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Department of Design, Manufacture and Engineering Management

Interactive digital support for concept design teams

by

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A thesis presented in fulfilment of the requirements

for the degree of Doctor of Philosophy

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Copyright Statement

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Abstract

This thesis develops a design method, the ICR (Inform, Create, Reflect) Grid, for improved utilisation of information during concept design. Although concept design is information intensive and critical to project direction, the effective management and use of digital information has not been adequately addressed. The ICR Grid is a prescriptive method which requires design teams to find and build information resources in parallel with creating solutions. As a solution-based approach it allows designers to freely explore ideas, while encouraging flexible thinking by using different modes of conceptual working (analysis, synthesis and evaluation). The output of the method is a linked grid of concepts and information sources.

The exploratory phase of the research examined current design process models and concept design methods, with team information use patterns explored through protocol analyses of a design task. This was followed by an examination of literature relating to digital information and a class study on technological support for student designers. The outcome of these explorations was an understanding that to enhance digital information use in concept design, a new approach was necessary.

Development began by correlating characteristics of computer games to concept design, with a view to applying new techniques to the structure and management of information. A number of scenarios were subsequently outlined, with one selected and developed using paper-based prototyping. This was eventually formalised as the ICR Grid.

Initial evaluation of the new method was carried out through a comparative study with the 6-3-5 Method, which revealed that although fewer concepts were produced with the ICR Grid, they were of a higher quality, variety and detail. Three different companies then used the ICR Grid to address relevant industrial problems, with generally positive feedback obtained on its performance. Several areas are identified for future work and the further enhancement of information use.

Chapter 1 Introduction

This chapter introduces the motivation and context (*Phase a*) of the research. In reviewing the issues for organisations in using information in new product development, concept design is identified as a phase in the development process that is both information-intensive and highly impactful on the future success of any project. It is argued that the specific information requirements of concept design and idea generation in particular are uniquely demanding, but have not yet been sufficiently addressed. The industrial, team and problem contexts identified for the research are subsequently outlined, providing a basis for further investigation.

1.1 Overview

Concept design is the process undertaken when trying to develop solutions for a given problem, and covers the generation of ideas through to the selection of an embodied concept. Associated activities are often undertaken by groups in a collaborative setting and despite the fact this is typically an informal process based around sketch work and discussion, a number of formal tools and techniques have been developed to support the process (Cross, 1994; French, 1985; Pahl & Beitz, 1995; Pugh, 1991; Ulrich & Eppinger, 1995). Although it has been observed that exposure to previous solutions can in some cases lead to fixation on particular approaches (Smith, Kohn, & Shah, 2008), access to appropriate information, principles, exemplars and context have been shown to be important in creating well-substantiated concepts and acting as stimuli for discussion (Benami & Jin, 2002; Chuang & Chen, 2008). This research is concerned with the issues of finding, organising and developing such information in digital form for effective use by the concept design team, with the ultimate aim of improving the quality of concepts produced.

1.2 Background

The starting point for this research was an examination of the issue of information in product development teams. This was triggered by experiences working as a product design engineer in various consultancies, where the disparity between the information research and concept generation was seen to affect the quality of concepts produced. At the beginning of a design project, research work often culminates in the development of a product design specification (PDS) document (Pugh, 1991, p. 44), but information used in its construction is not always utilised effectively in the act of new concept creation for reference or stimuli (Howard, 2008; McAdam, 2004). This can be particularly prevalent when designers prematurely or inappropriately engage with the range of digital tools at their disposal to the detriment of thorough conceptual thinking (Carkett, 2004; Robertson & Radcliffe, 2009).

The focus from the outset was therefore on exploring issues associated with concept design and information use during this phase of the design process, and developing a new approach to enhance information use and hence concept quality in contemporary product development. An issue identified early in the research was the plethora of approaches and tools currently available to designers (Wang, Shen, Xie, Neelamkavil, & Pardasani, 2002), and the perception that they lack relevance: a recent study by Arvidsson et al. (2003) of Swedish industry reported that only 28% of companies were familiar with design methodologies and only 17% actually used them in their working practices. Therefore, a key consideration was to develop something practical, and that could be usefully implemented in industry.

The product development cycle is concerned with the transformation of an identified need into a product which will address this need. Design is the means by which this is achieved, giving form and function to concepts through the combination of creative and technical expertise. Given that the starting point, motivation and path to this realisation is different for every project, it is no surprise that varying views have been offered on the nature of design. Indeed, the field may have evolved and matured considerably over the last forty years (Cross, 2007), but many fundamental terms such as *innovation*, *creativity* and *design* remain open to interpretation. In the UK, the Design Council, a body whose aim is to promote the use of design throughout the UK's businesses and public services, commissioned the Cox Review (Cox, 2005). As a major study focussing on how creativity can be used as a driver for productivity and performance improvements, the following definitions, as developed by Cox and adopted by the Royal Academy of Engineering, have been used in this work:

- **Innovation** 'The successful exploitation of new ideas, the process that carries them through to new products, new services, new ways of running a business or even new ways of doing business.'
- **Creativity** 'The generation of new ideas-either new ways of looking at existing problems, or of seeing new opportunities, perhaps by exploiting emerging technologies or changes in markets.'
- **Design** 'That which links creativity and innovation. Design shapes ideas to become practical and attractive propositions for users or customers- creativity deployed to a specific end.'

1.3 The product development process

The product development cycle encompasses a great many tasks and activities, transforming a perceived need into a tangible product solution. The body of literature in engineering design has grown with the purpose of optimising this process through the use of organisational structures and task-specific tools, and a number of key texts have emerged which despite numerous differences outline a similar overall approach to the development process and recognise many of the same key tools.

However, when immersed in the pressures and practicalities of day-to-day life in the workplace, theoretical models of the design process can easily fall by the wayside and suggested tools to enhance efficiency may seem more trouble than they are worth. As a result, project plans and formal tools are often pushed into the background while the team engages with activities such as sketching, modelling and testing. A key aim from the outset of this research was to assist with the practical needs of the design team, rather than burdening designers with additional bureaucracy or administrative overheads.

While a range of design process models were explored in the course of the research, and are outlined in Chapter 3, the model identified as being most applicable was Ulrich and Eppinger's (1995). This presents a range of tools that be practically implemented in order to move a design project forward (Figure 1.1). It divides the product development cycle into five tasks, with a number of relevant activities listed under the phases of Planning, Concept Development, System-Level Design, Detail

Design, Testing and Production and identifies the key tasks associated with each. In addition to this, a range of tools and methods are suggested to complete these discrete tasks, with the design team responsible for selecting the ones appropriate for their particular context.

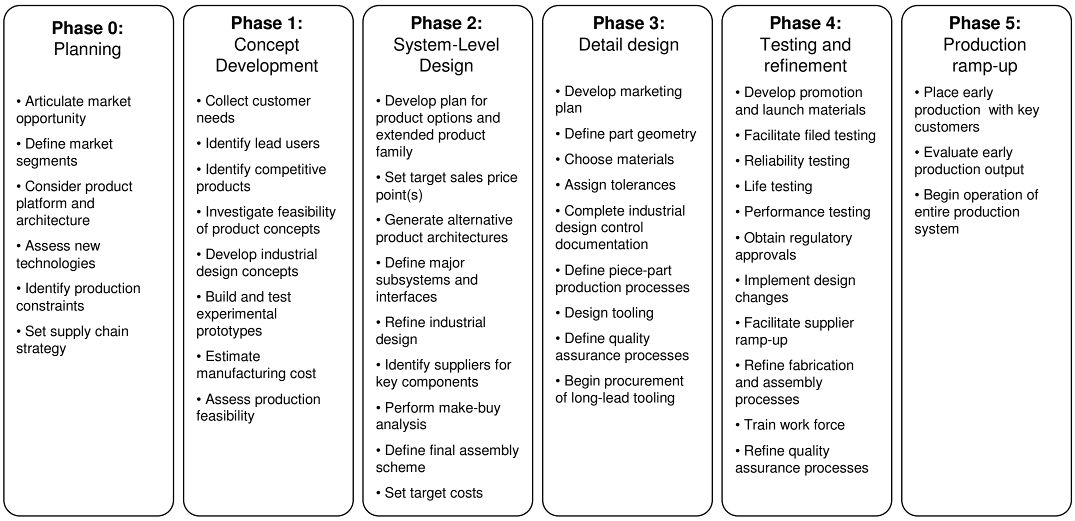


Figure 1.1: Tasks at each stage of the design process (Ulrich & Eppinger, 1995)

1.3.1 Importance of information

In contemporary product development innovation consists primarily of re-interpretation of existing knowledge and applying it in new ways: the few inventions that are fundamentally new are often rooted in large-scale R&D programmes. The majority of conceptual design work instead resides in incremental improvement or new configurations, utilising the vast information sources now available to us. Perkins (1994, p. 131) discusses in a review of famous inventions how strikingly it was that 'nearly every tale of invention unfolded over several years, with many false starts and dead ends', rather than a 'flash of inspiration'. This continuity of knowledge continues to be a major challenge in new product development today. Most standard product development process models make some reference to utilising relevant information, and systems of knowledge capture and classification continue to be explored (Culley, 1999; Eris, et al., 2005; Fruchter & Demian, 2002).

Examining Ulrich and Eppinger's Concept Development phase in more detail, the main input into the phase is design research, and the main output design concepts. This means there is scope for a huge range of material to be gathered, managed, utilised and synthesised into a number of concepts suitable for further development. Figure 1.2, based on Ulrich and Eppinger's overview of the development process, highlights this as the stage in which there is the greatest breadth of information to be managed. Effective utilisation of this range of material is therefore critical in exploring the problem space. At the System-Level Design phase there is a level of convergence as a concept is chosen and developed, taking the project in a particular direction. This followed by a further phase of divergence in Detail Design as variations are explored. The final stages relate to refining and preparing the product for production.

It would be wrong to assume that the breadth of information equates to the volume. While there is undoubtedly a large amount of diverse information used in concept development, during the detailed design stage there is also a great deal of information relating to the product embodiment to be managed, as indicated by the respective peaks on Figure 1.2. The information used in Detail Design, however, is typically contained within the CAD environment and relies on proven principles and testing (e.g. the material thicknesses and dimensions appropriate for a snap fit design). At the Concept Development phase, the breadth and volume of information to be absorbed and utilised in the development of design concepts is particularly challenging. Given its fundamental role in establishing direction and overall project success, it was therefore decided to focus on this early design stage and to examine ways of better integrating information and design activity.

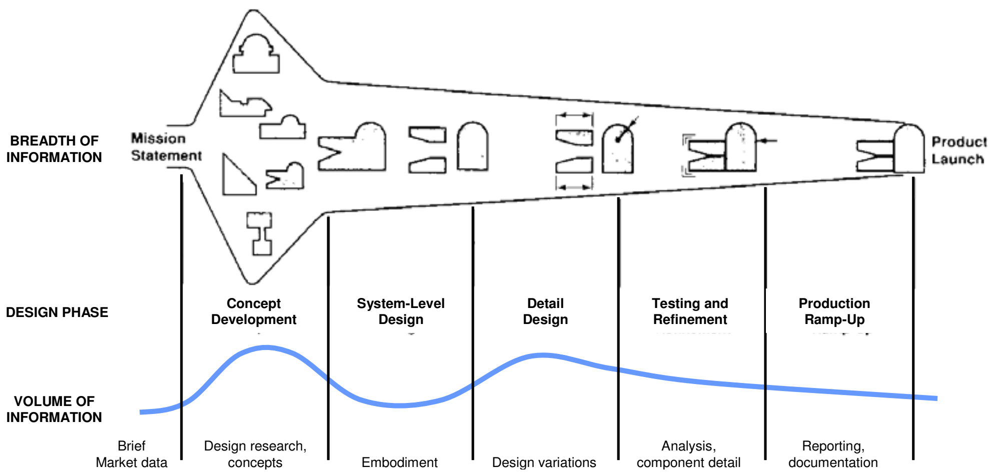


Figure 1.2: Information use in the product development process (after Ulrich and Eppinger)

1.3.2 Emergence of computer tools

Although the evolving field of information technology is often regarded as a modern invention, recording and re-using information to build on previous generations was a fundamental element of the first organised communities (Williams, 1987). Increasingly sophisticated means of capturing and storing information has facilitated the development of the large and complex products which are now commonplace in our industrialised society. Computer tools are now an integral part of product development, with a huge range used throughout the design process. While these have been developed and to serve and empower the designer, they can often inhibit the communication of ideas and intent (Baxter, 1995; Wodehouse & Bradley, 2003).

Figure 1.3 shows Gjon Mili's long-exposure photograph of Picasso sketching a centaur using a 'light pencil'. This image powerfully captures a moment of self-expression that would not be possible working in traditional media. Given that recording, presenting and using information in an effective way during the concept design stage is the main thrust of this research, Mili's photograph effectively illustrates how technology can be a powerful enabler rather than an obstacle in the execution of creative work.

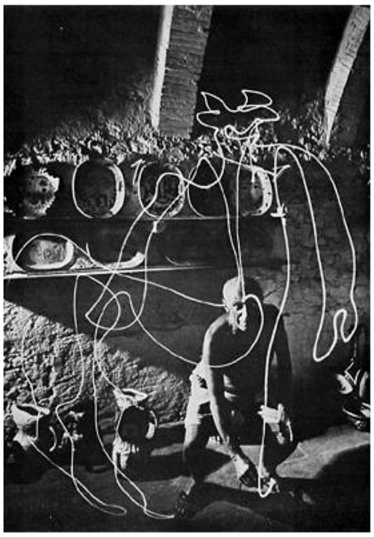


Figure 1.3: Picasso with Flashlight (Gjon Mili/Time & Life Pictures/Getty Images)

1.4 Focus of work

The focus of work is clarified in Figure 1.4. By integrating a series of diagrams from Ulrich and Eppinger (1995) it shows the particular stage of the development process addressed. As part of the concept development phase, the work is concerned with the task of generating and developing new product concepts. This task in itself can consist of a number of elements, with Ulrich and Eppinger highlighting *clarifying the problem, searching internally, searching externally, explore systematically*, and *reflecting on the solutions and the process*. This detailed breakdown provided a useful reference point, given that the focus of the research was on taking a design problem, integrating the design team and information in the development of new ideas, and providing a number of solutions for further development. This focus has been highlighted in blue at the right of Figure 1.4. The following sections review and define the research context further with regards to the industrial, team and problem settings.

