants’ expectations (Killing, 1982; Ring & Van de Ven, 1989). Collaborating hence may be an unrealistic approach for participants particularly if compromising is seen as negative, unsuccessful or less innovative.

**Pair-wise relations and sharing understanding**

When collaborating, participants confront issues about how to share understanding and foster aligned expectations trying to keep things simple (Brown, J.S. & Duguid, 1996: 133) and sustain mutual knowledge (Cramton, 2001). Organisational and knowledge boundaries are barriers to creating shared understanding (Kleinsmann, 2006; Kleinsmann & Valkenburg, 2008), and different object (individual) and thought (group) worlds impede synthesising expertise (Bucciarelli, 1994, 2002; Dougherty, 1992). These mechanisms (Familiarising, Associating, Regulating) help to explain how participants through *pair-wise relations* learn how to collaborate considering both their own object world (Bucciarelli, 1994, 2002) and other participants’ object and thought worlds (Dougherty, 1992). Participants through *pair-wise relations* can recognise individual expectations relating them to a person (object world) or particular groups (thought world) encompassed in *group relations*. Furthermore, through considering different object and thought worlds participants can establish complementary group standards and maintain these expectations to achieve their tasks together i.e. collaborate. This can involve establishing a system of values and meaning specific to a project group, i.e. within *group relations*, that individuals may reiterate in pair-wise interaction and understanding.

However, through *pair-wise relations* participants identify more similarities in perspectives with individuals than a project group i.e. engineers have more in common with each other than a whole group. This creates further problems as multiple sub groups are created through bonds that can be stronger than those defined by organisational boundaries (Brown, J.S. & Duguid, 2000). Management of a project group is particularly
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fraught when there are multiple bonds in a group as these can lead to a lack of clear direction and increased effort in making decisions.

**Pair-wise relations and group development**

In group development models [Bales (1966a); Bion (1961); Homans (1955); Moreland & Levive (1982); Tuckman (1965)] inter-personal relationships are highlighted as key for development yet there is little empirical evidence of how pair-wise relations influence progress – what do they do? Familiarising, Associating, and Regulating outline that pair-wise relations influence how standards and group norms are recognised, defined and maintained. Familiarising links to stages or phases in group development models that involve participants recognising each other – orientation (Bales, 1950, 1966a), forming (Tuckman, 1965), investigation & socialisation (Moreland & Levine, 1982, 1984). Associating suggests how groups move through stages [e.g. storming ↔ norming (Tuckman, 1965)], phases [e.g. socialisation ↔ maintenance ↔ re-socialisation (Moreland & Levine, 1982, 1984)], or group assumptions [e.g. fight flight → pairing (Bion, 1961)] as participants identify, or not, with each other. Regulating relates to aspects from phases in group development models [e.g. control – (Bales, 1950, 1966a)], and group socialisation models [maintenance – (Moreland & Levine, 1982, 1984)] that describe how a group maintains project standards, norms and expectations.

Participants and group performance can be adversely affected by these mechanisms. In Familiarising, individuals can focus on each other’s attitudes and negatively stereotype rather than allow open discussion (attitudes do not always predict behaviour), or participants fail to perform complex tasks in group interaction due to knowing who else is present [social inhibition (Allport, 1924)]. In Associating, individual stakes in a project increase and people treat it like their pet project limiting their ability to make realistic decisions [leading to groupthink (Janis, 1972)], or as established norms are challenged participants stereotype others to negatively portray each other and split participants into sub groups [group polarisation (Lamm, 1988)]. Finally in Regulating individuals through pair-wise relations can limit a group to following certain perspectives [over conformity (Smith-Doerr & Powell, 2005)], or participants put in less effort than usual as responsibility is dispersed [social loafing (Latané et al., 1979)]. Thus individuals need to appreciate the influence of pair-wise relations on group development when collaborating.

**Pair-wise relations, cooperating, and competing**

Developing pair-wise relations adds an extra dimension to how individuals balance competition and cooperation in addressing a paradox in strategic alliances. Through pair-
wise relations, participants move from formal and impersonal organisations (Gesellschaft) towards a group based on close inter-personal relationships (Gemeinschaft). This helps and hinders individuals and a group in how they adjust to foster aligned expectations. This is due to a paradox in strategic alliances that states that individuals are encouraged to pursue their own interests and simultaneously required to limit their interests to work together (Das & Teng, 1998). Participants hence need to balance competition and cooperation (Teece, 1992). In a group based on close pair-wise relations participants no longer adapt solely according to formal guidelines from one organisation; instead decisions become more nuanced and complex relating to group members. Individuals are compelled to understand how to trust each other, commit to each other, and (sufficiently) control each other to cope with this paradox.

In summary, the response to the Research Question is that:
1. Through pair-wise relations individuals can familiarise with, associate with, and regulate group relations.
2. Through pair-wise relations individuals can recognise their trust in, establish their responsibility to, and maintain (sufficient) control over other participants.
3. Pair-wise relations both help and hinder individuals and a group in how they adjust to foster aligned expectations of collaborating.

In presenting these findings it is also important to be aware of the limitations of this investigation and implications for future research. These are described next in reflecting on research.

7.2 Reflecting on research

Reflections in completing this investigation are presented in three parts. First considering what has been achieved and learnt (7.2.1) then limitations of research (7.2.2).

7.2.1 What has been achieved and learnt?

First, to what extent has the aim of this research been achieved? The aim of this research was to investigate how pair-wise relations influence group relations and outcomes in engineering design (Research Question) and six objectives were set to outline how the researcher intended to respond to this question (see section 1.3 p3).

**Objective 1:** To review relevant literature and develop, or adopt, a framework of concepts to investigate engineering design teams, group behaviour and collaboration.
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The researcher reviewed literature starting first in engineering design (chapter 2) and complemented by research on groups from social psychology, sociology and management academic disciplines (chapter 3). This represented an interdisciplinary approach to studying collaborating that provided further hurdles to balance and prioritise literature and accepted standards. In critiquing literature, a conceptual framework was adopted (see Figure 17 p65) that covered key concepts and topics affecting collaboration to interpret data from cases. This was chosen as it was relevant (established from observations of collaborating), flexible (no causality or relationships between themes) and holistic (can consider multiple themes and include a number of levels of analysis [individual, group, context]). Using this framework was successful in sensitising the researcher to suitable themes with final analysis focussing on Research Question constructs.

Objective 2: To design and conduct a longitudinal cross-case comparison of engineering design projects.

To achieve the second objective a qualitative longitudinal investigation was designed and completed (see chapter 4). Developing potential case studies involved an extensive period of time contacting and talking to individuals from numerous organisations to find active design projects as potential cases. This took significantly longer than expected due to slow responses from organisations, a reluctance to talk about current projects and developing legal agreements to ensure confidentiality where requested. A consequence of this was that data collection in the four case studies was completed in parallel instead of sequentially as originally envisaged. This placed a greater emphasis on systematically organising reflections on each case, but also allowed reflection across cases as data were gathered.

A benefit of having increased time in developing case studies was that the researcher could classify potential projects. In carrying out this classification, a set of cases was selected that were complementary and could be contrasted on two dimensions – design type and design setting (see section 4.3.2). This classification provided a clear outline for comparisons in cross-case analysis and a contribution to research approaches in engineering design to consider the context of designing. Using this classification increased the envisaged number of cases from three to four but allowed the researcher to collect data and provide new comparisons between design type and design setting in engineering design projects. In classifying cases into a design type there may be concern as to whether one design is more or less one type e.g. is Medical more ‘original’ than Engine. It may prove useful in future to consider design type as a scale to highlight further nuances and explanations of patterns of cases in each classification. This research is an initial step to
building established comparisons on design type and design setting by highlighting the benefits of using this classification.

Data were collected from five design projects (one pilot study and four case studies) involving 13 organisations. In total 30 individuals were interviewed from a representative sample of participants in each project. This has been supplemented by observations of group interaction and access to project documentation. Individual perceptions have been drawn out through two semi structured interviews per participant at two different points in a project. In particular observing group interaction and access to project documentation was crucial to develop an impartial understanding of a project and give further meaning to individual perceptions to understanding the research phenomena.

**Objective 3:** *To describe influences on the process of collaborating in design project teams.*

**Objective 4:** *To analyse how pair-wise relations influence collaborating in design project teams.*

**Objective 5:** *To develop existing or new (if applicable) concepts and theories based on empirical findings on how pair-wise relations influence collaborating in engineering design.*

In chapter 5 each case study is described individually before cross-case analysis in chapter 6. The chosen Conceptual Framework (Figure 17) was essential to initially organise data and sensitise the researcher about themes relevant to collaborating. It was hence flexible, holistic and relevant (see section 4.3.4) to capture data. Using this framework the researcher was unsuccessful in providing specific conceptual categories to understand patterns in data. Instead analysis led to new conceptual topics emerging through working between data, concepts and the Research Question. These have been used to describe patterns and underlying causes (see section 4.4.2 for method). Consequently, the researcher described in chapter 6 how design setting and design type influenced collaborating (Objective 3) and how pairs influence collaborating (Objective 4). New conceptual categories have been developed (Objective 5) from empirical data to analyse collaborating in engineering design and provide further topics for future research (section 7.3). Furthermore, these new conceptual categories are discussed in relation to current concepts and theories to illustrate what this research contributes to current literature.