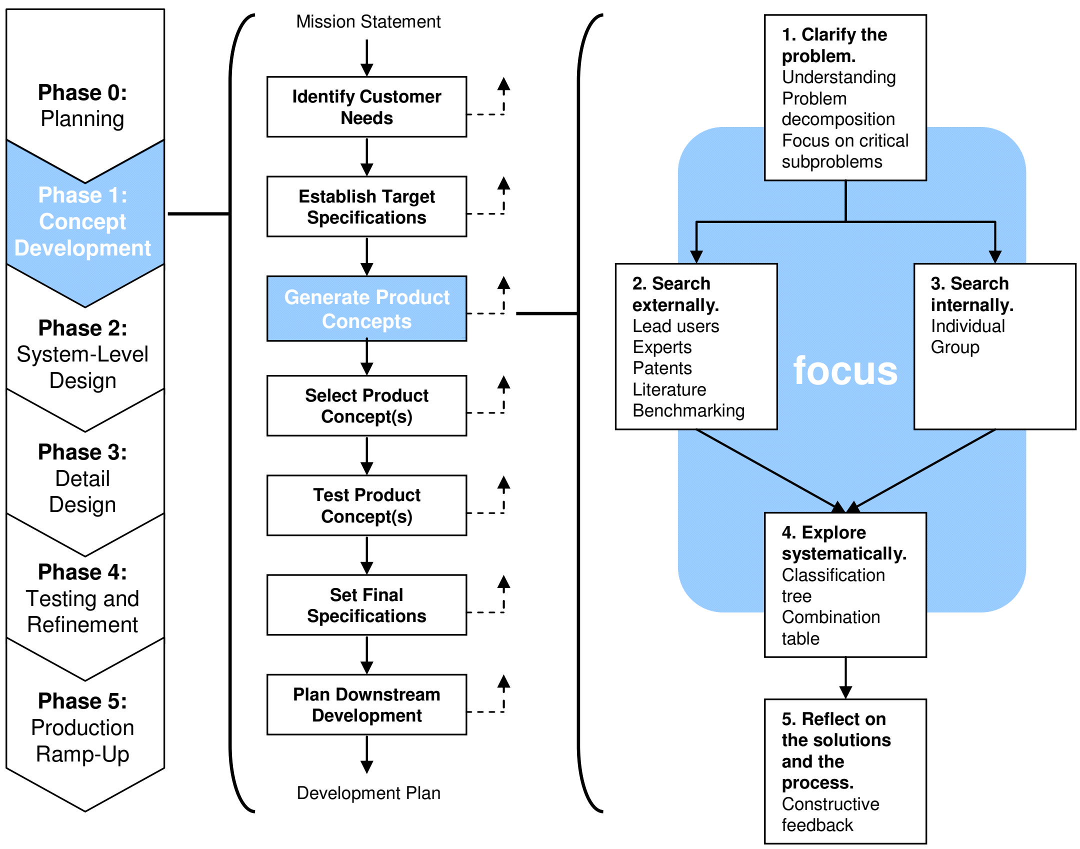


Figure 1.4: Focus of work in relation to Ulrich & Eppinger's model

1.5 Industrial context

The scope for innovation in concept design depends on the nature of the product, the market requirements and the state of relevant technology. Andreasen and Hein (1987) created a matrix (Figure 1.5) to identify these different categories of innovation. For an established product and technology, innovation is likely to occur at the component or sub-system level (*updating, replacement*). An example of this would be the automobile: the majority of cars continue to have four wheels and an internal combustion engine but there are still many areas that designers can innovate. It may be that market forces create demand an innovation (*supplementing*). For example, Flymo addressed an existing market of grass cutting, but specifically aimed to make a lawnmower that was less physically demanding. They subsequently innovated to produce a cutting blade which additionally provided lift to help the user move the device easily over the lawn, thereby supplementing the products already available on the market. It may be that a technology is available with no ready application for it (*adaptation*). In this case, innovation is required in order to find and apply it in a useful way. An example is the use of the Global Positioning System (GPS): this technology was released from its previously exclusive military use and resulted in a plethora of new products, such as devices to allow runners to track precisely how far and fast they run. The most radical level of innovation is when a product is new in both a market and technological sense (*diversification*). Although the iPod can be described as such a product, a more fundamental event in the personal audio history was the invention of the Walkman. Supposedly build at the behest of Sony co-chairman at the time Akio Morita, this created an entirely new category of audio device and earphone technology had to be developed to meet its requirements.

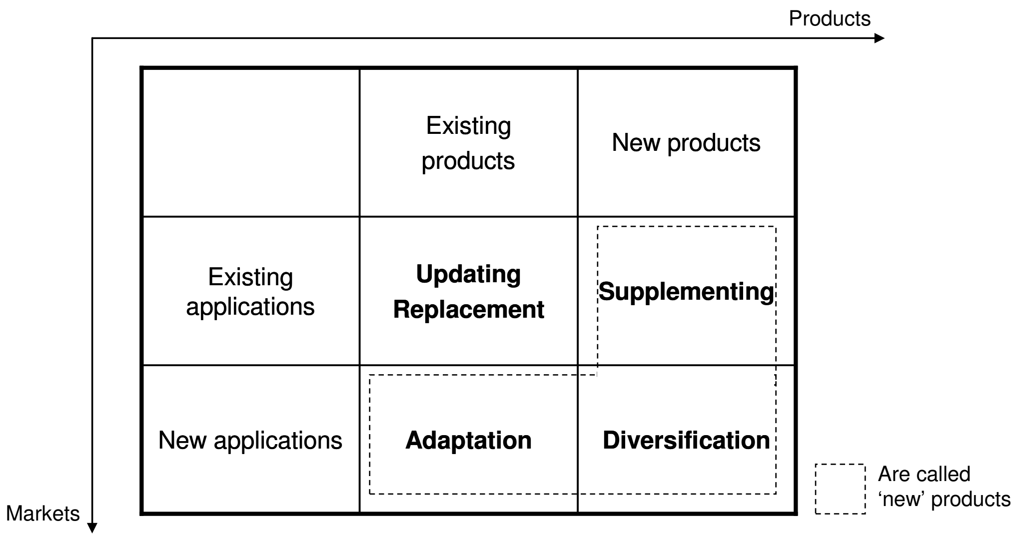


Figure 1.5: Project types (Andreasen & Hein, p.22)

The particular context of a concept design session can, then, greatly affect the approach taken by participants and the tools used to facilitate any work. A major factor in defining the approach taken is the information (both in volume and type) which is integrated into the concept design work. For example, solving more pressing problems with existing products or applications (towards the top left of the table) can be more suited to *logical* approaches where previous knowledge and problem focus are more rigorous, whereas radical ‘blue sky’ thinking (towards the bottom right of the table) can be more suited to brainstorming or a similar *intuitive*, open-ended tools (Shah, Kulkarni, & Vargas-Hernandez, 2000). This can be illustrated through the examination of two very different environments where information plays an equally critical role.

Firstly, the case of a large, established manufacturer that wishes to add a new model to its current product range. A company like Hoover, for example, has a corporate knowledge-base which has been built over many years and it can utilise this to move through the design process expeditiously. However, a long history in a particular industry also means that it must be aware of what it is trying to achieve with a new product. For established product fields there tend to be times of *static* and *dynamic* phases of innovation (Pugh, 1991, p. 174). A static phase of innovation refers to a period of incremental improvement, while a dynamic phase of innovation is when new technology facilitates a radical shift in the product category. For example, the history of floor cleaning has undergone the dynamic shifts from brush to bag to cyclone technology. Between each of these there are periods of incremental design innovation where general engineering performance, component and detail design are improved. For this kind of concept design work, the ability to refer to previous product data and information is critical, and the company will draw heavily on previous knowledge to innovate within the boundaries of its existing market position, production processes and design ethos.

On the other hand, a design consultancy may be working on blue-sky ideas to reinvigorate an existing industry. For example, IDEO (a leading global design and innovation firm) is hired by companies who desire a fresh perspective on their industry and rely on external consultants to bring a rigorously tested design approach in which they rapidly assimilate market, corporate and user information to drive concept development. Although they are hired on the basis of having enhanced expertise in the design process, in the actual undertaking of concept design they must quickly assimilate large amounts of information on new project areas each time they take on a new client. IDEO call this the ‘deep dive’ approach: adopting user-centred approaches such as observation, focus groups and other qualitative methods to quickly build a range of practical information used extensively in brainstorming and concept development (Kelley & Littman, 2001). A celebrated example of this was when challenged by ABC’s Nightline programme (ABC, 1999) to develop a new supermarket trolley design. The programme showed IDEO’s team rapidly gathering a wide range of primary and secondary information, assimilating observation videos, interviews and previous designs to rapidly brainstorm concepts and synthesis a completed design.

In both cases, access and use of appropriate information to stimulate and guide the concept process is invaluable. Perkins (1994) uses the term *adaptive novelty* to describe the development of new ideas based on previous knowledge, applying knowledge in a slightly different way, or taking principles from one field and applying it in a new context. This is an apt description of what is happening in concept design during a typical product development project whether it is an incremental product improvement by a large manufacturer or a transformative project led by an external consultant. In both cases, it is appropriate to contextualise the concept design session by framing it with relevant knowledge and information.

1.5.1 Concept sketchwork

The aim of this work is to examine information use by engineering designers when generating design concepts in typical industrial settings. This can consist of various types of design problem, from blue sky to more defined, but the assumed format of communication of these ideas is sketching. Those involved are therefore expected to have a level of sketching fluency sufficient for them to communicate their concepts effectively. It is therefore necessary to define what is meant by a *concept* in the context of this research, as although a concept is commonly accepted to be some kind of product or problem solution, terminology such as sketches and ideas add confusion in terms of the composition, detail and presentation of such schemes. Ulrich and Eppinger (1995, p. 108) offer a useful definition:

- **Concept** 'An approximate description of the technology, working principles, and form of the product.'

Concepts as described in the context of the research are therefore typically composed using line, marginal shading, and annotation, and communicate at least one fundamental innovation in the design embodied within an overall product context. Rogers et al. (2000), in their work examining the use of concept sketches to track design progress, define a scale of complexity for concepts ranging from 1-5. They discuss *lateral* and *vertical* transformation in relation to conceptual sketches, with lateral transformations denoting an obvious change in thinking or focus, and a vertical transformation denoting a more detailed concept embodiment. These can be broadly equated with *divergent* and *convergent* modes of design.

Their scale of complexity is primarily orientated to the type of 3D sketching undertaken by industrial designers, or someone primarily concerned with product form. Engineering designers may not have the same level of sketching proficiency, and the scale was therefore modified to categorise the level of sketch detail more realistically, as set out in Table 1.1. The number of levels has been reduced to three, and the criteria altered to take more account of the functional drawing typically undertaken by engineering designers in focussed concept design. Concepts in this context are expected to be Level 2 sketches, i.e. simple line drawings with accompanying text or annotation where appropriate.

Sketch type	**Example**
Level 1 – Low level detail (idea) Monochrome line drawing. May include brief annotation, but not more than a few words.	
Level 2 – Medium level detail (rough concept) Monochrome line drawing, but may include shading to suggest 3D form. Annotated to describe various concept functions and aspects.	

Level 3 – High level detail (complete concept)
Line drawing which may include shading and colour to suggest 3D form. Annotated to describe various concept functionalities and may include indicative dimensions.

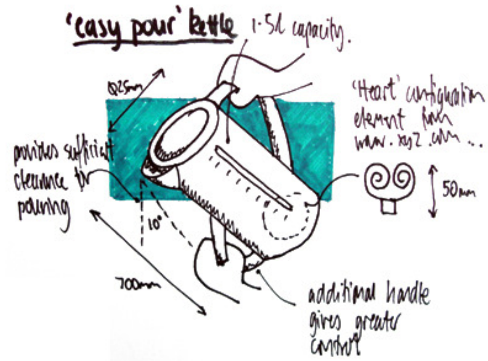


Table 1.1: Scale of concept complexity (after Rogers et al.)

1.6 Team context

The image of the lone inventor fighting to realise an inspired and revolutionary idea is persistent, but rarely reflects the actuality of new product development. Although Alexander Graham Bell, for example, was first to patent and is often credited with the invention of the telephone, he had a team of seventeen engineers working with him, whose work was in the context of a great deal of contemporary investigation (Gorman & Carlson, 1990; Williams, 1987). This does not detract from his insight or the fact that such visionaries have the ability to bring people together for a common purpose – an essential component of civilised society. Rather, it highlights that today's technological products are typically so large and complex undertakings that it is beyond the scope of one person to accomplish this alone, and that the challenge is to harness creativity of the range of individuals within the group by effectively coordinating their contribution. Indeed, one of the paradoxes facing the engineering industry is that large organisations must by their nature be run according to strict procedural and managerial processes to ensure maximise efficiency, and yet if they are to be innovative they must still be able to accommodate 'imaginative non-conformists not readily amenable to formal discipline' (Williams, 1987, p. 339). While not all designers are necessarily this headstrong, they are notoriously protective of the freedom to think for themselves – to be able to use their background knowledge, find specific new knowledge and to create new ideas in a way that can often only be achieved when working alone – while at the same time working as part of a team in the broader organisational sense (Lawson, 1980, p. 5).

Both Pugh (1991) and Ulrich and Eppinger (1995) suggest that it is important for designers to undertake a period of concept generation individually as well as in the group setting, with Pugh stating that the concepts are often better generated by individuals. Similarly, Leenders et al. (2007) argue that communication and creativity are closely linked, and from studies on design groups conclude that very low and very high frequencies of communication were the greatest barrier to creative achievement. While the authors state that the 'loose settings, free spirits, and a lack of strict boundaries' of unsystematic methods encourage creativity, they contend that careful introduction of systematic mechanisms to keep communication at an 'appropriate' level means that they need not inhibit design performance.

For a more typical product development scenario, which takes place in the context of commercial constraints, systematic approaches become increasingly relevant. An alternative approach to harnessing the creativity of individuals within the organisational environment is the use of suggestion systems to generate design ideas (Fairbank, Spangler, & Williams, 2003), providing a forum for people to easily submit ideas in a convenient and autonomous way without the intensity of a face-to-face group scenario. Such systems, however, do not foster the team spirit and collective energy which can be generated from a well organised group session.

Despite the development of various approaches to concept generation, brainstorming in its various forms (Osborn, 1953) remains by far the most common technique used by companies in industry today. From more structured sessions with set rules, timescales and recording procedures, to very informal meetings with just a whiteboard, the fundamental concept of bringing people together in order to share and develop ideas remains a powerful one.

1.6.1 Small, co-located team

The studies in this work have, therefore, been configured to represent a concept design meeting as it may typically take place in industry – a team of anywhere between 2-6 people with a design brief and an allocated timeframe to generate a number of ideas for further development (Figure 1.6). Given the focus of the research, the development of a new or augmented method was always considered a likely output. From the outset, therefore, a major consideration was that any new or augmented method should, as far as possible, continue to offer the flexibility and freedom engendered by brainstorming-type approaches.

Figure 1.6: Design team context

1.7 Problem context

Before the concept design phase can begin, project briefing documentation must be prepared. The precise nature and format of this documentation will vary according to the particular design project context (Maffin, 1998). Two key documents usually associated with project planning are the project brief and the Product Design Specification (PDS). The information captured in these documents can vary in quantity and can come from a wide range of places and, as with concept design, there is a range of potentially confusing terminology. Samuel and Weir (1999, p. 294) define the various factors communicated between the client and design team in forming the briefing documentation as follows:

- **Design goal** overall intent of the design
- **Design boundary** delimits the design search and investigation
- **Design objectives** the desired features of the design
- **Design criteria** the scales for ensuring the success of a design proposal in meeting specific design objectives
- **Design parameters** formalised expressions of the operating performance characteristics.

- **Design requirements** relaxable constraints
- **Design constraints** mandatory requirements of the design

Although this is a useful attempt to clarify the terminology, variation exists across the literature. Andreasen and Hein (1987, p. 143) interpret requirements slightly differently, illustrating the relationship between requirements and criteria as shown in Figure 1.7. The solution space is bounded by *requirements*, with any solution lying outside of these regarded as non-solutions. Within this space, however, there are a range of *criteria* (properties or qualities) used to separate the good solutions for the poorer ones. If a solution space is extremely tightly defined – for example, the wing mirror of a car which must interface with the car body, provide an adequate viewing angle, be sympathetic to the styling of the car and so on – then the space for creativity is more limited. Concept variations can still be created, but the difference between them is likely to be marginal. By focussing on one particular aspect, i.e. the viewing angle, it may be possible to create an incremental improvement in the performance of the design by focussing effort on that aspect. Therefore, very detailed design specifications are generally required for less ambitious, iterative design projects, whereas more open specifications are appropriate for more visionary or challenging design projects. This is similar to the notion of static and dynamic projects discussed in 1.5, above.

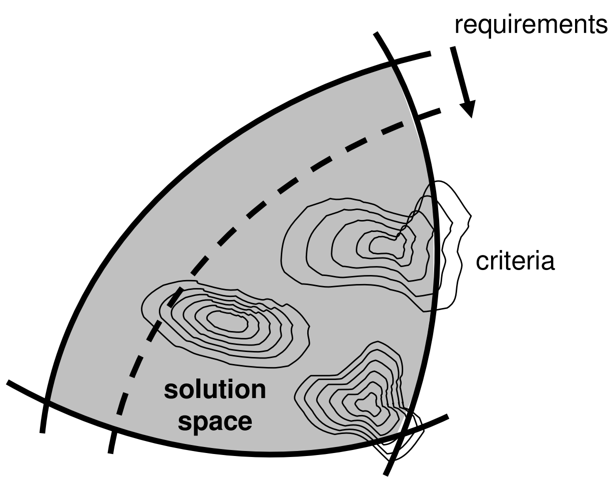


Figure 1.7: Solution space (after Andreasen and Hein)

The PDS or requirements document is sometimes regarded as an inhibitor to creative thinking at the 'fuzzy front end' of product development, but this is not necessarily the case (Zhang & Doll, 2001). It can, in fact, be important in establishing a shared team purpose and clarifying project targets. Boden (1994) argues that constraints 'make creativity possible', going on to explain that '…random processes alone, if they happen to produce anything interesting at all, can result only in first-time curiosities, not radical surprises'. Using the project brief or PDS as an information source to focus and drive development, then, seems a sensible approach to concept design and problem-solving. Pugh (1991) reflects this by placing a 'dynamic' PDS at the centre of his product development model, calling it the 'design core' that all other aspects of the process revolve around.

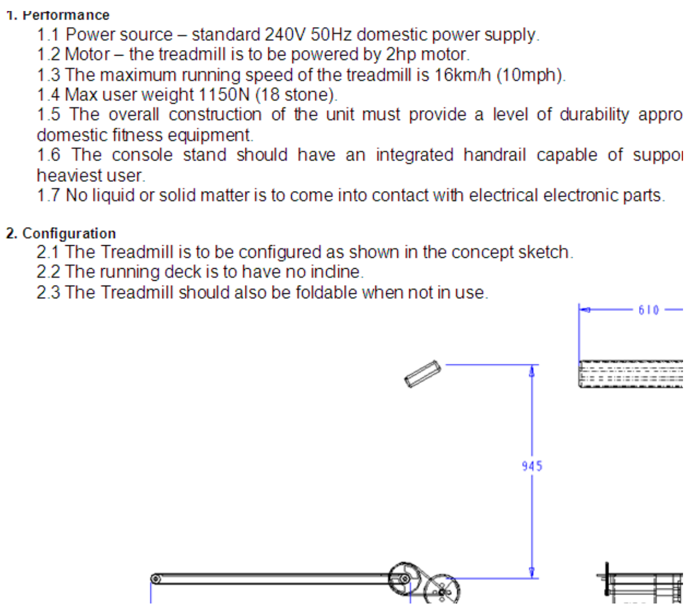
This treatment of the PDS as a set of dynamic boundaries which is applicable throughout the development process is admirable, but rarely practiced. While the format and relative importance of the PDS constructed can vary significantly depending on the industrial sector (Nellorea, Söderquistb, & Eriksson, 1999) in many smaller, less formal contexts the PDS is often constructed and then promptly discarded, and it is only when the product has been developed to a higher level that the document is retrieved from the bottom of a filing cabinet only to see that the product does not meet several key specifications. In computing – where highly defined requirements tend to drive development work – requirement-driven design approaches using computational methods to improve information traceability are emerging (Ozkaya & Akin, 2006). In engineering design too, large-scale projects in industries such aerospace and automotive utilise requirement-driven information systems and Product Data Management (PDM) to track changes to parameters and parts in complex CAD assemblies shared across many individuals and locations. In early, conceptual design, however, detailed specifications often do not exist or may be implicit in broader requirement statements.

Dorst and Cross (2001) highlight the definition and framing of a design problem as a key aspect of the creative process. They outline a study whereby a number of practicing industrial designers were set an identical design brief. Their concepts were then assessed by industrial design tutors, who were also practicing designers. Their main observation was that creative design consisted of problem formulation and solution generation in parallel, rather than in two discrete stages. This would suggest that any framework for creative design, where problems are often ill-defined or requirements still flexible, should have the capacity to allow new information or sources to be introduced to allow the problem definition to be refined as solutions are created.

To summarise, poor interpretation of requirement statements and over-utilisation of the design brief during concept generation are threats to effective concept design work. Simply labelling specifications as inhibitors of creativity is, however, inaccurate. If used effectively, they can aid to concept design work by focussing the creativity of the team around key topics or criteria, and help ensure ideas are generated in the areas where they are most likely to be of value.

1.7.1 Preliminary project requirements

This research will assume the presence of a preliminary brief or PDS document (the level of detail of which may vary depending on the design problem or challenge) to provide initial direction for the concept design work. In addition, it will attempt to understand in more depth the role requirements play as an information source in the design process, and how allowing information input during the concept design process can help resolve problem definition in parallel with concept development. An extract of a PDS document has been illustrated in Figure 1.8.


1. Performance
1.1 Power source – standard 240V 50Hz domestic power supply.
1.2 Motor – the treadmill is to be powered by 2hp motor.
1.3 The maximum running speed of the treadmill is 16km/h (10mph).
1.4 Max user weight 1150N (18 stone).
1.5 The overall construction of the unit must provide a level of durability appro domestic fitness equipment.
1.6 The console stand should have an integrated handrail capable of suppo heaviest user.
1.7 No liquid or solid matter is to come into contact with electrical electronic parts.

2. Configuration
2.1 The Treadmill is to be configured as shown in the concept sketch.
2.2 The running deck is to have no incline.
2.3 The Treadmill should also be foldable when not in use.

Figure 1.8: Extract of a PDS document for a treadmill

1.8 Summary

This chapter has established the research context as the use of information in concept design teams. Experiences in the product development process, and in particular the problems of managing large volumes of information at the crucial early stages, have been highlighted as the motivation behind the research. The relevant industrial, team and problem contexts have been reviewed, with the format, logistics and settings considered representative defined for each. This has allowed a clear characterisation of the research focus: engineering design teams engaged sketch-orientated design activity to address an initial problem specification. Using this basis, the research hypothesis can be summarised:

> *The enhanced use of appropriate digital information will result in the improved performance of concept design teams.*

The thesis addresses this hypothesis by reviewing the major issues associated with information use, identifying and developing a method for enhanced use of information, and evaluating its performance in relation to both design output and team interaction in experimental and industrial settings. The following chapter clarifies the methodology used to achieve this.

Chapter 2 Research aims, objectives and methodology

This chapter summarises the research undertaken and documented in the thesis. In Chapter 1, the problem of information use in concept design has been identified as the motivator for the research. Issues relating to the team, industrial and problem contexts have subsequently been highlighted. The thesis goes on to explore concept design, related information, and digital support tools in detail. A new method is then developed, informed by a review of computer gaming, which is described as having several characteristics relevant to the design context. The method is then applied in both experimental and industrial settings, allowing reflection on its effectiveness. This effectiveness relates primarily to the concepts produced (addressed by metrics including quantity, detail, variety, novelty, and quality) as well as more qualitative team aspects (including interaction, structure and engagement). In providing a methodological overview of the work, this chapter describes the literature studies undertaken in the development of the research focus and the rationale for the different research methods employed.

2.1 Aims and objectives of work

The research covered a range of topics, including a significant amount of investigative work prior to the development of a new method for concept design that is linked to information retrieval and use. The overarching aims and objectives can be outlined as follows:

Aim

To improve concept design output through enhanced use of digital information

Objectives

i. Establish the context of information use in product development

ii. Review current concept design approaches, creativity and the role of information

iii. Review the nature of design information – how it is shared and used by teams

iv. Investigate how digital technologies can provide information support for concept design teams

v. Develop a new method to enhance digital information use by the concept design team

vi. Evaluate the effectiveness of the new method in a series of controlled tests

vii. Evaluate the effectiveness of the new method through application to a number of industrial contexts

2.2 Overview of thesis

The thesis consists of ten chapters, as shown in Figure 2.1. A number of phases have been identified, including: *motivation & context*, *exploration*, *development*, and *application & reflection.* Elements of literature study run through the first six chapters of the thesis as the research problem was refined and the specific area of contribution identified. Similarly, six different studies were carried out from chapters four through nine as the research problem was clarified and the new design approach developed and tested.

Phase a introduces the field of concept development and the overall approach to the research. The topic of information use in concept design is established, and a number of the primary issues of concern are highlighted (Chapter 1). The research aims, objectives and methodologies for the rest of the work are then outlined (Chapter 2). The outcome of this phase was a clear line of development for the remainder of the research.

Phase b was the exploratory phase of the research, and concerned initially with understanding the range of concept design methods currently in use (Chapter 3). The particular issues associated with information use for that stage of the design process were then reviewed through literature and protocol analyses of a basic design task (Chapter 4). This was followed by an examination of literature relating to digital information and a class study of how technological support was provided at the point of need for designers engaging in concept design (Chapter 5). The outcome of this phase was an understanding that to enhance information use in concept design, a new approach would have to be developed.

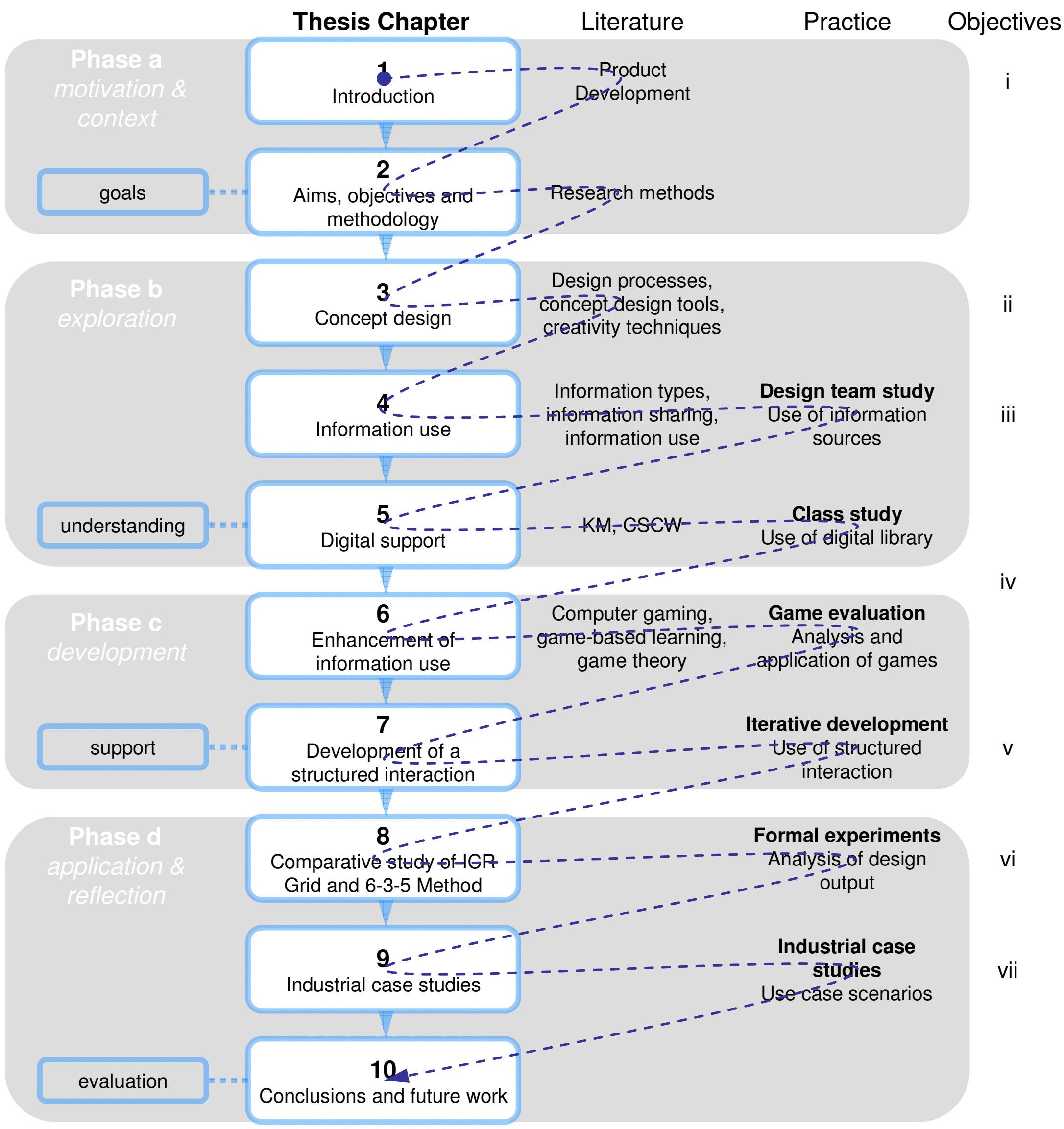


Figure 2.1: Overview of thesis and path of progress

Phase c of the research was concerned with the development of a new approach to concept design. Having identified a number of problems with the integration of digital information, new approaches such as social networking, crowdsourcing and computer gaming were considered (Chapter 6). Computer games, however, were identified as providing the most information-rich, engaging content and subsequently examined with a view to applying new techniques to the structure and management of the concept design task. A number of scenarios were consequently developed. Iterative development of a selected approach was then undertaken using paper-based prototyping, and the new approach named the ICR Grid (Chapter 7). The outcome of this phase was a formalised approach for concept design.