*Pair-wise relations, group relations and outcomes* (Research Question constructs) have each been analysed individually before considering how they influences each other. A descriptive understanding of how *pair-wise relations* influence *group relations* and *outcomes* (Research Question) has been presented with three mechanisms (see sections 6.6
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& 7.1.4) describing patterns and explaining how pair-wise relations both help and hinder individuals and a group in how they adjust to foster aligned expectations of collaborating (see section 6.6.4 & 7.1.5). This has focused on one path between components, i.e. how pair-wise relations influence group relations and outcomes. Further elaboration is required to consider other paths, e.g. group relations on outcomes and pair-wise relations and possible patterns of mechanisms that may emerge (see future research in 7.3).

**Objective 6:** To develop implications for practice of collaborating in engineering design based on empirical findings.

Lastly, suggestions for practice of collaborating in engineering design are presented in chapter 8. These are based on empirical findings from analysis in chapters 5, 6, 7 and have been distributed to participating organisations following thesis submission.

7.2.2 Limitations of research

Findings must be viewed within the limitations of the research design. Three limitations of this research are addressed: 1. Taking an interpretive approach, 2. Holistic explanations and 3. Collaborating as a multi-disciplinary topic.

The interpretive approach taken in this research (see section 4.2) is not typical in engineering design thus it is important to be clear about how to read these findings. Interpretive approaches are particularly suitable to look at process changes over time, the unpredictability of human behaviour and what collaborating means to an individual. This approach (interpretivism, subjective nature, qualitative data) is in contrast to typical research approaches in engineering design (positivism, objective nature, quantitative data), which have tended to consider one point in time, focused on causality and are characteristically more positivist.

In taking an interpretive approach, this research has a sample size of four cases classified on two characteristics (see section 4.3). Empirical findings are developed through comparing data across cases to make sense of events. With a small sample size, empirical findings give an indication, rather than a rule, to understanding the phenomena of collaborating in engineering design. To increase the external validity of findings, they are positioned and discussed in relation to current literature (see sections 7.1.1-7.1.5). To ensure reliability of findings and academic rigour a clear methodology is outlined based on literature from the field of management studies where research using interpretive approaches is more established (see section 4.5).
Furthermore, there is guidance instead of definitive solutions for those practicing collaborating in engineering design (see chapter 8). Taking an interpretive approach there is less emphasis on best practice and more on providing information for participants to understand the phenomena. Thus guidance focuses on key concepts and steps for individuals to make sense of what happens when they collaborate.

In this research the focus has been on holistic explanations instead of concentrating on one specific aspect of an engineering project, e.g. communication. This has meant that all social processes have been considered to develop an understanding of how participants collaborate. A large conceptual framework (18 themes) was initially used to be open and flexible in developing an understanding of potential patterns. Taking a holistic approach though limits the depth of analysis on social processes to allow an understanding of the whole picture to emerge, i.e. collaborating in an engineering design project. Thus findings point to important themes or topics for collaborating without studying how specific social processes contribute to collaborating. This provides opportunities for future research detailed in section 7.3.

Finally, in this thesis the topic of collaborations draws on literature from a number of academic areas. This is primarily based in engineering design as this is the context for this study, yet it has been vital to be aware of and use research in management studies, sociology and social psychology to develop findings.

### 7.3 Future research

The topic of collaborating in engineering design is under explored with little empirical research on how projects, participants and organisations influence and are influenced by the process of collaborating or context. Seven possibilities for further research are presented. Four suggestions extend this research: 1. Alternative paths in research constructs, 2. Additional cases, 3. Focussing on individual design phases, 4. Applying guidance. Three topics have emerged from this research that could provide further understanding of collaborating in engineering design: power and pair-wise relations, collaborating and its value, sharing understanding.

#### 7.3.1 Extending this research

First, existing data could be re-analysed to consider alternative paths through research constructs (e.g. group relations’ influence pair-wise relations and outcomes). Current research may also be extended by adding further cases. Recently finished projects would
provide interesting retrospective studies and expand the existing strategy (see 4.3). A second possibility would be to use conceptual categories derived in this research as an analytical framework to understand new sets of data looking at collaborating in engineering design.

A third suggestion is to focus on certain phases of product development. This research has considered the whole of a product development cycle. Future research could focus on individual phases to build up a detailed understanding of when each mechanism was relevant to participants’ involvement. This aims to recognise how participants manage as project membership is more fluid with individuals performing specific activities simultaneously on multiple projects.

A final suggestion is to use the guidance presented in chapter 8 as a template for collecting data from design projects to complement other forms of data collection. The effects of this guidance could also be analysed at the same time. This could be either from personal reflections in industrial projects or in design projects involving undergraduates.

### 7.3.2 Future research topics

The first topic is that of power and collaborating. The conceptual categories of Opportunity, Dependence, Regulating have emerged to characterise patterns across cases for both pair-wise relations and group relations and evoke two well researched themes – power and social capital. Researchers [e.g. (Pettigrew, 1973; Pfeffer, 1981)] have noted that dependence and resources are linked to power, hence further research could address calls to consider how power and social capital influence each other (Huxham & Beech, 2008: 559; Lotia & Hardy, 2008: 382-3). In particular research could focus on how individuals through pair-wise relations create, develop and influence different aspects of social capital [e.g. relational, cognitive and structural (Nahapiet & Ghoshal, 1998)] to succeed in collaborating in engineering design.

The second topic is to consider the value of collaborating in engineering design – why collaborate? This study does not investigate how individual and group experiences of collaborating influence future methods of collaborating i.e. how individual and organisational strategies change. This could consider perceptions of participants who collaborate and whether their perceptions meet with what they hoped to achieve in participating in a collaboration. This would include understanding how experiences of collaborating are transferred and whether individuals continue collaborating or avoid it. An important part of this would be to access a number of perspectives to present a description of how collaborating is valued across multiple levels (individual, department, organisation,
collaboration). Alternatively researchers could investigate how collaborating is valued by performing an economic and social analysis to discover both explicit and less tangible outcomes from collaborating. This would provide further knowledge on why collaborations fail to be mutually successful (Tidd et al., 2005) or meet participants’ expectations (Killing, 1982; Ring & Van de Ven, 1989), and why researchers do not recommend collaborating unless you have to (Huxham & Vangen, 2005: 37).

The last topic for further research is that of shared understanding. Sharing understanding is presented as part of collaborating and is a an emerging subject in engineering design with researchers considering barriers and enablers [e.g. Kleinsmann (2006)] and how Task and Team mental models influence group performance [e.g. Bierhals et al (2007b)]. Future research could develop this notion by considering if the process of sharing understanding changes during a project, e.g. from sharing similar to overlapping understanding, and how this may influence participants and outcomes. Secondly, research could focus on characterising specific aspects of the content of Task or Team shared understanding that are pertinent to success. This would appreciate what attributes are important in different design projects and aid participants develop characteristics that are suitable for their project – note this may emphasise different amounts of collaborating are required for success in projects of different design type or setting.

### 7.4 Discussion summary

In this chapter cross-case findings were discussed by comparing to current theories and literature on collaborating and engineering design. This was elaborated over three sections, first describing Research Question construct features (7.1.1-7.1.3), secondly by presenting mechanisms (7.1.4) and lastly describing how pair-wise relations influence group relations and outcomes (7.1.5).

In the first three sections (7.1.1-7.1.3) discussion illustrated that participants used interaction in pairs to supplement or replace group interaction where there was limited opportunities (due to physical distance, multiple projects, participants’ availability). This explains how individuals create a rhythm to interaction (Maznevski & Chudoba, 2000) recognising though that pair-wise relations complement rather than substitute group relations. Discussion also highlighted that participants relied on other individuals (technical expertise, procedures and practices, reputational stakes) in pairs and as a group more in complex projects (Clift & Vandenbosch, 1999) i.e. inter-organisational and
Discussion: influences of pair-wise relations

original design cases. The subsequent dilemma, that there was less opportunity for, and
greater dependence on pair-wise relations and group relations, poses factors of
performance against benefits of collaborating and is similar to a paradox introduced by
Håkansson and Ford (2002) about opportunities and limitations. Furthermore participants
response to alter how they interacted and developed shared understanding in pair-wise
relations and group relations reinforced the difficulty of sustaining shared knowledge in a
project (Cramton, 2001) and provides an explanation to why innovative solutions are not
always produced when desired (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005).

In section 7.1.3 findings focus on outcomes for an individual (Adjustments) instead of
project outcomes (Results). Participants’ adjustments provide insight into why
collaborating (e.g. Hardy & Phillips, 1998; Huxham & Vangen, 2005) and designing (e.g.
Bucciarelli, 2002; Minneman & Harrison, 1998) are associated with conflict, negotiation
and compromise as there is no prevailing consensus about how to collaborate.
Furthermore, the conflict between individual and collective interests (Kerr & Park, 2001) is
shown with parallels to a paradox in strategic alliances (Das & Teng, 1998) where
participants need to balance competition and cooperation (Teece, 1992). Thus, individuals
having to resolve this paradox provides further insight into why collaborations take
significant time & effort (Gray, 1998: 479; Huxham & Vangen, 2004).

In section 7.1.4, three mechanisms (Familiarising, Associating, Regulating) are related
to literature. Discussion on Familiarising support a correlation between mutual trust,
collaboration and communication (Maier et al., 2008) showing that Familiarising explains
some of these links i.e. individuals through pair-wise relations recognise different needs
and develop expectations of each other’s motives [i.e. how to trust people (Das & Teng,
1998)]. Furthermore Familiarising describes how individuals developed how to trust each
other and new expectations to reduce the complexity of events (Luhmann, 1979).