Phase d was concerned with the application of the developed approach. This was achieved through formal experimentation using groups of PG students (Chapter 8) in a comparative study with the 6-3-5 Method where metrics were used to evaluate design output and feedback gathered on participant response. A number of companies with ongoing design issues were invited to use the ICR Grid to develop potential solutions and provide feedback on its performance in various industrial settings (Chapter 9). The final chapter (Chapter 10) is used to summarise the work, reflect on the achievements against the initial aims, and makes suggestions for future work. The outcome of this phase was an evaluated method for information use in concept design, with a number of recommendations for its further development.

2.3 Overview of literature

The literature reviewed in the thesis encompassed a number of areas as the exploration of the research problem continued to evolve. The starting point was the field of product development and of particular interest was the use of information in the generation of new concepts. To better understand the concept design phase, major process models and the range of concept design tools available were reviewed, along with the area of creativity and the psychological aspects associated with the generation of new ideas and problem-solving. Having established the merits of information as a stimulus and reference for concept design, ways to support this in the digital arena were explored. The areas of Computer-Supported Collaborative Work and Knowledge Management were reviewed, and problems with team interaction with digital information highlighted. This resulted in the review of computer gaming, game-based learning and game theory as a means to improve this interaction with information.

Research Phase	Chapter	Topic	Literature	Inference
a *Motivation & context*	1	Product development	Overview	Importance of information use in design
b *Exploration*	3	Concept design	Design processes, concept design tools, creativity techniques	Appropriateness of solution-based approach for designers
	4	Design information	Information types, information	Benefits of information for concept design

			sharing, information use	
	5	Digital support	CSCW, KM	Lack of engagement with digital tools
c *Development*	6	Team interaction	Computer gaming, game-based learning, game theory	Improved interaction mechanism

Table 2.1: Summary of literature throughout research

A diagrammatic overview of the literature areas is illustrated in Figure 2.2. This shows the areas explored, the relationships between them, and where the research is felt to have contributed significantly to the existing literature. While it is accepted that these areas could be mapped in a number of different ways, the figure helps to describe the evolution of the research. From a starting point of information use in product development, the four main branches of exploration (in chronological order) were: concept design; information in concept design; computer support for information use; and ways to improve team engagement (using computer support tools). The areas where a significant contribution to the existing literature has been made include *concept design tools*, as the developed approach offers something different from those currently available, *information sharing* and *information use*, as the approach suggests new ways to interact with digital libraries and information sources, and *team interaction*, as the approach provides a structure for concept design activity.

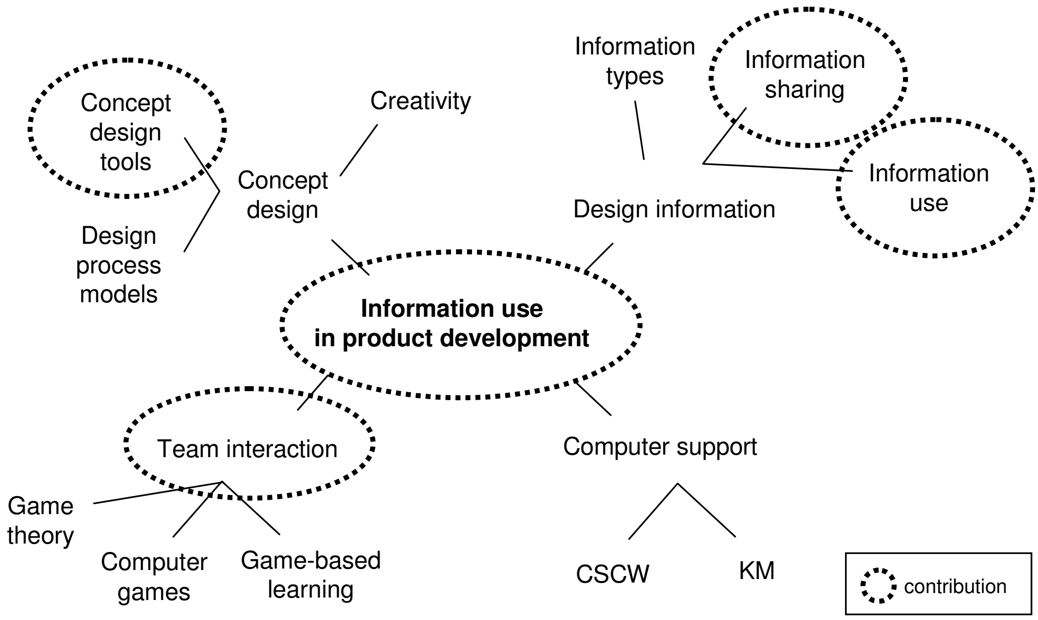


Figure 2.2: Literature map with highlighted areas of contribution

2.4 Design research methodology

Despite the fact that design research continues to mature (Cross, 2007), there is a general lack of consensus on appropriate methodologies and critical questions (Finger & Dixon, 1989). The inherently open-ended and highly variable nature of design can make formal evaluation of new approaches problematic, and have prompted concerns of a lack of rigour (L. T. M. Blessing & Chakrabarti, 2002). In his overview paper of design research methodology, Reich (1995) states that methodologies are 'socially constructed', stressing that different design contexts will require specific approaches. However, he advocates the adoption of an archetypal research structure of: (1) *observations or preliminary studies*, (2) *hypothesis formation*, (3) *hypothesis testing*, (4) *hypothesis evaluation*, and (5) *hypothesis acceptance or rejection*. Duffy and O'Donnell (1998), writing specifically with the field of design in mind, suggest that there are a number of key elements that build and interlink during the research process. This consists of a similar framing, exploring and validating process using the terminology of: *research mission*; *needs analysis*, *research framework*, *research approach* and *validation and evaluation*.

Blessing et al. (1995; 2002) describe the main problems in design research as the human element, the large number of influences, their interconnectivity, and the uniqueness of every design process. Figure 2.3 illustrates their research model, consisting of an initial *descriptive* study based on empirical data and analysis which allows an understanding of the current situation to be developed. A *prescriptive* study, where an intervention is applied, is then undertaken to form and evaluate the prescribed design support mechanism. The effect on current practise is then evaluated in a further *descriptive* study. The research in this instance follows this model closely, with initial studies used to evolve understanding of information use in concept design, a new method for concept design to support digital information use developed and tested in controlled studies, and finally the results evaluated in the design context.

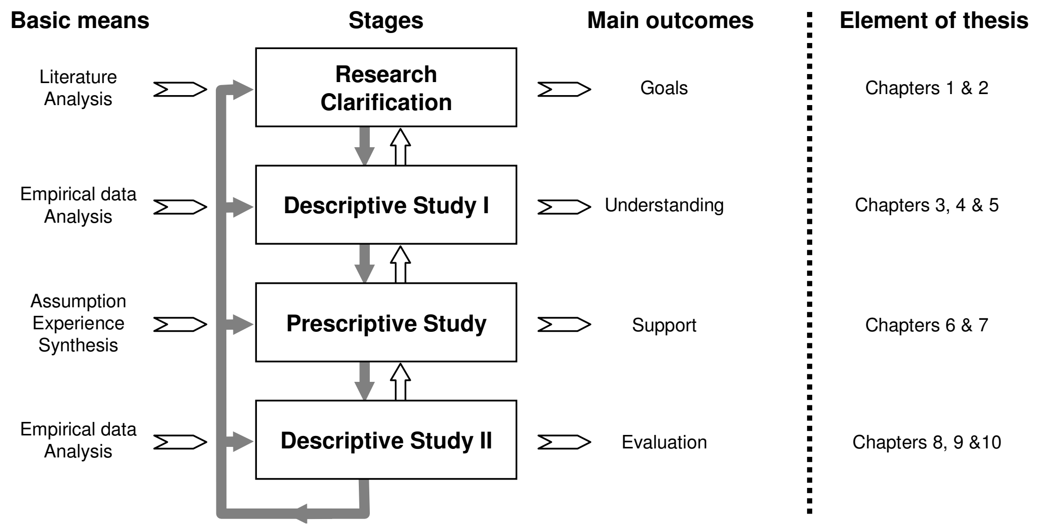


Figure 2.3: Blessing's Design Research Methodology and correlation to thesis

In moving between phases of research, it is necessary to adopt various research *methods* as appropriate within the overall *research methodology*. In light of this a number of different methods were utilised and these are summarised in Table 2.2. In general terms, the methodological position was qualitative, with a number of quantitative measures included where and when appropriate. This was considered most applicable as the studies generally consisted of small numbers with in-depth observation and analysis used to draw conclusions (Kumar, 1996).

In Phase b (*exploration*), information was identified as the element of concept design which merited attention. However, it was necessary to develop an understanding of the specific issues in order to guide the development of any new approach. In order to achieve this, a number of small-scale studies were undertaken, guided by relevant literature at each stage. These included: a *protocol analysis* involving postgraduate and research engineers to illustrate literature on information availability and use in concept design (Chapter 4); *observation and monitoring* of a class of undergraduate product designers based on the development of an integrated digital environment to address Knowledge Management and Groupware issues (Chapter 5).

In Phase c (*development*), new approaches for enhancing the design team's use of information were explored. The movement for productive use of computer games was explored, and number of games then evaluated through *primary testing*. A number of scenarios were developed using the insights gained (Chapter 6). *Iterative design* was then undertaken in the development of robust interaction mechanics (Chapter 7).

In Phase d (*application and reflection*), the testing of the developed approach was undertaken firstly through *quasi-experimental* comparative studies with the 6-3-5 Method, the closest existing design method to that suggested (Chapter 8). Questionnaires were used to gather additional qualitative information in addition to the analysis of conceptual output. Finally, a number of *industrial case studies* were carried out to evaluate the approach in context, with semi-structured interviews used to gain additional feedback (Chapter 9).

Research Phase	Chapter	Study	Research methods	Inference
b *Exploration*	4	Design team study	Protocol analysis, observation	Benefits of information for concept design
	5	Engineering design project study	Data logs, observation, questionnaire	Lack of engagement with digital tools
c *Development*	6	Games review	Primary testing	Improved interaction mechanism
	7	Development of structured	Iterative design – paper prototyping	Mechanism refined and formalised

		interaction	and testing	
d *Application & reflection*	8	Comparative study of ICR Grid and 6-3-5 Method	Quasi-experimental analysis of output, questionnaire	Benefits compared with 6-3-5 Method
	9	Industrial case studies	Case studies, semi-structured interviews	Usefulness in range of industrial settings

Table 2.2: Summary of research methods throughout research

2.4.1 Design team study

Protocol analysis involves recording and transcribing an event and categorising the resulting interactions using a designated schema (Blaxter, Hughes, & Tight, 2001). The reasons for choosing this approach at this early point in the research was to develop a better understanding of *how* designers tend to work, rather than *what* they actually produce. An identical design task was carried out by two groups, with only one group having access to information resources. In this instance, a combination of the Transcript Coding Scheme (TCS) proposed by Huet (2006) and Critical Situation Analysis (CSA) proposed by Badke-Schaub et al. (2002; 1997) were used to frame and analyse the results. This revealed the working patterns adopted in both sessions and how access to information sources influenced them, and concluded that access to stimuli provided a number of tangible benefits during conceptual design.

2.4.2 Engineering design project study

Having identified digital libraries and groupware as technologies to provide digital information support, the implementation of a system combining these elements was studied in the context of an undergraduate engineering design project. The contrasts between expert and novice behaviour have been highlighted as an issue in descriptive studies of the design process (Ahmed, Wallace, & Blessing, 2003; Cross, 2004). However, the use of design novices in testing new methods has actually been advocated by a number of authors (Antonsson, 1987; Reich, 1995) as a way to garner unbiased feedback – 'real' designers are highlighted as having set working practices and prejudices which may affect evaluation. In the case of this study, the focus was on interaction with a digital library and a mixture of methods (data logs, observation, questionnaire) were used to provide as rich an understanding of utilisation as possible.

2.4.3 Games review

While social networks are indicative of the increasing connectivity of our digital lives, it is computer gaming that provides the most vivid examples of cutting-edge, immersive experiences. A number of contemporary computer games were therefore identified for primary evaluation to examine the relevant feature sets, game structures and interface designs in information-rich environments. Evaluations of games have used a range of approaches, including quantitative methods (Ip & Jacobs, 2004), surveys of large numbers of players (Vorderer, Hartmann, & Klimmt, 2003), and analysis of characteristics based on aggregating magazine reviews (Pinelle, Wong, & Stach, 2008). However, it has been suggested that the value systems created by players in the playing of games are best understood through in-depth studies (Barr, Noble, & Biddle, 2006). Given the specific nature of the application of the gaming interactions, it was felt this was the most appropriate approach, and therefore primary evaluation of a number of games was undertaken. Four genres were identified (Apperley, 2006), and exemplars from each played and evaluated against a set of criteria. A number of scenarios utilising features and characteristics of these genres for concept design teams were then developed.

2.4.4 Development of structured interaction

After a set of mechanics for an enhanced concept design team interaction were created, they were then developed through iterative, paper-based design tests using groups of researchers, academic staff and postgraduate students. Regarding the iterative approach to research and development in the gaming field, Zimmerman (2003, p. 176) states that iterative design is:

> '…based on a cyclic process of prototyping, testing, analyzing, and refining a work in progress. In iterative design, interaction with the designed system is used as a form of research for informing and evolving a project, as successive versions, or iterations of a design are implemented.'

Paper-based approaches have been suggested as highly effective in optimising usability of games (Federoff, 2002), and in ensuring shared understanding (Lauche, 2005). The optimisation process was tracked using key indicators of performance

(Dewan, 2001), and software appropriated to perform functional aspects as necessary. After six iterative stages, an interaction mechanism was formalised that was robust enough for formal evaluation.