Establishing aligned expectations in Associating provided evidence of how sense
making in pairs is used to develop commitment based on inter-personal bonds comparable
to legal and more formal obligations observed by Ring & Van de Ven (1994). Furthermore,
discussion about Associating describes how individuals through social relations reinforce
identity and social solidarity whilst highlighting potential problems with multiple groups
[e.g. fragmentation of a project group (Adler & Kwon, 2002)] and multiple commitments
that test the balance between conflict and collaboration.

Discussion on Regulating highlights that it is not enough to understand how to create
shared understanding in collaborating. To refine a design problem into a less abstract state
collaboratively, participants need to update and maintain complementary standards, behaviour and norms of a project group. Regulating illustrates that through pair-wise relations individuals can enact cooperation and communication for an entire design project (Badke-Schaub & Frankenberger, 1999a) yet this can create brokerage positions (Burt, 2000) and limit a groups’ access to social capital.

These four sections provide a foundation for an answer to how pair-wise relations influence group relations and outcomes (7.1.5). Engineering design becomes more reliant on social processes as participants have less experience of their design context (i.e. design setting and design type). This changes the rhythm of interaction and the three mechanisms describe how a group and individuals are influenced. Participants aim to reduce their uncertainty about how to collaborate through pair-wise relations. This acknowledges the importance of bonds across traditional boundaries, participants’ flexibility and additional effort, and how pair-wise relations influence group development (positively and negatively). In summary, the response to the Research Question is that:

1. Through pair-wise relations individuals can familiarise with, associate with, and regulate group relations.
2. Through pair-wise relations individuals can recognise their trust in, establish their responsibility to, and maintain (sufficient) control over other participants.
3. Pair-wise relations both help and hinder individuals and a group in how they adjust to foster aligned expectations of collaborating.

Following the response the Research Question the penultimate section (7.2) describes reflections on completing this research. This covers what has been achieved and learnt and limitations of findings. This is followed by suggestions of topics for further research (7.3). This chapter provides input to develop suitable guidance recommended in the next chapter (8) before presenting conclusions about the contribution of findings to answer Research Question in the closing chapter (9).
8 Implications for practice – meeting expectations

In this chapter general implications for practicing collaborating in engineering design are described founded on empirical findings in chapters 6 & 7. The aim of these implications for practice is to improve the success of collaborating by highlighting the influence of circumstance(s) on participants i.e. individuals and the group, emphasising that these may change over time. In understanding circumstance(s) participants can recognise what influences their ability to collaborate and actively manage the uncertainty of completing their tasks.

A series of questions are presented for participants to consider implications of how they collaborate. These are not prescriptive as this would mislead participants to the challenges and uniqueness of collaborating. The intention is that these implications will appeal to managers and participants of design projects who hope to gain from understanding previous design projects to improve the success of future ones. Applying these implications is outside the scope of this thesis but provides areas for further research (see section 7.3.2).

First, a definition of collaborating (8.1) is provided\(^4\), then implications for practice (8.2) are described in two sections covering social processes (8.2.1) and pair-wise relations (8.2.2). Suggestions for applying implications in practice are described (8.3) focusing on how to consider perspectives (8.3.1) of both individual (8.3.2) and group (8.3.3) before concluding with a chapter summary (8.4).

### 8.1 Collaborating in engineering design

The aim of collaborating is to combine skills and expertise of individuals in a group to design a product. The process of collaborating is often inferred from working in a team or group but here it is defined as more than individuals carrying out their specified role; project participants interact and transfer individual understanding into shared understanding crossing disciplines, departments and organisations. This allows individuals and a group to learn, create and maintain a similarity about how issues are conceptualised and what is expected to design a particular product. Consequently, participants can assess their circumstances from the same perspective to achieve their goals, solve complex problems and develop original solutions. Collaborating in a design project is recognised when there are high levels of interaction and a high dependency between individuals in carrying out their roles successfully (see section 1.4 for literature references). Thus,

\(^4\) The process of collaborating is defined in section 1.4 (p12), whilst a summary is included here as this chapter is also intended to be an independent document for use by those collaborating in engineering design.
collaborating primarily occurs between individuals but at its peak groups are seen to produce results that individual efforts alone could not achieve.

Currently collaborating is a popular choice to solve complex problems or develop a competitive organisational strategy, however it also fails to produce innovative solutions, falls short of individual’s expectations, and takes significant time and effort with researchers recommending avoiding it if possible (see section 1.2 p2 for literature references). To help make sense of these contradictions, implications for practice are described next based on empirical research to improve the success of collaborating in engineering design. This starts with considering an individual perspective, then a group perspective before describing how these perspectives may be applied in engineering design projects.

8.2 Implications for practice – managing to collaborate in design

There are two general themes for participants to consider in order to improve their understanding and expectations of collaborating in engineering design. These themes are intended to sensitise practitioners to circumstances of collaborating and form the basis for practical suggestions outlined in section 8.3.

8.2.1 Collaborating, social processes and circumstances

Collaborating takes more time and effort where participants have to learn how achieve their tasks or how to work together. As circumstances become less familiar to participants in engineering design projects there is a greater reliance on social processes in pairs and a group to achieve tasks in a project group (see Findings 4-6, 9-11). In collaborating participants are likely to have to cope with new or different circumstance working across knowledge and/or organisational boundaries. In these circumstances participants increasingly have to learn how to achieve their tasks in addition to accomplishing them. What is expected to happen is less explicit and less defined by established working practices; hence participants interact to understand how to combine their roles, capture progress and identify possible implications on their activities.

In novel or different projects there are more challenges to individual expectations about a project (e.g. changes to project participation, delays, design revisions, or requirements for additional resources), and social processes become more relevant to successfully achieve a finished product. With social processes becoming more prominent, methods for sharing aligned expectations transfer from established organisation working practices or design procedures to individuals. Participants adjust how to trust, commit to and sufficiently control each other to foster aligned project expectations (see Findings 12-14). For a
Implications for practice – meeting expectations

manager this places greater emphasis on managing individuals *in addition* to managing tasks, here it is important for managers to make individuals aware of these changes so they can respond and learn to collaborate. For participants, in addition to performing their role(s) they need to develop an understanding of their circumstances, how they may change and influence their own activities.

Where timescales may change it is prudent to build flexibility into existing processes e.g. allowing additional opportunity for reviews, or having regular project updates, specifically to reinforce a group’s common purpose (see Findings 1-3, 7-8). Maintaining a shared understanding is particularly advisable where there is diversity, e.g. multiple departments / organisations or multiple areas of expertise are involved. In particular, a shared group understanding emphasises aligned group expectations. This raises individual awareness across organisational and knowledge boundaries of appropriate standards to help a project group identify what is feasible.

### 8.2.2 Pair-wise relations and collaborating

In new situations, specifically developing and supporting *pair-wise relations* can assist participants to make sense of their circumstances (see section 6.6.1, Findings 15-17). Through *pair-wise relations* participants can access additional perspectives to establish how to complete their tasks in a project. Consequently individuals are encouraged to consider both their perspective and that of others to define aligned expectations outlining how they are committed to each other (see section 6.6.2, Findings 18-20). Individuals can maintain established group standards, norms and expectations through creating a rhythm of interaction in *pair-wise relations* though this should not be seen as a substitute for group interaction (see section 6.6.3 Finding 21-23).

Participants and managers should also be aware of possible limitations on understanding when *pair-wise relations* are increasingly used to transfer information. There is a risk that in using *pair-wise relations* it may encourage certain perspectives to be dominant in a group or participants may focus exclusively on their own activities. This can undermine the purpose of being a project group, e.g. to combine knowledge of participants, by not involving participants’ different perspectives. This presents a greater challenge to sharing understanding and expectations where there is a broader diversity of participants and fewer opportunities to interact. To mitigate this challenge and manage aligned expectations it is recommended that participants establish and maintain *group relations*. *Pair-wise relations* are hence *supplementary* to, not a *replacement* for, *group relations* when collaborating in engineering design.
8.3 Suggestions for applying implications in practice

There are no imperatives to what participants ‘should’ do with these implications for practices as to do so would be presumptuous, mistaken, or both. The author has no control over what practitioners may end up doing, yet it would be remiss to not give some direction on how these implications may be applied. First suggestions on applying perspective(s) to collaborating in design are described (8.3.1) covering how, who, and when. Next there are two section detailing two perspectives: individual (8.3.2) and group (8.3.3). In these sections a series of questions are described (including worksheet templates) for participants to use to reflect on their expectations of collaborating in a design project, individually (see Table 13 & Table 14) and as a group (see Table 15).

8.3.1 Applying perspective(s) to collaborating in design

In these implications for practice two perspectives are outlined in the process of collaborating – individual and group. The purpose of recognising multiple perspectives in collaborating is for participants to understand each others’ expectations and subsequently develop some common agreement of what is expected from each participant in a project group. But how can this be achieved? Who would be involved? And when does this take place?

How to capture individual and group expectations

Two approaches are proposed for capturing individual and group expectations – (a.) in a workshop or (b.) as part of project management. Both use the same material (detailed in sections 8.3.2 & 8.3.3) with steps set out as below:

i. Distribute templates (Table 13 p196, Table 14 p198) to project participants for them to complete individually.

Note. This is for individuals to reflect on the characteristics of their project and how they will collaborate (see section 8.3.2 for further details).

ii. Convene project participants to a group meeting to discuss similarities and diversity of perspectives with the group after completing the first step.

Note. This for participants to look at their group composition and note where there is similarity and diversity (see section 8.3.3 for further details).

iii. Use the Group template (Table 15 p201) to structure discussion and record individual perspectives.

iv. Establish a perspective that represents the project group (Table 15).

v. Distribute complete copy of Table 15 from group meeting to project participants.
Implications for practice – meeting expectations

Note. This aims to provide participants with a reference document to reduce potential ambiguities between individual and project group perspectives.

In approach (a.) the responsibility of organising and running a workshop is removed from the project team. The main advantage is that project managers and coordinators can participate rather than organising and running the event. Furthermore a facilitator with experience in the domain of collaboration can bring further insights whilst providing information to address concerns or queries from those considering these implications.

Alternatively in approach (b.), this material can be applied through project management. A project manager can follow the steps outlined above to develop individual and group perspectives on collaborating. It is recognised though that adding further tasks to a project manager’s role may be unpopular or unproductive, if so the workshop method offers an alternative.

Who to involve in understanding collaborating

It is recommended that all those involved in a project participate in this activity to encourage all to reflect on their circumstances and how they collaborate to capture an accurate group perspective. Nevertheless this is optimistic, and it may be judicious to select a representative sample of participants to discuss and develop a group perspective – though this should try to encompass the diversity of those involved.

This guidance has been developed with small project groups in mind (up to 25 participants in a project team), yet larger projects may also find performing this exercise beneficial. In this situation it is proposed to carry out steps ii to iv, in two stages – first with a representative sample of participants to discuss the whole project team, and secondly then these representatives could discuss with their own respective groups (e.g. departments/organisations). These discussions would then be reported to a project manager to complete the final step (v.).

When to consider the process of collaborating

The aim of carrying out these exercises at the start of a project is to provide participants with information to help them adjust their expectations of how to collaborate with each other. Circumstances and projects change, and if there are changes, the attributes of a project may also change (e.g. finances, setting, project priority, awareness of progress etc). If attributes change, they may impact upon how participants view the project individually or as a group; hence it is advised to complete these exercises (outlined in sections 8.3.2 & 8.3.3) during a design project.
It is not proposed to frequently repeat these evaluations as this is likely to distract from the purpose of a project. Instead, it is considered valuable for participants to re-evaluate when they believe initial project attributes have changed (either progressively or suddenly). In this research (see sections 6.5, 6.6) four challenges are identified that provide an impetus to evaluate and reconsider how participants collaborate:

1. Design revisions (new design or project requirements, design reviews etc.).
2. Members join / leave project.
3. When expected timescales for task completion alter or are not met.
4. Requests for additional finances.

The first challenge considers changes to designs. When new design or project requirements are added to the current design they can seem logical to some, yet to others it may contradict or even impose further work to complete their tasks. If all participants are aware of proposed changes then possible implications can be voiced to make all aware of the new situation and the implications from the proposed changes. In design reviews (stage gates or similar) what is acceptable is highlighted and group standards set. These standards may differ as different areas of technical expertise are involved. Hence it is useful for participants to be aware of what is expected especially when designs are revised.

The second challenge is a change of membership. This may mean a loss or gain of expertise, perhaps participation will increase and more interaction will be required to understand new assumptions or concerns. Consequently making participants aware of who is involved and participating means a project are more likely to adjust to the new composition of participants.

The third challenge noted in these studies was when tasks took longer than expected. This can be for a variety of reasons; what is important is that individuals in a group are aware of what is happening and why. It may be because participants have under estimated timescales due to the novelty of their task, or because they have other projects of a higher priority. Not meeting timescales is likely to influence other tasks, and participants’ perceptions of each other. A group can also benefit by using this time delay to accomplish their work to a higher standard.

The last challenge to expectations is when a project requires additional finance to meet its objectives. Individuals may question why finances are needed – initial expectations may have only planned for certain approaches to be used with finances available based on these approaches. In collaborating there are no prescribed ways to work; participants actively develop how to achieve their tasks whilst carrying them out. Recognising what participants
Implications for practice – meeting expectations

actually do when collaborating will help a project group identify whether and where additional finances are necessary and acknowledge individual contributions to a project.

These challenges to expectations outline when it is useful to consider how changes may affect each participant. This is to note that not all participants may be aware or involved in these challenges and undertaking a review would re-establish the circumstances of their project. Recommendations for capturing individual and group perspectives are described next in sections 8.3.2 and 8.3.3.

8.3.2 An individual perspective – what is important for an individual to collaborate

In this section the aim is for participants to focus on their own role(s) by taking an individual perspective on their design project. The purpose of this is twofold: first for participants to reflect on how characteristics of their project may influence how they carry out their own task, and secondly for participants to consider how they need to collaborate. This is separated into two respective categories under the questions: what is new about this design project? and to what extent do I need to collaborate? This encourages participants to make explicit how they intend to collaborate.

What is new about this design project?

Few projects in engineering design are identical hence it is useful to outline attributes of a project that influence how individuals collaborate. Based on cross-case comparisons six attributes are presented to consider how a project may be different to previous ones namely: participants, finances, role, aims, project setting, project design type (Figure 36).
tasks. The ‘project setting’ refers to the membership structure e.g. inter department and the
‘project design type’ classifies the design between variant, adaptive or original noting this
may be different for an individual and project.

Each attribute represents an element of uncertainty for an individual in completing their
task, e.g. who will I have to depend on? or how will I perform this role? When an attribute
is similar to previous projects, e.g. the same membership, then individuals can be more
certain about what they can expect in the project from participants, and hence plan
accordingly to achieve tasks. Anything that is new or different implies a greater uncertainty
for an individual and also for other participants as previous experience is less indicative of
how to collaborate. For example, when an individual takes on a new role they may interact
with others differently to before and hence previous experience of working together is less
practical and even misleading to understand how to interact together. In order to explore
each attribute there are five questions for individuals to respond to when they are starting a
project:

1. What is this project?
2. What is new/different about this project?
3. Are there any effects from these novelties on your role?
4. How do these effects influence the certainty of accomplishing your task?
   (Greater/Same/Lower)
5. Who do you know could assist you with these effects?

These six topics (project attributes) and five questions are combined in a template for
individuals to complete (see Table 13).

It is proposed that all participants individually take a short period of time as they start
on project to complete Table 13. The intention of Question 1, what are the project
details?, is to ask individuals to define their project (using topics from this research that
have an impact on collaborating). In Questions 2 & 3 individuals are encouraged to think
about how this project differs from previous projects they have participated in before
stating any possible effects of these differences may have on their role. These three
questions help participants to classify their new project in terms of previous projects. For
example in answering questions one and two for the project design type topic you are
clearly stating which design projects (and processes) you expect this project to be similar
to. Additionally this encourages an individual to reflect if there are any differences to
similar projects e.g. this is an original design project type yet what is different/new is that
working practices are less rigidly defined. This helps break down factors that contribute to
how an individual views a project and how they will need to collaborate. An example of
the third question and topic of *individual role* is that a new role could mean more
responsibility in the project. This increase in responsibility may require or encourage an
individual to take different approach to interacting with other participants as they want to
ensure they fulfil their role successfully.

<table>
<thead>
<tr>
<th>Table 13 – Collaborating template for ‘What is new about this project?’</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attributes</strong></td>
</tr>
<tr>
<td><strong>Date</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1. Project</td>
</tr>
<tr>
<td>details</td>
</tr>
<tr>
<td>2. Novelities</td>
</tr>
<tr>
<td>/difference</td>
</tr>
<tr>
<td>about this</td>
</tr>
<tr>
<td>project</td>
</tr>
<tr>
<td>3. Effects</td>
</tr>
<tr>
<td>of novelities</td>
</tr>
<tr>
<td>on your</td>
</tr>
<tr>
<td>role</td>
</tr>
<tr>
<td>4. Certainty</td>
</tr>
<tr>
<td>of task</td>
</tr>
<tr>
<td>completion</td>
</tr>
<tr>
<td>(delete as</td>
</tr>
<tr>
<td>applicable)</td>
</tr>
<tr>
<td>5. Who can</td>
</tr>
<tr>
<td>assist you</td>
</tr>
<tr>
<td>with these</td>
</tr>
<tr>
<td>effects?</td>
</tr>
</tbody>
</table>

Having considered the first three questions, in *Question 4* individuals are prompted to
make an overall judgment on their certainty of task completion in comparison to previous
projects – Greater / Same / Lower. This allows an individual at a glance to recognise topics
that potentially will require further effort to ensure tasks are completed successfully.

*Question 5* is perhaps the most important – *who could assist you with these effects.*
Findings in this research have shown participants are more active through inter-personal
relationships when they are in unfamiliar situations or when uncertain about their tasks,
project or other participants. Having considered what, if any, possible novelties or differences and effects may be important, it can be overwhelming trying to understand, manage and overcome them. By putting down names of relevant individuals, participants can highlight who they can interact with to understand what is happening. This may be somebody in the project team, or perhaps outside of the project, what is important is that participants think about who has experience of these effects and could help to understand what they are experiencing and how best to achieve their role.