2.4.5 Comparative studies

A comparative study was chosen since the 6-3-5 Method contained a number of similarities to the method developed – the ICR Grid. 6-3-5 requires the rotation of sketchwork around the team, but does not formally include the use of information and evaluative elements incorporated by the new approach. The formal evaluation therefore took a quasi-experimental approach to reveal the resulting differences in performance. The conditions were controlled to provide as balanced a comparison as possible, but elements such as the design brief, items in the digital library and the team make-up across all sessions introduced elements of variability. The cause and effect analysis remains, but the independent variable (in this case the design approach) must be regarded as an indicator rather than cause of any results (Dane, 1990). Eight teams of postgraduate students were required to perform two different design tasks, using the ICR Grid for one and the 6-3-5 Method for the other. This proved a sufficient number to reveal clear patterns in measured output, with the qualitative feedback obtained proving similarly consistent. Although more experienced than the undergraduate students used in the class study, the participants were still not practising designers. They did, however, make focussed and enthusiastic participants who were aware of the context of the approaches in the design process and were able to clearly discern the differences between them. Unlike the previous exploratory studies, which looked at behavioural characteristics in the use of physical and digital resources, the focus was on output from the concept design session, using a range of measures such as quantity, variety and quality. This quantitative approach was necessary to verify the performance of the ICR Grid as having tangible benefits for concept design. The results were supported by post-experiment questionnaires to provide additional insight.

2.4.6 Industrial case studies

Case studies are generally used to answer 'how' and 'why' questions, focussing on real-life contexts (Gerring, 2007). On completion of the controlled experimental studies, the benefits of the new approach had been documented. It was desirable, however, to examine its performance in the industrial setting. Three companies, each from very different sectors, were selected to illustrate how the method would perform in varying contexts. In each case, a pertinent design challenge was identified. The case study protocol (Yin, 2009) involved evaluating the current company practice, finding a design challenge and developing a briefing document, running a design session, debriefing the participants in a semi-structured interview and analysing the conceptual output of the session. Stake (1995), and Yin (1994) identify at least six sources of evidence important in case studies, including documents, archival records, interviews, direct observation, participant-observation and physical artefacts. In this instance, observation, interviews (in the form of semi-structured interviews) and archival records (in the form of design output) provided the means of evaluation.

2.5 Summary

This chapter brings to conclusion Phase a (*motivation & context*) of the research – information in concept design has been identified as the focus of the research, and the architecture of the thesis, with various literature studies and research methods employed within the overarching research methodology, has been outlined. It should be considered that the development of a new method or process is in fact a design process in itself, involving similar phases and decision points, albeit in a more structured academic framework. It is therefore necessary to construct a methodology suited to the particular aims and objectives of the work and to reflect consistently on their effectiveness. These initial chapters provide the foundation for the structured exploration of issues relating to concept design, information use and digital support that follow, and in turn allow deeper reflection on what interventions can be made to improve current practise.

Chapter 3 Concept design

This chapter marks the beginning of Phase b (*exploration*) of the research. Having outlined the problems relating to information use early in the product development cycle, the literature relating to concept design and the role of information is examined more closely. After reviewing a number of recognised product development process models, the range of tools for concept generation are examined and categorised. Issues with concept design are then explored regarding creativity, the creative process and how information is utilised in the creation of new ideas. A more integrated, solution-focussed approach which allows designers to acquire and use information at the point of need is subsequently identified as a point of focus for the research.

3.1 Design process models

Design process or methodological models are aids to the development process, helping to structure people, tasks and information in an appropriate way. Tools and methods are employed to complete specific tasks within such a framework. Techniques and approaches are concerned with the way in which these are employed for any given project. In the context of this research, it is worthwhile to clarify these terminologies:

- **Process/ methodology** The overall sequence of tasks to achieve a particular goal.
- **Tool/ method** A means to perform a specific task in a systematic way.
- **Technique/ approach** The use and combination of tools and methods.

Although Ulrich and Eppinger's model has been identified in Chapter 1 as providing a point of reference for this research, five prominent design models have been reviewed with particular attention to their approach to concept design, how information is handled, and the particular tools and techniques suggested to support conceptual design work.

3.1.1 French

First printed in 1971 under the title 'Engineering Design: The Conceptual Stage', French's design model (1985) is one of the earliest in the field of engineering design. French describes design consisting essentially of: '1) the generation of good schemes (conceptual design); 2) securing the best embodiment of those schemes (the problem of best embodiment); and 3) the evaluation of alternatives' (p.3). The text, however, concentrates primarily on conceptual work and is illustrated through the use of a series of technical examples. Although the design model identifies logical steps for the developmental process, there is little discussion of the various tasks carried out at each stage, with French admitting in the text that it does not address design management or its relationship to other organisational functions. Although a number of 'methods' are covered, there is little discussion of blue-sky or generative design thinking, with most focussing on techniques such as optimisation or matching to develop fairly detailed design concepts.

3.1.2 Pahl and Beitz

In a highly systematic approach that was first published in German in 1977, with the first English edition appearing in 1984, the Pahl and Beitz (Pahl & Beitz, 1995) model is one of the best known in engineering design. The authors outline a detailed series of steps which 'none of which may be skipped if they most promising solution concept is to be reached' (p.40). Before even engaging with conceptual design, they advocate that a form of checklist is completed. This includes considerations such as: 'has the task been clarified sufficiently?; must further information be acquired?; is it possible to reach the chosen objectives within the financial constraints?; is conceptual elaboration really needed, or do current solutions exist?; and to what extent should the systematic approach be adopted' (p.160). The steps detailed in their conceptual design phase focus on establishing the essential problems by *abstraction* of the PDS by developing function structures and organising solution principles on this basis. These are then combined and developed into concept variants. *Information* is listed as the first stage of this process, presumably in reference to the PDS. The following stages of establishing functions and solutions are categorised as *definition* and *creation*, despite the fact that the tools and techniques recommended require continual searching and utilisation of knowledge.

At the solution principle stage, a number of tools are advocated to assist in the development of new ideas. These have been divided into a number of categories: conventional aids (literature searching, analysis of natural systems, analysis of technical systems, analogies, measurements and model tests); methods with an intuitive bias (Brainstorming, 6-3-5 Method, Delphi Method, Synectics); methods with a discursive bias (systematic study of physical processes, systematic search with the help of classification schemes, use of design catalogues). When a range of solution principles have been created, these are then combined using either systematic (morphological matrix) or mathematical (compatibility matrix) techniques to give a range of concepts for evaluation.

3.1.3 Pugh

The Pugh (1991) design model was one of the first to carefully consider input from different disciplines in the design process using a *design core* to highlight various inputs through the outlined phases. The primary concern of Pugh's Conceptual Design phase is 'the generation of solutions to meet the stated need; in other words it involves generating solutions to meet the PDS' (p.67). The requirement of a PDS is similar to Pahl and Beitz's rigorous specification checklist, if not quite so onerous. Pugh advocates an iterative approach, consisting of alternating phases of generation and convergence to reach a final concept. Although tools are suggested, the designer is left to choose the appropriate format and duration of the process.

Pugh cites the work of McGrath (1984) in suggesting that although there is a general movement towards design team activity, individuals have been recognised to be more creative and productive in generating concepts. Pugh suggests combining an individual with a team approach, i.e. generating concepts individually and selecting and enhancing as a team. Pugh's overview of the Total Design process lists *information acquisition* and *synthesis* as discipline-independent techniques applied during the Conceptual Design phase, and *concept selection* for Detail Design. Despite this, there are no explicit methods for the gathering and use of appropriate information, only a mention that in the concept generation environment it is important to have access to 'information sources, data banks and the like' (p.70).

A number of methods are suggested to aid creativity, and can be categorised according to whether they require a solution to already exist: analogy, brainstorming, attribute listing, and checklists do, and are by inference more suited to the early stages of the phase; inversion and combination do not, and are therefore more suited to the later stages of the phase. The suggested approach to convergence is using the Controlled Convergence Matrix to rank concepts against a datum. This would be undertaken a number of times during the phase before a final concept is decided upon.

3.1.4 Cross

The Cross (1994) model is somewhat unconventional in that it visually describes the extracting of sub-problems from the overall design challenge, the generation of sub-solutions to address these problems and the recombination of these to provide an overall solution which meets the original problem. In the 'doing of design', Cross mentions a range of *creative* methods (such as brainstorming, Synectics etc) to help stimulate creative thinking, and *rational* methods (such as objectives trees, functional analysis etc) which encourage a more systematic approach. One method is highlighted for each of the stages in the design process. In the Generating Alternatives stage, the one most relevant to this work, Cross discusses the use of morphological charts to co-ordinate the creation and combination of ideas into concepts.

3.1.5 Ulrich and Eppinger

The Ulrich and Eppinger (1995) model provides a practical guide to the development process, with a thorough list of stages and tasks outlined. They define concept generation as a process which 'begins with a set of customer needs and target specification, and results in a set of product concepts' (p.102). This is at variance with the Pahl and Beitz and Pugh models in that the stage does not end with a single concept with which to proceed: concept selection is undertaken as a separate, subsequent stage in the process. They advocate a short but intense approach to concept generation (15% of development time), and suggest that a team should produce hundreds of concepts, of which a smaller number '5 to 20 will merit serious consideration' (p.98). A Five-Step Method with appropriate tools is suggested: 1) simplify the problem in to sub-problems (functional diagram, decomposition by sequence of user actions, decomposition by key customer needs), 2) search externally (interview lead users, consult experts, search patents, search published literature, benchmark related products), 3) search internally (suspend judgement, generate a lot of ideas, welcome ideas that may seem infeasible, use graphical and physical media; make analogies, wish and wonder; use related stimuli, use unrelated stimuli, set quantitative goals, use the gallery method), 4) explore systematically (concept classification tree, concept combination table), 5) reflect. Although this is presented as a linear sequence, the iterative nature of this process is highlighted and design teams encouraged to design their own process to suit using the suggested tools as a starting point.

The internal search task is where the creation of new concepts take place, although Ulrich and Eppinger declare it is useful for the designer to consider the internal search as 'a process of retrieving a potentially useful piece of information from one's memory and then adapting that information to the problem at hand'. This, combined with the explicit external search task, indicate that information is regarded as considerably more important than with other design models. Set tools for undertaking the creative task of concept generation are not described, only a set of guidelines (suspend judgement, generate a lot of ideas etc) and hints (make analogies, wish and wonder etc). It is notable that Ulrich and Eppinger follow Pugh in citing the work of McGrath (1984) in suggesting that individuals will generate more and better ideas than a group. They advocate a mixed format approach, whereby team members spend at least some time alone to create concepts, but ensure meetings take place as they are critical for 'building consensus, communicating information and refining concepts' (p.90).

3.1.6 Summary of design process models

Process models are often characterised as descriptive or prescriptive, in that they can either describe the activities taking place at each stage in the design process, or prescribe methods or tasks to be completed (Finger & Dixon, 1989). Descriptive models are generally more solution-focused and heuristic in that they rely on the designer's experience and rule of thumb to navigate through the process. Prescriptive models are more systematic, requiring designers to adopt particular procedures in a logical sequence. In practice, most major texts on the design process, including those reviewed above, have a mix of descriptive and prescriptive elements, with broad stages outlined and a number of tools and techniques suggested for use as appropriate.

A general trend in the literature has been a shift in concern with the issues in solving particular technical design scenarios towards organisational and management considerations as part of the product development cycle. There is, however, considerable variation in scope and intent on the part of the authors of the five models reviewed, and some general observations on each of these have been included in Table 3.1. As would be expected, there is significant overlap in the creative methods suggested to assist with the generation and development of concepts, with the most common tools such as brainstorming mentioned by all. Given that the texts reviewed are concerned with the entire design process rather than concept design exclusively, these lists are far from exhaustive and do not explore in depth the nature and scope of the concept design. To better understand these issues, therefore, a further review was carried out, this time focussing specifically on concept design methods and tools.

Author (date of 1st edition)	**General comments**	**Creative tools**
French (1971)	Simple representation of the design process. Based on technical examples, does not address management or relationship to other functions. Most of the text revolves around the Conceptual design stage.	combinative ideas, search for alternatives, logical chains, past practice and changed circumstances, brainstorming, use of solid models
Pahl & Beitz (1977/1984)	Clear, detailed stage-driven process. Iteration built into each stage. Provides little flexibility for different types of design project.	conventional: literature search, analysis of natural systems, analysis of technical systems, analogies; intuitive: brainstorming, 6-3-5 Method, Delphi method, synectics; discursive: systematic study of physical processes, systematic search using classification schemes, use of design catalogues

Pugh (1991)	Distinctive process layout, with 'design core' central throughout. Numerous cross-organisational contributions to the design process identified. Generally descriptive, with few defined processes and structures.	analogy, brainstorming, attribute listing, checklists, inversion, combination
Cross (1994)	Unconventional visualisation of design process, advocating the development of problem and solution in tandem. One principal method highlighted for each stage of design process.	brainstorming; synectics; enlarging the search space; morphological chart
Ulrich & Eppinger (1995)	Easy to understand, practical guide through the development process. Logical and thorough list of stages and tasks. No formal links between tools and documents. No explicit iteration or feedback loops between stages.	search internally: analogies, wish and wonder, related and unrelated stimuli, quantitative goals, gallery method; systematic: classification tree, combination table

Table 3.1: Summary of concept design in major design models

3.2 Concept design methods

In 3.1 above, tools and methods were categorised as 'means to perform a specific task in a systematic way'. For clarity, these terms can be further delineated: a method implies a set of steps (a procedure) whereas a tool implies facilitation (such as a computer program) for the completion of such tasks. Although the major texts on the engineering design process cover a number of methods and tools to support creative working, in recent years a diverse range has been developed to help spark the creativity of workers across all industries. The website developed and maintained by the Mycoted creativity and innovation company (Mycoted, 2009), for example, lists 168 discrete creativity methods. In the area of engineering design, there exists a tension between the requirement for systematic methods to be employed by organisations in order to control and manage new product development, and the unstructured approach which is generally associated with creativity. In a review of concept generation methods for design teams, Shah et al. (2000) address this dichotomy by categorising applicable methods as *intuitive* or *logical*. Intuitive methods are designed to overcome 'mental blocks' and encourage diversity of thinking, whereas logical methods utilise mechanisms to systematically decompose and analyse the problems, often relying on technical databases or established engineering principles. Their full classification of concept design methods is set out in Table 3.2.