Where there are new or different details for a project, participants should allow additional time and effort to achieve their own task(s). After classifying a new project regarding how it can influence an individual’s role, it is recommended that participants reflect on the extent they collaborate in a project to understand how to effectively achieve their tasks. This is considered next.

**To what extent do I need to collaborate?**

After reflecting on what is new about a project, it is recommended that individuals think about how relevant collaborating is to complete their role. The process of collaborating involves sharing, developing and maintaining a shared understanding between participants. It may be assumed that participants should always collaborate, but collaborating takes time, effort (see sections 1.2, 1.4 & 3.4 for literature) and may be superfluous or not recognised for certain tasks or roles. So, for an individual to be effective in completing their own tasks and role it is beneficial for participants to consider the extent of collaborating required so they can target where to place their efforts. Six questions are proposed for a participant to consider at the start of a project to manage the extent they need to collaborate:

1. Who do I need to collaborate with to achieve my tasks?
2. What is the purpose of collaborating?
3. When in design process do I collaborate with them?
4. How frequent do I collaborate with them?
5. What methods do I use to collaborate with them (e.g. regular meetings, CAD, etc)?
6. What prior experience of collaborating in these roles do we have?

A template is presented in Table 14. Similar to Table 13, it is recommended that participants complete Table 14 before, or as soon as, they start working on a design
Implications for practice – meeting expectations

project. The purpose of these questions is to understand the extent of collaborating with each participant in a project.

Table 14 – Collaborating template for ‘To what extent do I need to collaborate?’

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Person A</th>
<th>Person B</th>
<th>Person C</th>
<th>etc</th>
<th>Interpreting responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. With who do I need to collaborate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Who I need to interact with or be aware of their progress</td>
</tr>
<tr>
<td>2. Purpose of collaborating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Why I need to collaborate with whom and what is required</td>
</tr>
<tr>
<td>3. When in design project</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>When I need to work with whom</td>
</tr>
<tr>
<td>4. Frequency of collaborating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>How much time I am likely to use in personal interactions</td>
</tr>
<tr>
<td>5. Method of collaborating</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>How I am likely to collaborate, what provisions I need to ensure I can collaborate</td>
</tr>
<tr>
<td>6. Prior experience we have in our roles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>How much I can rely on our previous personal experiences</td>
</tr>
</tbody>
</table>

Responses to Question 1 outline who an individual needs to collaborate with to achieve their role. This allows an individual to be aware of possible dependencies or who to focus effort with. Question 2 is used to expand on the first question by asking an individual to qualify their purpose of collaborating. This gives an individual a reminder of what needs to be transferred or shared in collaborating – this may be information or problem solving. The aim of Question 3 is to ask individuals to consider if other participants are only temporarily part of a project. This aims to help participants plan when to place effort in collaborating with each participant. In Question 4 individuals are asked to recognise how much time is likely to be committed to collaborating e.g. daily short talks, monthly meetings etc. This, in conjunction with Question 3, may highlight that individuals require greater collaboration at different points in a project e.g. designers may initially require a high frequency of interaction during conceptual design before reducing as embodiment and detail design phases are completed. In Question 5 participants reflect about how they intend to collaborate e.g. this may only be possible in face to face interaction. If participants are not co-located then solutions (and their associated costs) need to be outlined e.g. weekly video conferences for a group team meeting. The aim of Question 6 is to enable participants to be aware of how prior experience of collaborating may, or may not, be relevant. If roles are different between individuals then there are likely to be
different dynamics and expectations; hence it is worth considering how these may have changed and if so what this implies will be different.

The purpose of these questions in Table 13 and Table 14 is to encourage each participant to consider what they need to accomplish their own role and how the circumstances of a project can help or hinder them. The questions provide a structure for individual reflection on whether to, or how to collaborate. Most participants only need to interact and collaborate with certain individuals in a group. In particular when individuals are new or different, participants should allow additional time (and ideally additional resources) to learn how to collaborate together. Key to reflection is selecting individuals that provide a starting point to assist them in unfamiliar aspects of their task (Question 5. Table 13). Creating inter-personal relationships will expand their own perspective to consider others and be aware of possible future problems. The aim is for participants to develop an understanding of what is involved, and not have idealised or unrealistic expectations.

Furthermore, a group could use information from these templates (Table 13 & Table 14) to recognise who participants are highly dependent on or how participants perceive their own role in the group. Up to now the focus has been on individual efforts to categorise what is important for an individual to be able to collaborate successfully. At the same time participants need to be aware of the project group that they are part of. A group perspective is presented next to organise reflection on a project group.

8.3.3 A group perspective – considering similarity and diversity in a collaborating group

Participants are brought together in a design project to complete what individual efforts alone cannot. This creates a group of individuals who are similar, e.g. they are part of this project group, and yet often diverse, e.g. each participant has their own approach to collaborating. This similarity and diversity within a group creates a tension between being part of a group and being an individual (see chapter 3 for literature) and it is important to recognise both aspects of this tension. In this section participants are recommended to look at their group composition and note where there is similarity and diversity. The aim of looking at similarity and diversity is to highlight where participants may see similar or different approaches, where individual attributes are aligned or contradictory, and to prompt participants to develop and maintain similar expectations to collaborate successfully.
Eleven questions from the six attributes presented in section 8.3.2 (see Figure 36 p194) are proposed for a group to discuss:

1. What technical areas do we represent in this project?
2. What is the priority of the project?
3. What are the financial resources for roles and overall group?
4. To what extent are finances for roles/tasks itemised?
5. Which departments and organisations are represented?
6. What are individual and group aims?
7. What roles are represented in the project?
8. How do individual roles influence each other?
9. How is progress of tasks made visible to the group?
10. Who reviews progress?
11. What type of activities are being undertaken to achieve tasks?

The purpose of these eleven questions is to make visible similarity and diversity between participants for them to be aware of their circumstances. The aim is for members to contribute their interpretation and to record an overall project view. This is done in two parts, first to make participants aware of each individuals’ expectations, and secondly to establish expectations for the group. It is the responsibility of an individual to present to a project group what they expect in partaking in a project and a project group also has a responsibility to set what is expected from individuals. In using this set of questions individuals and a group are prompted to create an opportunity to make expectations less ambiguous and more explicit reflecting both aspects of similarity and diversity in the group. A template of how these questions may be used is shown in Table 15 including a perspectives (columns) for each individual, one for the overall project group, and one with advice on how diversity and similarity may be interpreted for each question.

In Question 1 participants consider the similarity or diversity of technical areas represented. From answering this question, a group highlights technical expertise that participants are capable of representing, and consequently any gaps or limitations e.g. only one expert in the innovative technology. This may also emphasise where information exchanges may be ambiguous as there are technical boundaries e.g. if there are potentially multiple meanings to language, which could be resolved by establishing clear definitions of how terminology is be used.
<table>
<thead>
<tr>
<th>Attributes</th>
<th>Group perspective – what is similar and different?</th>
<th>Interpreting similarity/diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Technical areas represented in project</td>
<td>What technical areas are covered vs. what are required. If diverse concern with common terminology, assumptions, greater need for technical representation to consider possible implications.</td>
<td></td>
</tr>
<tr>
<td>2. Project priority</td>
<td>How project priority varies. Mix of participants’ availability</td>
<td></td>
</tr>
<tr>
<td>3. Financial resources per role (&amp; group)</td>
<td>How are resources split. Indicates size of roles in group, involvement in project</td>
<td></td>
</tr>
<tr>
<td>4. Extent of itemised finances</td>
<td>Detail of individual working plans, e.g. less itemised planning may allow extra flexibility in adapting to changes.</td>
<td></td>
</tr>
<tr>
<td>5. Representing which department, organisation</td>
<td>Which organisational boundaries are crossed. Working methods, standards, expectations, assumptions etc may differ</td>
<td></td>
</tr>
<tr>
<td>6. Aim(s) individual &amp; group</td>
<td>Where in the group aims are aligned to project aims.</td>
<td></td>
</tr>
<tr>
<td>7. Roles represented in project</td>
<td>Are roles compatible, Are roles duplicated / missing</td>
<td></td>
</tr>
<tr>
<td>8. Affected by other roles in group</td>
<td>Where roles are dependent on others; where interaction is required between individuals, who is in high demand</td>
<td></td>
</tr>
<tr>
<td>9. Visibility of individual progress to group</td>
<td>How participants are aware of change / development / progress of individual aspects of project</td>
<td></td>
</tr>
<tr>
<td>10. Who reviews progress</td>
<td>Who has technical responsibility, differences may imply different standards etc</td>
<td></td>
</tr>
<tr>
<td>11. Type of task activity</td>
<td>Research vs. implementation, or both – implementation activities are more likely to meet planned expectations; identify areas of risk to whole project</td>
<td></td>
</tr>
</tbody>
</table>
Implications for practice – meeting expectations

**Question 2** is used to note each participant’s *project priority* to make it explicit to others how their availability may be affected during the course of the project i.e. those with a low priority are likely to work on other projects that may disrupt progress on this project. Outlining *financial resources* in **Question 3** can be sensitive. However, responding to the question can make two aspects visible to the group – i. the amount of time available from each participant and ii. how likely individuals are going to be available for and involved in a project. For example if an individual has a large role in the project, a corresponding level of involvement may be expected.

In **Question 4** participants consider *the extent that finances are itemised* for each individual. How individuals plan financial contribution may be highly itemised down to each step in a process or at the other extreme may simply by under a broad description to achieve an objective. Outlining similar or diverse approaches prompts participants to be aware of how flexible other participants are likely to be to support changes that require additional finances, e.g. there is likely to be limited financial flexibility from participants using detailed prescriptive practices.