The strengths of the intuitive methods are their flexibility and the creativity they engender. Relying less on external information, they instead depend on the knowledge and inspiration of participants to rapidly produce design ideas. If a group of participants gel as a team and has the requisite skill set to address a problem, intuitive methods can be highly effective in harnessing the synergy generated by such methods.

Logical methods, on the other hand, benefit from bringing past solutions and prior knowledge to bear on the design problem. They also, however, tend to prescribe the way a problem must be approached. Although more suited to large organisations where set development paths are desired to bring structure to complex processes, logical methods can nevertheless provide valuable insight into how to create mechanisms for integrating information.

Progressive methods are of particular interest in that they incorporate an element of information sharing while allowing participants to work freely in both individual and group modes. They generally utilise sketches and discussion in ways similar to uninhibited concept design practices, with a number of restrictions in terms of duration and format to help ensure the development of concepts within the session. The majority of the information managed and communicated, however, is generated internally by the design team during the course of the session rather than through the introduction of relevant external sources.

The methods shown Table 3.2 in italics have been described further below – these were selected by the author as prominent examples in each category and to provide a comprehensive overview of the range of methods.

Classification	**Sub-classification**	**Examples**
Intuitive: use mechanisms to break what are believed to be mental blocks	Germinal: aim to produce ideas from scratch	Morphological Analysis, *Brainstorming*, K-J Method
	Transformational: generate ideas by modifying existing ones	*Checklists*, Random Stimuli, PMI Method
	Progressive: generate ideas by	*6-3-5 Method, C-Sketch*,

	repeating the same steps many times, generating ideas in discrete progressive steps	*Gallery Method*
	Organisational: help designers group generate ideas in some meaningful way.	Affinity Method, Storyboarding, *Fishbone Diagrams*
	Hybrid: combine different techniques to address varying needs at different phases of ideation	*Synectics*
Logical: involve systematic decomposition and analysis of the problem, relying heavily on technical databases and direct use of science and engineering principles and/or catalogues of solutions or procedures	History-based: use past solutions catalogued in some form of database	*TRIZ*, design catalogues
	Analytical: develop ideas from first principles by systematically analysing basic relations, causal chains, and desirable/undesirable attributes	Forward Steps, Inversion, *SIT*

Table 3.2: Classification of creative methods (after Shah et al.)

3.2.1 Brainstorming

Popularised by Osborn (1953) in the 1950s, brainstorming consists of a group of people working together in a non-critical environment to generate a high number of ideas. Although there are many variations, there is generally a facilitator, fixed timescale and whiteboard or appropriate writing implements. Organisations such as IDEO (Kelley, 2006) have made this approach central to their corporate culture, and such is its popularity brainstorming is often used as shorthand for any meeting where groups try to develop some ideas. This can be to its detriment when groups undertake the activity informally and half-heartedly with disappointing results. Other criticisms include that it can be personality-driven, with the loudest participants dominating, that the quality of ideas can be suffer given the pressure for quantity, and the lack of opportunity to develop idea threads within a session can be frustrating. Its simplicity and power, however, mean it is firmly established as the most popular approach to concept generation in industry today.

3.2.2 Checklists

Osborn's Checklist (Osborn, 1953) was developed as a way to help transform existing ideas into new ones by consulting a series of simple questions to provide stimulus. For an existing solution or a proposed concept, each question is addressed in turn, and new approaches to the problem are explored. The Checklist consists of suggestions such as magnifying, miniaturising or rearranging elements to create new concepts. A derivation of Osborn's checklist is SCAMPER: Substitute, Combine, Adapt, Modify, Put to another use, Eliminate, Reverse.

3.2.3 6-3-5 Method

The 6-3-5 Method (Rohrbach, 1969), also known as Brainwriting, was developed as an alternative to brainstorming. The name reflects the format, in that a team of 6 participants sketch 3 ideas every 5 minutes. After each five minute round, the concepts are passed round to the adjacent participant. The team is then able to draw on others' ideas for inspiration as they wish. If all participants complete the session properly, a 30 minute session should produce 108 ideas. The focus of the technique is therefore on quantity – the results of the session would then be used for further concept development and evaluation.

3.2.4 Gallery Method

Developed by Hellfritz (1978), and described by Pahl and Beitz as a tool in their systematic approach, the Gallery Method uses both individual and group modes of working. After being briefed on the design problem, participants are required to sketch their ideas individually and intuitively. These are then pinned on the wall for the group to debate and discuss the merits of each. Ideas and insights from the group discussion are then used by individuals, again working alone. This approach combines the productivity and insight of an individual working alone with the power of group discussion to spark new ideas and directions.

3.2.5 C-Sketch

Collaborative sketching (C-Sketch) is an idea generation method developed in 1993 in the Design Automation Lab (DAL) at Arizona State University (Kulkarni, Summers, Vargas-Hernandez, & Shah, 2001). It is an extension of the 6-3-5 Method in that a group of designers rotate concept sketches without verbal clarification in an iterative fashion. Using the C-Sketch method, each designer develops one sketch in a predetermined cycle-time and passes it to the adjacent designer. This designer can change, add or delete aspects of the design solution as they see fit while maintaining the overall premise of the design. This is repeated until all participants have added to each concept, giving a number of conceptual sketches equal to the number of participants at the end of the session. This method emphasises the development of sketches amongst the group, while not providing the variety of ideas that emerges during 6-3-5.

3.2.6 Fishbone Diagram

Originally developed by Ishikawa (1985) in the context of Quality Control, Fishbone Diagrams – also known as Cause and Effect or Ishikawa Diagrams – have also been used in engineering design situations (Samuel & Weir, 1999). It discourages partial or premature solutions, and shows the importance and relationships between different parts of a problem. It is constructed by drawing a horizontal arrow with the title of the issue to be explored – this forms the backbone of the fish. Spurs at 45º for every associated issue the group can think of are then drawn and labelled at the end. Each spur is considered in turn, with sub-branches added for associated causes. These can then be used to help guide the creation of different concept embodiments.

3.2.7 Synectics (analogy)

Synectics is a proprietary method which combines a number of different techniques to analyse the problem and then force alternative approaches. Developed by Bill Gordon and George Prince and owned by Synectics Ltd[1], it draws heavily on the use of analogical thinking. On a more simplistic level, analogy can be used to force parallels and similarities with other related products, technologies or ideas to stimulate new approaches to a problem. It can, however, be limited by the experience of the participants involved (Walker, Dagger, & Roy, 1991).

3.2.8 TRIZ

Probably the best known systematic design approach, TRIZ (Altshuller, Altov, & Shulyak, 1994; Rantanen & Domb, 2002) is a Russian acronym which can be roughly translated as 'The Theory of Inventive Problem Solving'. Developed by Genrich Altshuller during the late 1940s, TRIZ structures creativity according to conflicts which have been shown to arise between different engineering parameters.

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[1] http://www.synecticsworld.com, (Accessed: 4th January 2010)

Altshuller was a Patent Officer who noticed certain principles emerging consistently and began to categorise these, before using these to develop a range of tools to aid creativity. Although TRIZ encompasses a number of tools and techniques, the 40 inventive principles and its associated contradiction matrix is the best known. Contradictions are common when developing technical requirements for a product. For example, the design challenge may be to design a table which is light but also strong. Reducing the amount of material, however, tends to impact negatively on the strength characteristics of a design. Asthuller created a 39x39 Contradiction Matrix (Figure 3.1) that allows the designer to refer to a list of 40 Inventive Principles that can be helped to solve the contradiction. Using the table example, the vertical axis of the table is used to find the improving parameter – in this case improved strength – and the horizontal axis used to find the worsening parameter – in this case weight. The corresponding cell in the table then directs us to a number of Inventive principles (1 – segmentation; 26 – copying; 27 – cheap short living objects; 40 – composite materials) which stimulate idea generation. The Inventive Principles are intended to be used to then guide the development of design solutions.

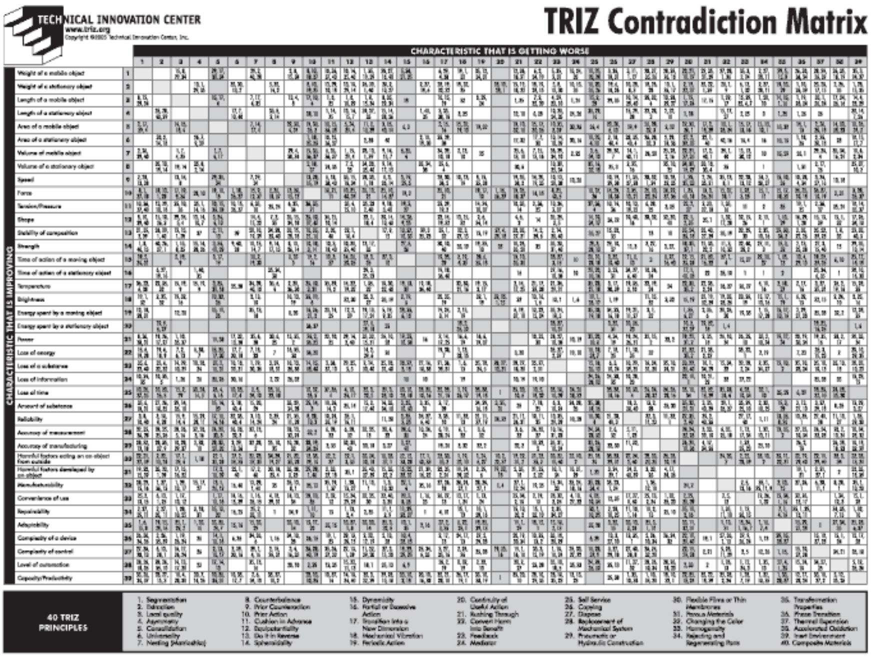

Figure 3.1: The TRIZ[2] contradiction matrix

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2 http://www.triz.org (Accessed: 5th January 2010)

3.2.9 Systematic Inventive Thinking

Systematic Inventive Thinking (SIT)[3] is a proprietary system developed in the Netherlands in 1996 and is used by several large multinational companies including Philips, Siemens and Kodak. It is similar to TRIZ in that it is derived from Altshuller's findings, and uses the patterns of solution characteristics he identified to develop five thinking tools (closed world, function follows form, limit rather than dilute, path of most resistance and qualitative change) for the stimulation of design ideas. Its more simplistic approach means it is easier for organisations to learn and use in different areas without recourse to a database of any kind (versus the large database of effects and examples in TRIZ).

3.2.10 Summary of creative methods

Given the industrial context outlined in Chapter 1, different approaches have different desirable features. *Intuitive* approaches in general are attractive as a means of encouraging interaction for small groups in a way that is not overly-restrictive. Of these, *progressive* approaches incorporate an element of structure to ensure that concepts continue to evolve as appropriate during the course of design sessions. *Logical* approaches, on the other hand, introduce external and history-based examples that can aid the development of sound solutions

An 'ideal' concept design method would blend the best of these elements. Although only broadly indicative, Figure 3.2 uses Shah et al.'s (2000) categorisation scheme to map the concept design methods described against the type of information generally utilised. It summarises that more intuitive methods tend to rely on internal information, while logical methods introduce more history-based and external information. For example, brainstorming generally relies on the prior knowledge of the participants when they enter the room, whereas SIT will facilitate the consultation extensive databases. While the gap at the bottom left indicates that logical approaches do not generally exist for interrogating our own internal knowledge, it is the gap at the top right which is of primary interest in this work. This suggests there is an 'information gap' in concept design – methods that integrate new information rigorously while adopting a flexible approach to problem solving.

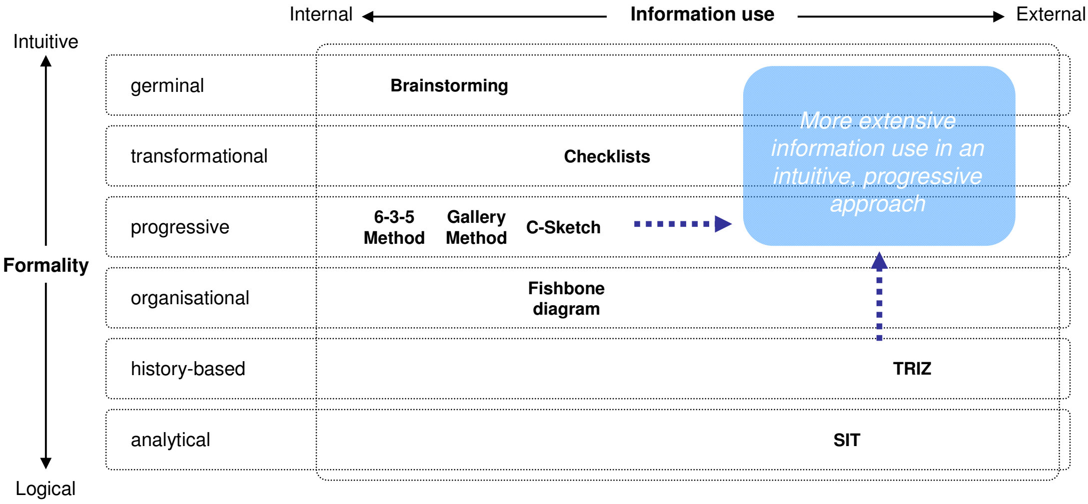

Figure 3.2: Map of concept design methods and information gap

3.3 Design creativity

Creativity is a term often associated with conceptual design work. To create – to produce or bring into existence new ideas – is a psychological process subject to a large body of literature, spanning a wide range of fields including philosophy, psychology, cognitive science design and management. It is an increasingly valued attribute in a competitive business environment, but according to Goldenberg and Mazursky (2002) there are widespread difficulties in finding ways to 'organize, investigate and emulate the phenomenon of creativity' (p.31). Benami and Jin (2002) have evaluated the literature in cognitive science and applied it to the field of design, breaking the cognitive process down into some detail. They suggest that the designer is stimulated to explore ideas, and cognitive processes then come into play as these are assimilated. Despite this, they do not address the issue of teams – in particular the proposition that the levels of interaction and reflection on ideas in the creative process can be optimised to improve the creative output of design teams (Paulus & Yang, 2000). Hubka and Eder (1988) are more sceptical: in their systematic approach to design they question if 'creativity' in a generic sense can be measured in any consistent way, instead emphasising the importance of setting optimal conditions for successful concept design by directing creative activity towards the most useful areas.

[3] http://www.sitsite.com (Accessed: 5th January 2010)

The most tangible definitions of creativity in the field of psychology include different categories. For example, Schilling (2006) states that creative works can be novel at the *individual producer* level, the *local audience* level, and the *broader societal* level. Similarly, Boden (1994) distinguishes two senses of creativity: *psychological* (P-creativity) and *historical* (H-creativity), with a P-creative idea being one that is novel to the person in whose mind it arose, whereas an idea is H-creative if it is P-creative and no other person in human history has had it before. Boden also observes that most ideas have been had before in one form or another, often by different social groups in different historical times.