Recording the *departments and organisations* involved in **Question 5** prompts participants to recognise potential boundaries to transfer and exchange knowledge, assumptions to standards and working processes. This emphasises that not only knowledge (Question 1), but organisational boundaries create different approaches that influence how participants are likely to collaborate.

Stating *aims* in **Question 6** may seem trivial, still when aims are visible participants are more likely to understand individual behaviour and what is trying to be achieved. Consequently, a project group is more likely to establish overall aims that manage to represent participants’ involvement.

The purpose of discussing participants’ *project roles* in **Question 7** is to ensure that all are aware of who is performing what (and hence who knows what), where there may be redundancy and where there may be a lack of skills. This is not always clear as roles, participants, department and organisations may be new to individuals; thus clarifying roles aims to establish a project group’s capabilities.

Following stating individual roles, it is proposed to discuss how individuals are *affected by other roles* in **Question 8**. This supplements individual reflection on one’s own task(s) (see Table 13, Table 14) to define who is dependent on whom in order to fulfil roles and tasks highlighting where there is likely to be high levels of interaction between participants.

The purpose of **Question 9** is to qualify *visibility of individual progress* to the group. This enables participants to identify how to check on design developments, progress and
any changes. This is particularly useful for participants who are influenced by other roles or tasks (see Question 8.)

**Question 10** asks individuals to consider *who reviews progress*. This is to establish potential differences in technical responsibility, which may point to which standards are relevant for participants.

Lastly in **Question 11** it is relevant for participants to describe their *type of task activity*. This raises awareness in the group of potentially different activities in one project e.g. some could be performing research activities whilst others are implementing well defined activities. Each activity requires different support and has different associated risks to achieving completion. Clearly stating these types of activities provides information to all involved to be able to assess the likelihood of meeting initial expectations.

It is not expected that response from all participants in a group will automatically be transparent particularly when participants are unfamiliar with technical expertise or individuals. Participants should hence bear in mind that each individual may also have unstated or hidden responses to these questions i.e. there may be other aims than those explicitly stated. It is still worthwhile to create a discussion about what participants are willing to share to identify potential synergies or mismatch in achieving collaboration.

In interpreting a completed table, high levels of similarity or diversity would be denoted by a smaller or larger amount of differences between members across the majority of responses. Where there are high levels of diversity there are greater challenges for individuals to be represented by the group. High levels of similarity present challenges to creativity (group norms can dominate), presenting alternative solutions or approaches to designing. Ultimately it is important that participants are aware of the similarity and diversity that bring them together in a project. The success of collaborating in a group is linked to participants recognising what a group has (what keeps it a group e.g. interdependency of outcomes) and being able to access and develop those attributes to attain their goals.

Completing these template will not automatically result in successful projects. In this chapter participants are encouraged to start to understand collaborating as individuals *and* as a group through a series of questions that allows individuals to systematically reflect on how they collaborate. What is vital is that participants move beyond postulating and organising what is happening *individually* to actively interacting with relevant parties as a
Implications for practice – meeting expectations

group. Without this, participants are less likely to understand what is happening in a project and how to meet expectations and successfully collaborate.

It is important to note that these questions and templates are not a means for stereotyping or stating causes of why participants’ behaviour is unexpected. The purpose of these templates is to make sense of collaborating situations and support participants to have realistic expectations. What is crucial is that participants develop and maintain their understanding from their current circumstances and instead of speculating about other individuals, interacting with them.

8.4 Summary of collaborating guidance

In this chapter practical implications of this research were presented to improve the success of collaborating in engineering design by developing and maintaining realistic and aligned project expectations. The aim of these implications is to encourage participants to make sense of circumstances both as individuals and as a group in a design project to recognise how they can collaborate.

Recommendations were presented detailing how, who and when to evaluate how participants are collaborating in engineering design. Three templates are presented – two for individuals and one for a group, for participants to structure their understanding of collaborating in engineering design. These form a basis for individuals and a project group to reflect systematically on what expectations are from individuals, and vice versa. This gives clear and visible indications of standards and aims to create open discussion and recognise similarity and diversity within a group. This does not determine open discussion and it is important that participants note that individuals or organisations may hide or not state explicitly their own attributes.

These implications for practice are based on research carried out over 2006-2010 in four separate design projects involving a total of ten organisations. This is not prescriptive and the aim is to prompt understanding through providing a series of questions/attributes to help participants make sense of their circumstances to collaborate successfully. The list of questions/attributes is not absolute as the purpose is to start and prompt participants to consider their role in a new project. Following this chapter, conclusions are presented for this research.
9 Conclusions

This thesis finishes with the main conclusions and their contribution to understanding collaborating in engineering design. The changing context of collaborating in engineering design has been discussed outlining how, currently, collaborating involves multiple departments, disciplines and organisations. Collaborating is promoted by professional associations (e.g. ASME, 2008, 2009) and governments, and features in many organisation strategies, yet there are problems sustaining shared knowledge and many collaborations fail to produce innovative solutions or be mutually successful. Thus there is a need to understand how engineers continue to perform their activities when collaborating.

Collaborating is a relational concept i.e. it has to involve at least two parties. In this research the basic form of collaborating is two individuals and is represented through pair-wise relations. Collaborating also occurs when people interact and create shared understanding in a group and this is described through group relations. Lastly, outcomes represent how participants react and adjust to achieve their activities in collaborating. Six objectives were set (see section 1.3) and conclusions to each are described next before summarising the response to the Research Question.

Objective 1: To review relevant literature and develop, or adopt, a framework of concepts to investigate engineering design teams, group behaviour and collaboration.

Current knowledge about collaborating in engineering design was accumulated. This involved an integrative interdisciplinary approach to select a framework of relevant concepts to understand pair-wise relations and group relations. This was based on literature in engineering design and supplemented by research in management studies, sociology and social psychology. In the review the researcher concluded that empirical studies in engineering design typically focused on one or two social processes in groups [e.g. communication Eckert et al (2005), Maier et al (2008), Minneman (1992)], in projects crossing only departmental boundaries [e.g. Kleinsmann & Valkenburg (2008), Larsson (2007)], and with limited recognition of how the novelty of design tasks may influence design teams [e.g. Frankenburger & Badke-Schaub (1998b: 156), Ostergaard & Summers (2009)]. In other academic disciplines research was presented to describe key aspects on group behaviour, theories on sharing understanding and key topics and challenges in collaborations. This led to adopting a conceptual framework from Huxham and Vangen’s (2005) research on collaboration practice. This was chosen as it was relevant (established from observations of collaborating), flexible (no causality or relationships between themes)
Appendix

and holistic (can consider multiple themes and covered a number of levels of analysis
[individual, group, context]). This was successful in sensitising the researcher to suitable
themes relevant to understanding collaborating in engineering design.

**Objective 2:** To design and conduct a longitudinal cross-case comparison of
engineering design projects.

An interpretivist approach was taken to investigate collaborating in engineering design.
This focuses on a subjective perspective of the nature of phenomena and uses qualitative
methods and methodology to generate meaning and understanding from data. A
longitudinal study has been completed comprising of one pilot study and a cross-case
comparison of four design projects in industry. Two dimensions were used to classify the
four main cases: design setting (intra or inter-organisational) and design type (adaptive or
original). In total, 30 participants from 13 organisations were interviewed at two points in
each project with additional data collected from meeting observations and project
documentation. Using these individual perspectives, a picture of collaborating project
teams has been presented (chapter 5) and then analysed (chapters 6 & 7). Limitations of
this type of research design have been described. Taking an interpretivist approach
expands research in engineering design beyond typical positivist approaches. It illustrates
alternative approaches to understand social phenomena and builds on recent research (e.g.
Kleinsmann, 2006; Kleinsmann & Valkenburg, 2008) that focuses on making sense of
individual experiences whilst contributing a descriptive understanding to develop design
methodologies (Blessing et al., 1998).

**Objective 3:** To describe influences on the process of collaborating in design project
teams.

The process of collaborating in engineering design has been shown to be affected by
design context. Two dimensions have been compared – design type and design setting.
There was a greater need for activities to reduce the ambiguity of collaborating where
design type or design setting was more novel to participants – typically in original design
cases and inter-organisational design settings. To reduce ambiguity and achieve their work
participants shared with other individuals their Task understanding (e.g. of design
scenarios, procedures) and Team understanding (e.g. of participants’ capabilities). Thus in
cases of higher ambiguity, participants supplemented explicit design procedures and
working practices with efforts in sharing understanding between each other to address a
lack of established common procedures or practices. Thus where there was greater
ambiguity, participants instead of defined processes had greater discretion on how
collaborating was achieved. This provides some empirical evidence to why collaborating takes significant time and effort (Gray, 1998: 479; Huxham & Vangen, 2004). In highlighting the importance of understanding project context, further work remains to comprehend how it impacts on product quality, development timescales and costs. This research has expanded current understanding about the complex nature of organisational and inter-organisational boundaries (Santos & Eisenhardt, 2005) starting to address how individuals learn to combine their knowledge in practice (Tomiyama, 2007) by providing empirical evidence to why there are differences between design theory and practice.

**Objective 4: To analyse how pair-wise relations influence collaborating in design project teams.**

Based on findings in this study, individuals through *pair-wise relations* interact and share understanding to collaborate and achieve their individual activities. This fits with current literature but also describes how *pair-wise relations* can supplement (or replace) *group relations* in a design project. This is explained by Opportunity and Dependence. There are different prospects for individuals to interact and develop shared understanding (Opportunity) in pairs or as a group; and participants have different requirements of each other or the project in order to achieve their aims (Dependence).

It has been argued that *pair-wise relations* influence *group relations* and *outcomes* by three mechanisms: Familiarising, Associating, and Regulating. Familiarising outlined how participants recognise different expectations and highlighted how through *pair-wise relations* individuals recognise who knows what, tacit group norms and how to trust other participants. Associating explained how participants through *pair-wise relations* establish individual responsibility and commitment in a project group. It described how individuals establish similar or conflicting goals and reinforce individual or project group identity – particularly when there are stronger connections between those of similar groups or there is fragmentation when sub groups have high solidarity. Lastly, Regulating presented further understanding to how through *pair-wise relations* individuals can maintain shared knowledge and working norms in a group. Regulating also provided empirical evidence of how participants through *pair-wise relations* control group standards when projects are no longer managed by one party, and can create pressure for individuals to conform or broker change.

Each mechanism is dichotomous such that it outlined how through *pair-wise relations* individuals are helped and hindered in achieving their tasks. Individuals are helped by
developing their understanding of activities and participants, in effect learning how to collaborate with each other to achieve their tasks. Participants are hindered by narrowing individual understanding of a project to topics and interests of two participants; this can distance participants from a project group or create a false sense of security as individuals are unaware of what other individuals expect or assume their work will fit with other participants.

In sum participants through *pair-wise relations* reduced their uncertainty about how to achieve their tasks together i.e. how to collaborate. Most revealing is how individuals balanced identifying how to collaborate through *pair-wise relations* or *group relations*. Making these approaches visible to participants can highlight potential complications to how individuals collaborate. Thus the construct of *pair-wise relations* is important to understand how people work collaboratively in design projects.

**Objective 5:** To develop existing or new (if applicable) concepts and theories based on empirical findings about how *pair-wise relations* influence collaborating in engineering design.

Seven new conceptual categories are introduced to describe how *pair-wise relations* influence collaborating in engineering design – four features and three mechanisms. Features (Opportunity, Dependence, Results, Adjustments) are specific to Research Question constructs (*pair-wise relations, group relations, outcomes*). These features are used to describe a dilemma that participants face and which is more acute where boundaries are crossed i.e. there is less Opportunity for and greater Dependence on *pair-wise relations* and *group relations* in inter-organisational or original design cases. In response to this dilemma individuals altered their involvement in *pair-wise relations* and *group relations*. Changing the dynamics of how individuals interact and develop their shared understanding reinforces the difficulty of maintaining shared knowledge in a project group (Cramton, 2001) and gives some explanation to why innovative solutions are not always produced when envisaged (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005).

Project and interim Results revealed a mixed and unclear pattern across the four cases. However, looking at individuals highlighted that participants made Adjustments when expectations were challenged. Participants repeatedly questioned how to achieve their tasks and collaborate (how to trust, commit to, control other participants). This repetitive process of questioning and adjusting contributes to explaining why collaborating (e.g. Hardy & Phillips, 1998; Huxham & Vangen, 2005) and designing (e.g. Bucciarelli, 2002; Minneman & Harrison, 1998) are linked to conflict, negotiation and compromise as there is no prevailing consensus about how to recognise, define and maintain aligned project
expectations. Individuals adjust. Furthermore each participant redefined their own expectations about what was required yet simultaneously a project group defined expectations. This captures a conflict between individual and collective interests (Kerr & Park, 2001: 116) and draws strong parallels to a paradox associated with strategic alliances (Das & Teng, 1998) where participants need to balance competition and cooperation (Teece, 1992). Thus, participants repeatedly resolving this paradox during a project provides further insight into why collaboration takes significant time & effort (Gray, 1998: 479; Huxham & Vangen, 2004).

Three mechanisms (Familiarising, Associating, Regulating) described how pair-wise relations influence group relations and outcomes. Familiarising explained some of the links between collaboration, mutual trust and individual needs (Maier et al., 2008) i.e. individuals through pair-wise relations recognise different needs and develop expectations of each other’s motives [i.e. how to trust people (Das & Teng, 1998)]. Individuals learn how to trust each other and revise their expectations to reduce the complexity of events (Luhmann, 1979). Associating identified that commitment or affiliation to a project is an outcome via pair-wise relations and described how individuals through social relations reinforced identity and social solidarity. This highlighted potential problems with multiple groups [e.g. fragmentation of a project group (Adler & Kwon, 2002)] and multiple commitments that test the balance between conflict and collaboration. Regulating demonstrated that through pair-wise relations participants were active in providing direction to ensure that their individual activities were complementary to other participants. This illustrated that through pair-wise relations individuals can enact cooperation and communication for an entire design project (Badke-Schaub & Frankenberger, 1999a) yet this can create brokerage positions (Burt, 2000) and limit a groups’ access to social capital.

These mechanisms concur with current literature under the theme of social capital (e.g. see Nahapet, 2008 amongst others) describing effects for individuals and group regarding access to information, influence over people and reinforcing identity (individual and group).

In total these seven conceptual categories provide topics for academics to investigate how individuals collaborate in engineering design. These categories present some insights to why there is currently discrepancy between theory and practice (Bucciarelli, 2003; Hales, 1991; Stempfle & Badke-Schaub, 2002) as participants in practice have to learn how to collaborate in addition to understanding how to perform their technical design tasks.
Objective 6: To develop implications for practice of collaborating in engineering design based on empirical findings.

Findings have been developed into guidance for those practicing collaborating in engineering (chapter 8). Implications for practice focused on differences in individual and group expectations due to six topics: design type, design setting, finances, aims, participants and role. The aim of this guidance was to aid project participants in considering their circumstances through both individual and group performance expectations and to foster aligned expectations to collaborate.

In this thesis, research focused on pair-wise relations and addressing:

Research Question: How do pair-wise relations influence group relations and outcomes in collaborating engineering design teams?

Engineers in new contexts developed pair-wise relations to use inter-personal networks to coordinate their own activities, particularly when they are less certain about how to achieve their tasks (Kraut & Streeter, 1995). However altering the balance between pair-wise and group interaction changed the rhythm of interactions in a group which influences a team’s efficacy in maintaining standards and managing change (Maznevski & Chudoba, 2000).

Familiarising, Associating, and Regulating each described Adjustments that individuals make through pair-wise relations to help reduce their uncertainty about successfully achieving their activities. When individuals’ adjust their goals and activities to collaborate, a project may become less innovative or successful for them. This helps to explain to why many collaborations are perceived to fail in producing innovative solutions, in being mutually successful (Gray, 1998: 479; Hardy et al., 2005; Tidd et al., 2005) or in meeting participants’ expectations (Killing, 1982; Ring & Van de Ven, 1989).

When collaborating, participants confront issues about how to share understanding and foster aligned expectations. These mechanisms help to explain how participants through pair-wise relations consider both their own object world (Bucciarelli, 1994, 2002) and other participants’ object and thought worlds (Dougherty, 1992) in collaborating. This also explains how further problems are created with multiple sub-groups existing through bonds that are stronger than those defined by organisational boundaries (Brown, J.S. & Duguid, 2000).

Familiarising, Associating and Regulating mechanisms described how pair-wise relations are linked to various stages in group development models [e.g. Bales (1966a);
Bion (1961); Homans (1955); Moreland & Levive (1982); Tuckman (1965)] and how groups through pair-wise relations move between stages. They also highlight how pair-wise relations can lead to other group phenomena that adversely affect group performance e.g. social inhibition (Allport, 1924), groupthink (Janis, 1972), group polarisation (Lamm, 1988), over conformity (Smith-Doerr & Powell, 2005), social loafing (Latané et al., 1979).

Finally, developing pair-wise relations adds an extra social dimension to how individuals pursue their own interests whilst limiting their interest in working with other participants (Das & Teng, 1998). A group based on close pair-wise relations no longer adapts solely according to formal organisational or task-based guidelines; instead decisions become more nuanced and complex relating to group members. Hence individuals are compelled to understand how to trust each other, commit to each other, and (sufficiently) control each other to cope with this paradox.

In sum there are three main conclusions to the Research Question:

1. Through pair-wise relations individuals can familiarise with, associate with, and regulate group relations.
2. Through pair-wise relations individuals can recognise their trust in, establish their responsibility to, and maintain (sufficient) control over other participants.
3. Pair-wise relations both help and hinder individuals and a group in how they adjust to foster aligned expectations of collaborating.

The topic of collaborating in engineering design is under-explored with little empirical research on how projects, participants and organisations are influenced by the process of collaborating or by context. Future research can expand the validity and generalisability of findings presented here through a replication and comparison strategy. Furthermore this research has highlighted three areas where future investigation is warranted: 1. Power and pair-wise relations in a design team, 2. Collaborating and its value, 3. How the process of sharing understanding changes during design projects. This is to address how power and social capital influence each other in design teams; to provide further knowledge about how collaborations fail to meet participants’ expectations; and to develop descriptive understanding for design methodologies about how sharing understanding is relevant to successful product development.