Sternberg and Lubart (2005) criticise authors such as de Bono (1973) for developing creative tools without understanding the underlying psychological processes associated with creativity – its 'commoditisation'. Aside from these *pragmatic* approaches, they also identify *psychodynamic*, *psychometric*, *cognitive* and *social-personality* approaches to the study of creativity. Their own work focuses on the 'confluence' of these factors to expedite creativity. In the concept design team context, it can be assumed that all these factors are at play but it is beyond the scope of the research to investigate the underlying psychological processes of individuals and teams in the process of generating ideas. In a broader sense, the cerebral hemispheres are now a commonly accepted part of behavioural and brain science, with the left side of the brain (which predominantly controls the right side of the body) acknowledged to deal mainly with sequential, analytical and logical reasoning, with the right side of the brain (which predominantly controls the left side of the body) dealing mainly with imaginative, intuitive and holistic thinking. The ability to use 'right-brain thinking' to create ideas and synthesise knowledge is viewed as being critical as society advances towards a knowledge-driven era (Pink, 2005). Engineering design, with its requirement for both analytical and creative thinking in the development of new concepts, is a two-sided brain activity. As a result, engineers who are adept in both these modes of thinking have a flexibility that few other disciplines can match, and will be highly desirable with employers for having the ability not only to assimilate information and analyse problems, but to create new approaches and ideas to solve them. The aim of this research, then, was to arm the design team as well as possible for design work by providing access to appropriate information, and to determine weather this does indeed improve the concepts produced by the team.

3.4 Integrated approach

A number of authors have looked at making the concept design phase more integrated. Suh's (1990) 'axiomatic' approach to design consists of a 'continuous interplay between what we want to achieve and how we want to achieve it' (p.25). This is manifested in the balancing of design parameters (DPs) with functional requirements (FRs). The general emphasis is, however, on the management of manufacturing and detailing rather than creative techniques or concept generation.

Keinomen and Takala (2005) have developed a generic framework consisting of the 'activity layers of product concepting'. These layers incorporate the acquisition of knowledge, the development of concepts and their evaluation. The authors point out that the principal aim of concept design, as opposed to product design in general, is to develop 'new and different proposals'. It must be done, however, within the constraints set by the context. They observe that although a large number of team-based approaches have been developed for creative design work, fewer have been successfully embedded into company processes and information flows.

Lim and Sato (2006) suggest an approach to designing whereby 'multiple viewpoints' are adapted when formulating a design problem. Essentially, they advocate identifying relevant aspects of use, and using these to manage information needs and identify requirements for generating solutions. They propose a Design Information Framework (DIF) to address this, whereby a design problem is addressed from a number of viewpoints, and requirements created for each of these. Although they do not discuss concept generation in detail, it suggests that the categorisation of information and concepts could lead to more discrete solutions. The issue then is how the designer moves 'across' categories to ensure that all requirements are met, and that the best aspects of each solution are integrated.

3.4.1 Three modes of design thinking

All of the models described above require the designer to be able to undertake multiple tasks, to handle different types of information and to be able to switch between different modes of thinking in a prescribed manner. As a basic psychological process, concept design is often divided into three modes. Osborn (1953) describes the creative problem-solving process of comprising: fact finding (problem definition and preparation), idea finding (thinking up ideas and leads) and solution finding (evaluation and adoption). One of the first to apply this to the area of engineering design was Asimov (1962, p. 43). Cross (1994) develops the concept further in arguing prescriptive processes tend to follow a basic structure of analysis-synthesis-evaluation where analysis addresses all the design requirements for a problem, synthesis addresses solutions for each performance specification and evaluation addresses the accuracy with which these meet the requirements. Sim and Duffy (2003) identify a set of generic design activities numbering 27, but still categorise these three main aspects. Gero (2004) used the analysis-synthesis-evaluation elements in evaluating his Function-Behaviour-Structure framework.

It has been suggested (Cross, 1994; Dorst & Cross, 2001) that shifting between these modes in a flexible way can be beneficial, given the designer's tendency to make 'rapid explorations of problem and solution in tandem, in the co-evolution of problem and solution' (Cross, 2004) rather than follow linear stages. This shifting of attention was the subject of attention in a series of tests conducted by Santanen et al. (2003): participants in brainstorming sessions were prompted to change topics every two minutes through the use of stimuli, with the authors reporting that this positively impacted the creativity of design solutions produced. Goldschmidt (1991) has made similar observations regarding the sketching, emphasising the importance of 'shifts in perception' that occur during this activity with regard to creativity and the development of novel design solutions.

Restrepo and Christiaans (2004) further explore problem/solution focussing strategies in design, arguing that designers are often solution-led rather than problem-led, and concluding that information and its accessibility are critical in supporting this activity:

> 'Even when information exists and is relevant, it would not be used if its source were perceived as inaccessible. These are good reasons to make information tools more accessible to designers and, why not, fun to use!'

The provision of information support for concept design in a way that allows intuitive rather than prescriptive working, while having sufficient structure to allow the co-ordination of individuals within a team, has therefore been identified as a point of focus for the research. Rather than demanding significant work on design requirements and background research (competitor products, relevant technologies etc.) as a pre-cursor to concept generation, it aims to embrace the fuzziness of design problems and allow designers – who will often engage in sketching and idea creating activity as soon as a problem has been identified – to bring information *into* this process in an *activity-based* approach (as opposed to a *phase-based* approach) that allows repeated iterations of cognitive activities. Figure 3.3 shows how the linear concept design process can be revised to increase the *proximity* of information to the task of designing. In a typical phase-based process, information is gathered in the initial analysis of the design problem, concepts are then created in response to them, and these are then evaluated with one or a combination of concepts selected for further development. While these phases are not absolutely discrete, they are generally completed serially. In the proposed activity-based process, rapid iteration and movement between different modes of thinking are actively encouraged. While information input is still associated with analysis, the continual revisiting of it means it is more likely to be used in the other modes.

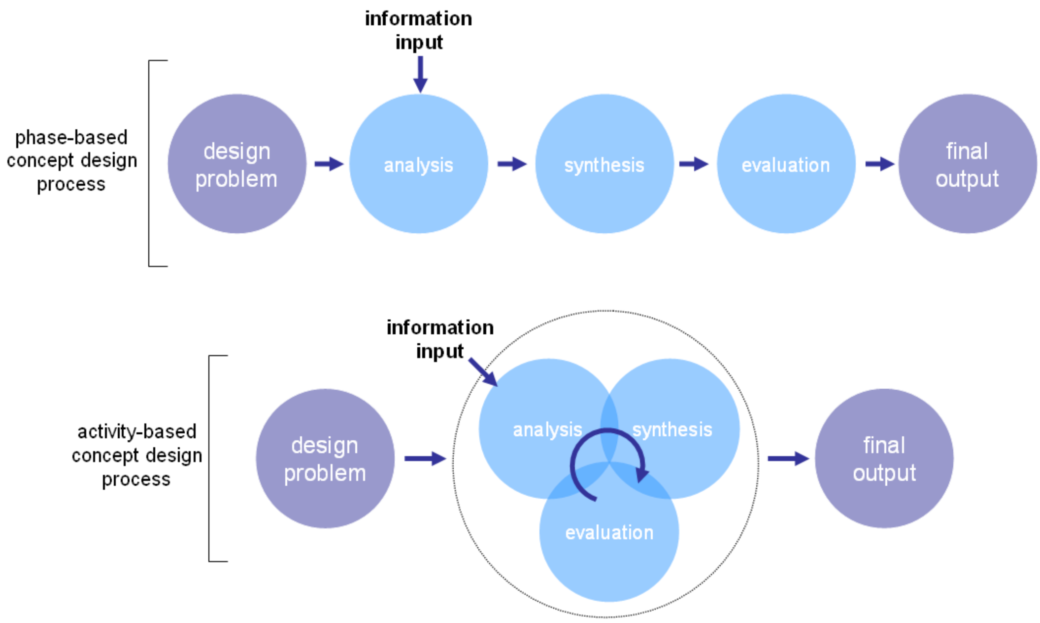

Figure 3.3: Idealised phase vs. activity-based concept design process

3.5 Summary

This chapter has reviewed major design processes and their approach to concept design. In addition, the range of specific tools developed to assist with the creation of new ideas has been considered. Creativity and its bearing on the production of ideas have been considered, with its interplay of different areas of literature. The research has been placed firmly in the area of design by focussing on the practical aspects of conceptual work and the requirement for a prescriptive, activity-based method to support this. The modes of thinking that are fundamental to concept work – analysis, synthesis and evaluation – and the tendency for designers to move between these different modes to quickly engage in solution-orientated, idea-based ('designer-ly') approaches to problem-solving, has been embraced as an opportunity to improve information support at this point of need. It has therefore been suggested that by allowing information to be drawn into the concept activity by designers as required may be a more effective way to enhance concept work, making the information more relevant, integrated, and vivid. The following chapter will explore in more detail the types of information that are appropriate to support this activity and how the proximity of information can be optimised to encourage this behaviour.

Chapter 4 Information use in concept design

With access to resources in design established as desirable for concept design, this chapter explores the issue of design information in more detail. After reviewing the nature of information and its use in concept design, a protocol analysis was undertaken to study the use of information resources as stimuli during the concept design phase. Two team-based design sessions were carried out – one with and one without access to resources – and then analysed for different types of activity. It was found that instances where the design brief was referenced led to more analytical and evaluative activities, and that instances where sketches, models and competitor products were cited led to more exploratory and debating activities. On the basis of these results, a number of recommendations are made for the provision of information resources during concept design.

4.1 Background

The common cliché in design research that 'all design is re-design' (Goel & Craw, 2006) highlights the fact that the majority of concept design work is re-configuring existing knowledge or technologies. Therefore, it is critical for any product development team to be aware of the most appropriate knowledge for design (such as past solutions, market data, emerging technologies) in order to save duplication of effort and to stimulate creative energies in the most effective areas. To aid their engineers and designers, IDEO have for many years utilised something known internally as the 'Tech Box' (Kelley & Littman, 2001). Essentially a trolley with numerous drawers of interesting mechanisms, sample materials, fastener designs and so on (Figure 4.1), it began life with an employee who kept these examples as an aid during the concept development process. This was so well regarded by their designers that the company quickly formalised it as an internal design tool, and eventually duplicated it across their numerous offices. It continues to evolve, with employees suggesting items for inclusion, and use of the company's Intranet to catalogue the contents, providing a valuable and convenient resource for designers to utilise at their convenience. The IDEO TechBox provides both reference and stimulus for concept design in a form that is accessible and practical, and as such is a point of inspiration for this research. While its contents can be easily handled, viewed, discussed and discarded by a group undertaking concept design, however, it does not necessarily contain the range of formats and types of information that are utilised through the process. The purpose of this chapter is to explore these in full, and to do this it is first necessary to define what is meant by information in the research context.

Figure 4.1: IDEO's Tech Box (IDEO, all rights reserved)

4.1.1 Defining information

Information is commonly differentiated from data as having a level of context added to it through modelling, formatting or organisation, while *data* are more fundamental representations of statistics, objects or events (Liebenau & Backhouse, 1992). In the field of interaction design, Shedroff (1999) further develops the concepts of *knowledge* and *wisdom* as higher stages in assimilation. Information can be transformed into knowledge by adding the value of experience, with conversations and integration providing enhanced, specific narrative. Finally, an internal understanding of the processes and relationships gained through evaluation and interpretation of these knowledge items can provide wisdom.

Shedroff's overview has been developed for the design team context, as illustrated in Figure 4.2. In the concept design task, the purpose is to synthesise information to make knowledge items. An annotated sketch, for example, can encapsulate a large amount of contextual information specific to the problem, raw data in the form of engineered designs according to fundamental principles and equations, and wisdom in the form of designers' individual experience gained from previous projects and practice.

For the purposes of this research, then, information in terms of the resources and context provided to the design team is the variable of primary interest, with the effect this has on team interaction and consequent synthesis of new knowledge items (concepts) the area of study.

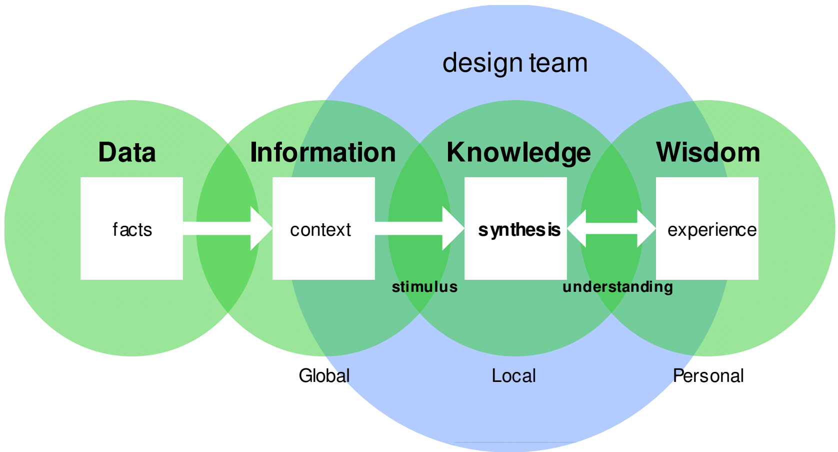

Figure 4.2: Information in the design team context (after Shedroff)

4.2 Communicating information

The information sourced and generated during concept design must be shared effectively for the design team to be successful. The rapid verbal exchanges characteristic of the brainstorming-type, informal design sessions commonly utilised (Sutton & Hargadon, 1996) do not necessarily lend themselves well to the utilisation of information sources. To achieve this, it is necessary to have clear methods of organisation and communication. Individuals can build complex mental maps of information resources that may be understandable to them but confusing to others. An example of this is the messy office desk which may look disorganised to casual onlookers but makes perfect sense to its occupier. Figure 4.3 shows the office of Albert Einstein, who clearly did not have a systematic way of organising all the information resources contained in it and yet was able to work extremely effectively. Indeed, such individuals are often able to find a particular document immediately when required to do so (Lansdale, 1988; Malone, 1983). The personalisation of information allows individuals to tailor these mental maps to their own requirements

(Rousseau, 2004). For the team context, however, collective models are required to allow everyone to understand where and how resources are located.