In this chapter, responses to Objectives and Research Question have been summarised based on empirical findings and current literature. The author has outlined claims for how pair-wise relations influence collaborating in engineering design focusing on group
Appendix

relations and outcomes. Findings emphasised that the study of pairs, in addition to individuals and a group, is critical in understanding how human behaviour influences collaborating in engineering design. There are clear contributions to academic and practitioner audiences. First, a holistic longitudinal analysis of collaborating in engineering design is presented drawing comparisons between projects of different design types and design settings. Seven new conceptual categories are introduced and compared to existing theories and concepts about groups, collaborating, and engineering design. Secondly, implications of findings are also set out for practitioners in guidance topics to aid participants make sense of the challenges in engineering design projects and hence improve their success in collaborating.
10 References

Conclusions


BERG, B.L. (2004) Qualitative research methods, Pearson Education.


Conclusions


Conclusions


Conclusions


Appendix

Sample templates for interview instruments

1st Interview

Introduction

1. Researcher background & interview purpose:
   - Develop a picture of project through their individual experiences over time

2. To begin could you tell me a little about you and how you have become involved in this project? (context)

Project

3. What is the project about? (aims, history etc)
   - When did the project start?
   - How did you get involved in the project?
     - What factors led you to work in the project?
     - Organisation / individual
   - How much time do you spend on this project?
   - At what stage is the project?
     - What are the milestones over the next few months?

Role & performing role

4. What do you do in the project? (role)?
   - What are you aims in the project?
     - Project aims, individual aims? Picture?
   - What is your interest in the project?
     - Why are you working with these organisations / individuals?
   - How do you carry out your role in ITP?
   - How do you carry out your research in this project?
     - Examples? Tell me more? What happens then?
   - When in the project do you need to accomplish your research / role?
     - How does this influence the project?
       - Examples of past / present / future?
References

- Has your input changed over the project? How?
  - How does this affect your involvement? In what way?
- How does your role fit with others in the project?
  - How do you interact / combine the roles to create the design?
    - How is interaction achieved? Examples, defined?
    - How does the group work together?
    - Could this be improved / avoided? How? What happens then?
- Did you know anybody before the project?
  - Through working / socially?
  - How does it influence how you work with them? and the others?
    - Examples, why, consequences? Tell me more? What happens then?
    - How does this influence the project? Why? In what way?
  - How have you got to know the others in the group?
    - Examples
    - Has this influenced how you work with them? influenced the project? Could this be improved? How?
- How does the group design (work) together?
  - What influences designing in this group?
    - Organisation of the project? / How are decision made?
    - In what way? Example?
    - Could this be improved? How? What would you like to change
  - How does working in a group affect the way you work?
    - How? What way?
    - What is important to consider? Why? Example? How achieve?

**Future of role (formal and personal)**

5. How is your work going / progressing?
- What is influencing the progress of your work?
  - How does that fit with expectations? Why? Examples?
  - What could improve / avoid the situation?
- Impact of your work on the project?
  - Impact on colleagues? Why? Examples?
  - What could improve / hamper team working together?
- How is overall project going?
  - How does that fit with expectations? Why? Examples?
  - What in your opinion has contributed to it? In what way?
• Is working in this group what you expected? (organising / working methods)
  o Examples? Why? Tell me more? What happens then?
  o How could improve / avoid?
• What are you personally looking to gain from the project?
  o Why? Examples?
  o How are you preparing to achieve that?
    ▪ Individually / group
• What are you enjoying?
  o Why? Does it help you to work in this group?
  o Would you change anything?
• What are the challenges facing the team at present?
  o How? In what way?
  o How planning to overcome?

2nd Interview

Introduction

1. An update:
  • Second of two looking at collaborating in design projects
  • In the interim I have attended some meetings and had access to project output
  • Develop a picture of project through their individual experiences over time

Project

2. What has happened this project since we last spoke?
  • Individual / Group / Project

3. What is happening at the moment in this project? (project transition, note any changes to previous expectations, how things are, salient aspect of project?)
  • At what stage is the project?
  • How are you involved at the moment? When were you most involved? does that influence how you contribute?
  • What is expected from you? How achieved?

4. What has the group had to do to get to this point?
  • How, why? Factors?
  • What have been the project milestones (task and other)?
References

- What has influenced this group in working together? Why?

**Individual**

5. What have you had to do to get this point?
- What have you had to overcome? Why? How?
- What have been milestones for you? Task and other
- What have you learnt from working on this project? (task and group)
- How has working on this project gone for you?
  - What has contributed to that?
- How has working with these people gone?

6. How are things going with other members
- What had to do with others why? Who? Impact on results?
- What have you had to consider in with each person?
  - Have they changed? Why? how?
  - Has that affected how you perform your role?
  - Has that affected the group?

**Time**

7. Do you consider the overall project objectives in performing your role?
   a. why? When? Different at different stages?
8. What happened and why vs what expected and why
   a. Previous challenges
   b. What did you expect to happen
     i. project?
     ii. Group? / individual
   c. Why? Examples? How?
- How have you managed to cope?
Compilation of cross-case findings

Pair-wise relations: opportunity

Finding 1. Individuals interact with each other more when there are more opportunities and continue to develop understanding in pairs to achieve their tasks together. This was more evident in intra-organisational design projects.

Finding 2. When participants are not physically co-located there are fewer opportunities to develop understanding in pairs about how to collaborate. Participants were more geographically dispersed in inter-organisational and original design projects.

Finding 3. When participants work together on other projects (current or past) there are additional opportunities for pair-wise interaction and shared understanding. This was more likely in intra-organisational and adaptive design projects.

Pair-wise relations: dependence

Finding 4. There was a greater reliance on pair-wise relations to achieve a participant’s activities where individuals shared complementary Task understanding or distributed Team understanding. This was more evident in inter-organisational and original design type projects.

Finding 5. Participants establish role dependencies and design contingences through pair-wise interaction when design processes are modified or combined. This was more likely in inter-organisational and original design type cases.

Finding 6. Individuals maintain their own reputation by actively conveying their project priorities and judging others’ priorities in pairs when activities are novel to them. This was more likely in, but not exclusive to, inter-organisational and original design cases.

Group relations: opportunity

Finding 7. Opportunities were fewer and less regular for group interaction and reviewing group progress in inter-organisational cases.

Finding 8. Unexpected changes to individual availability reduced opportunity for group interaction limiting recognition of current progress. Intra-organisational cases with product domain orientated organisational structures were least affected.
Group relations: dependence

Finding 9. Where participants share complementary technical understanding (original designs) and distributed organisational working practices (inter-organisational cases) there is a greater reliance on a project group to identify design constraints and risks.

Finding 10. Where design procedures were less predetermined or more likely to change, role dependencies and design contingencies in the group were less visible and required periodic review. This was more typical in original design and inter-organisational cases.

Finding 11. Organisations and departments maintained their own reputation by conveying their priorities and allotting participants’ availability for a project. There was a greater variation of organisational reputation stakes in inter-organisational cases and of departmental reputation stakes in original design cases.

Outcomes: Adjustments

Finding 12. As expectations about a project were challenged (e.g. delays), participants distinguished how to trust each other to recognise different expectations. Individuals in inter-organisational and original design projects were more active in identifying how to trust each other as differences in project expectations were less clear.

Finding 13. When expectations were challenged, participants redefined their commitment to a project and each other to establish aligned expectations. Participants were more active in inter-organisational and original design cases where there was a greater variety of connections between participants.

Finding 14. When expectations were challenged, participants considered how to (sufficiently) control other participants’ activities to maintain aligned expectations. Participants were more active in learning how to share control of activities in inter-organisational and original design cases.

Mechanism: Familiarising

Finding 15. Through pair-wise relations participants recognised how their activities (Task & Team) fit into a project group and how to trust other participants’ expectations. Participants were more active distinguishing how activities fit together in inter-organisational and original design cases.

Finding 16. Through pair-wise relations participants recognise group behaviour and how to trust participants. Participants were active in this when they had new roles,
tasks or few occasions for group interaction. This was more typical in inter-organisational and original design projects.

**Finding 17.** Familiarising in pairs without group interaction was likely to reduce awareness of group standards, norms, expectations and require participants to recognise how to trust each other. Individual expectations were more likely to differ from group expectations in inter-organisational and original design cases.

**Mechanism: Associating**

**Finding 18.** Through pair-wise understanding individuals establish how their own standards/perspectives correspond to group norms and other participants. Participants were more active in establishing similarities and differences in expectations in inter-organisational and original design cases.

**Finding 19.** Individuals adopted group standards through pair-wise relations with core members to establish aligned project expectations. Participants adopted project standards through pair-wise interaction more in inter-organisational and original design cases.

**Finding 20.** When designs changed and challenged project plans, *pair-wise relations* were not always sufficient to establish aligned expectations between individuals. Incompatibilities led individuals to reconsider their commitments to each other with greater differences within a group in inter-organisational and original design cases.

**Mechanisms: Regulating**

**Finding 21.** Through *pair-wise relations* participants maintained control of group standards and individual behaviour. Participants were more active in regulating standards in inter-organisational and original design cases.

**Finding 22.** As participants intuitively adjusted together through pair-wise understanding to foster aligned expectations, further coordination of the project group was required to maintain complementary individual and group standards. This was more difficult in inter-organisational and original design cases.

**Finding 23.** Through *pair-wise relations*, individuals maintain access to resources to support a project (e.g. information, finance), increasing individual control over how activities were achieved. Changes in participants’ goodwill were more evident in inter-organisational and original design cases.