Figure 4.3: The messy desk of Albert Einstein (Time & Life Pictures)

Based on a review of common representations for the exchange of information in the engineering design process, Hicks et al. (2002) identified categories as shown in Figure 4.4. *Structure* is highlighted as the main differentiator between *informal* and *formal* information. This means that formal information is more likely to be organised in hierarchies or similar structures and have additional contextual information associated with it. These elements tend to shift information items into the realm of knowledge items, making them more re-usable in different design settings. This can be particularly important in an educational context when designer students are learning when and how to apply new knowledge, but in industry the time required for adequate capture and organisation can make such approaches unappealing. This is particularly applicable to conceptual design when teams are often working intensely and in informal ways.

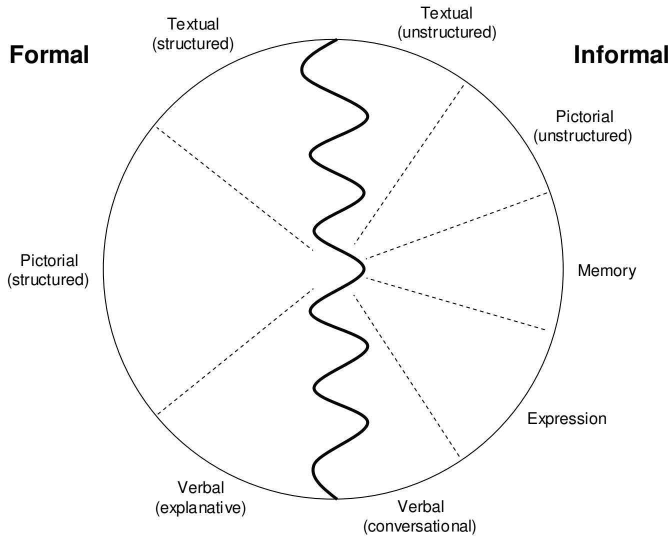

Figure 4.4: Classes of formal and informal information (after Hicks et al.)

The role of concept sketches as a focus for concept design provides a unique format for team members to communicate their thoughts and ideas. This is supported, however, by a number of other media, verbal communication and social structures that allow the team to work together effectively. This means that when one of these elements is inhibited (for example when a member of the design team is not comfortable sketching, or when someone is embarrassed about participating verbally in a brainstorming session) steps can be taken to overcome the problem (for example, by allocating more time to sketch, or taking turns to suggest ideas).

When teams are distributed, communication issues become even more critical and difficult to solve, as many of these channels are inhibited. The nuances of language and gesture used to fully express meaning, for example, are often lost across lower resolution webcam and videoconference technology. In highlighting the problems faced by virtual teams, Gibson and Cohen (2003) identify broad categories of information management for design projects (Figure 4.5), distinguishing information *unique* to the individual and *common* to the team. They emphasise the particular importance of maintaining high levels of *social* and *contextual* information in situations where teams are distributed. While it is important to recognise the significance of these categories, this research is focussed on enhancing the level of use of *task* information during concept design. The structures of access and use of this category of information, and any prescribed mechanics of interaction to optimise these, will inevitably inform the way the team subsequently communicates. It is necessary, then, to first consider the information elements being utilised in the design activity.

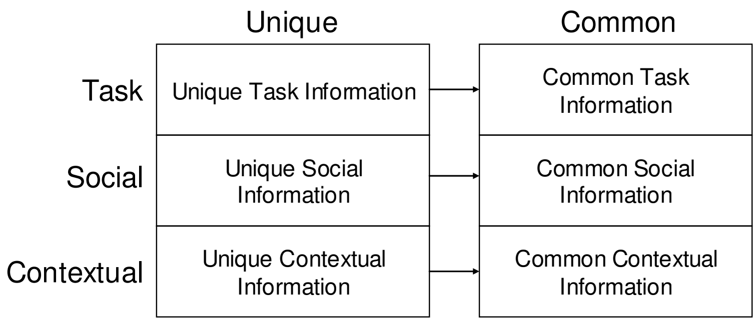

Figure 4.5: Information management for virtual teams

4.3 Information in the design process

The volume of information that is generated and managed through the product development process is significant. Different types of information are prevalent at different stages, and Table 4.1, developed from work by Ion et al. (2004) sets out some examples of information typically generated and sourced through the stages outlined by Ulrich and Eppinger's process. The Concept Development stage aligns most closely to the work addressed in this research but there is significant overlap between these categories, and in the development of new concepts it can be expected that significant amounts of information in the stages from Planning through to Detailed Design could reasonably be expected to be utilised.

Design Stage	Examples of information generated	Examples of information sourced
Planning	PDS/ briefing documents, project plan, meeting notes and general communications	market data, company reports
Concept development	brainstorming notes/sketches, sketches, drawings, rough calculations, meeting notes and general communications	competitor and related products, previous design schemes
System level design	sketches, drawings, rough mock-ups and physical models, cost evaluation calculations, meeting notes and general communications	patents, previous design schemes
Detail Design	detailed drawings and design calculations, final costing calculations, 3D solid models, mathematical and numerical models, meeting notes and general communications	textbooks, catalogues, suppliers' data
Testing and refinement	experimental data, manufacturing drawings, bills of materials, test specifications, assembly methods	standards, databases

Production ramp-up	sales presentations, demonstrations, photographs, product instructions, presentation graphics	customer feedback, retail data

Table 4.1: Information and the design process (after Ion et al.)

4.3.1 Information taxonomies

Vincenti's approach to categorising design information in *'What Engineers Know and How They Know It'* (1990) is built on case studies from the aeronautical industry. His categorisation scheme has been shown to be popular with practicing engineers (Broens & de Vries, 2003). It identifies six categories of knowledge: *fundamental design concepts* (operational principles and normal configurations), *criteria and specifications* (specific, quantitative objectives for a device derived from general, qualitative goals), *theoretical tools* (mathematical formulas or calculative schemes, whether grounded in nature or based on past experience), *quantitative data* (universal constants, properties of substances, physical processes, operational conditions, tolerances, factors of safety, etc), *practical considerations* (information learned mostly on the job and often possessed unconsciously, rather than in codified form) and *design instrumentalities* (procedures, ways of thinking, and judgmental skills by which the process is carried out).

Rohpohl's (1997) more theoretical approach to the classification of technical knowledge identifies four types: *technical know-how* (implicit knowledge or skills for handling technologies) *functional rules* (instructions which can be used without being understood theoretically), *structural rules* (the 'assembly and interplay of the components' of a technical system), and *technological laws* (theoretical knowledge for solving design problems), while also identifying a fifth type of knowledge as *socio-technological understanding* (knowledge of the interrelationship between technical objects, the natural environment and social practice).

A taxonomy based on the idea that the design of artefacts has to take into account their dual nature – the physical and functional – is suggested by de Vries (2005). He subsequently delineates knowledge as *physical* knowledge (e.g. knowledge of materials used), *functional* knowledge (knowledge of what it means to function as a kettle), *relationship* knowledge between the physical and functional nature (e.g. knowing that a certain material property makes a device useful for a particular function), and *processes* knowledge (in the functioning or in the making of the artefact). This holds an appeal given its practical nature and direct relevance to the engineering design activity.

In an even more plain analysis, Hubka and Eder (1988) split design knowledge into just two categories: knowledge *for* design (appropriate science and technology) and knowledge *of* or *about* design (the science of designing). Knowledge of or about design becomes more important for long-term projects in terms of helping teams navigate through the design process. For a concentrated concept design activity, however, it is likely that knowledge for the design task at hand will be more highly valued.

A summary of these taxonomies is set out in Table 4.2. The demonstrated esteem and greater granularity of Vincenti's scheme makes it an appealing choice on which to base any analysis of information use in concept design. Vincenti himself acknowledges that this list is not exhaustive and that overlap exists between categories. They do, however, tend to relate to different stages of the design process, with *fundamental design concepts* most useful in the development of new solutions (although *criteria and specification*, *quantitative data*, and *theoretical tools* can also be identified as relevant under certain circumstances). Vincenti's definition of fundamental design concepts as 'operational principles and typical structures' can be interpreted can be interpreted broadly as any self-contained, independent information source that can be utilised in used in concept design work. It is worthwhile considering, then, the composition of concept design information specifically.

Vincenti	Rohpohl	De Vries	Hubka & Eder
Criteria and specifications	Socio-technological understanding	Functional	For
Quantitative data	Technical know-how	Physical	About
Practical considerations	Functional rules	Relationship	
Fundamental design concepts	Structural rules	Process	
Theoretical tools	Technological laws		
Design instrumentalities			

Table 4.2: Taxonomies for engineering design

4.4 Concept design information

Court et al.'s (1996) work on Information Access Diagrams suggests that designers prefer to follow well established, reliable information paths, and observes that when undertaking new designs, colleagues, drawings and catalogues were preferred sources of information. Similarly, Chuang and Chen (2008) contend that in creating and developing new concepts, visual sources such as images, sketches, models and competitor products are typically used. These types of visual information have been shown to outperform textual sources in studies of idea generation in both the absorption and composition of ideas primarily due to conciseness (McKoy, Vargas-Hernández, Summers, & Shah, 2001). A great deal of information can be encapsulated within a single item, for example a concept sketch could contain information on material properties, function, aesthetics and so on. Indeed, the notion of concept sketches as 'gestalts' has been mooted (Kulkarni, et al., 2001), suggesting that designers can 'read off' a sketch more than was initially invested in its creation. Smith et al. (2008) make further suggestions regarding the effect of the quality of material presented, concluding from studies that exposure to commonplace ideas resulted in unoriginal designs, but seeing novel ideas resulted in more original designs. A number of specific taxonomies to address concept-related information have been developed, and these are reviewed below.

4.4.1 Concept taxonomies

In developing a classification system for design concepts that is understandable for human beings and can be utilised in computational programming, Horváth et al. (1998) developed an ontology (broader than a taxonomy in that it has 'an intentional semantic structure that defines and arranges all related notions') that includes *entities* (a set of objects), *situations* (a specific arrangement) and *phenomena* (a set of physical effects), with these combining to form a particular *behaviour*. The objective of this systematic approach is to develop a clear definition of concepts relating to a particular application, formalise relationships between them based on their categorisation, and convert these into alternative designs.

Muller and Pasman (1996) describe a model for extracting design knowledge from existing concepts, with the purpose of using it to structure an image database to support concept design. They suggest a typology (a typology focuses on idealisation through 'abstraction and classification of precedents') of *proto-typical* (use) features, *solution-typical* (form) features and *behavioural-typical* (use) features. Possible overlap or issues with categorisation are viewed as having possible positive effect with respect to increasing the 'bandwidth' or range of possibilities for a certain feature when undertaking conceptual design work.

Similarly, Benami and Jin's (2002) studies on cognitive processes suggest that ambiguous entities provide a greater level of stimulation in creative design work than non-ambiguous entities. Derived from the *function-behaviour-structure* model suggested by Gero and McNeill (1998) in their analysis of design protocols, they classify stimuli into four categories - *behaviour, form, function* and *knowledge* - and found that for a group concept design session behaviour stimuli, which were the most ambiguous, led to the generation of most ideas. Considered to all fall inside Vincenti's *fundamental design concepts*, a summary of these taxonomies is shown in Table 4.3.

Horváth et al.	**Muller & Pasman**	**Benami & Jin**
Entities	Proto-typical	Function
Situations	Solution-typical	Form
Phenomena	Behavioural-typical	Behaviour
Behaviour		Knowledge

Table 4.3: Taxonomies for concept design

4.4.2 Concept design stimuli

Given that the interpretation of resources during the creative task can be so unpredictable (a sketch may contain information on form, function, behaviour or any combination; a competitor product may provide reference or stimuli with regards to any number of its characteristics) a more practical approach to the identification of stimuli was deemed necessary. Rather than attempting multiple interpretations of concept content, describing information based on its relative location in the physical (person, team, world) or contextual (same, similar or dissimilar) sense were identified as established and useful approaches.

Shedroff (1999), whose overview of information was adapted at the start of this chapter for context, describes information as being *global*, *local* and *personal*. Information at the global level is liable to be unstructured and without context – akin to data. Local information come from the problem domain and is therefore more likely to have direct relevance. Personal information is the knowledge contained within individuals that must be externalised and shared with other team members. This categorisation scheme is typical for information and knowledge management in general.

In developing an approach to the management of creative stimuli specifically, Howard (2008) proposes a matrix based on the source of information: whether it was *internal* or *external* (to the industrial domain) and *random* or *guided* (in how specific the retrieval mechanism was to the task) as differentiators. Howard additionally emphasises the effectiveness of *guided*, *internal* resources in concept design, showing that designers generally prefer the higher levels of relevance of these sources and demonstrating that they lead to more ideas per stimulus than more abstract or distant analogical resources.

Alongside their formal taxonomy described above, Benami and Jin (2002) additionally delineate *short distance* (closely related) and *long distance* (distantly related) analogies, recommending that stimuli should be 'meaningful, relevant, and ambiguous' for optimal design performance.

Finally, Ulrich and Eppinger (1995) whose process was identified as an important point of reference for this work in Chapter 3, categorise conceptual design methods as *internal* and *external* to the design team. Methods that are internal utilise knowledge and information contained within the team, while external methods rely on past projects, design theory and other sources to inform the process. The fact they choose to categorise concept design methods along these lines illustrates the fundamental importance of the location of stimuli when used in concept design.

The various schema have been above have been compared as set out in Table 4.4, and rationalised as an adapted scheme with distinct categories. This adapted scheme delineates information as *personal* to individuals in the team, *directly related* to the industry or problem domain, and *indirectly related* in the form of other globally available information sources.

Shedroff	Howard	Benami & Jin	Ulrich & Eppinger	Adapted
Personal	n/a	n/a	Internal (to team)	Personal
Local	Internal (to domain)	Short distance	External (to team)	Direct
Global	External (to domain)	Long distance		Indirect

Table 4.4: Taxonomies for concept design stimuli

4.4.3 Application to the design context

When considering the industrial context outlined in Chapter 1, and IDEO's use of the Techbox described at the start of this chapter, typical design teams undertaking informal brainstorming-type activity often have access to competitor products or examples from previous projects. These quick-to-access and easy-to-use types of resources typically fall under Vincenti's (1990) fundamental concepts category in that they are self-contained entities describing operation, configuration and structure. Despite its potentially confusing terminology (internal and external could easily refer to individual as well as domain) Howard's (2008) work in identifying guided, internal (direct) sources as most effective for concept design is considered highly appropriate and illustrative of the appropriate level of practicality. In focussed, progressive concept design work, the resources principally used are chosen selectively, not randomly, and relate to the specific design task rather than relying on high-level analogy. While a proportion of indirect stimuli may also be appropriate to encourage more radical ideas, the presence of comprehensive direct stimuli is of primary relevance in ensuring that the team has the requisite knowledge and expertise at their disposal to reach feasible and adequately detailed solutions. This does not necessarily preclude the possibility of diverse and imaginative design solutions. With fundamental, guided, and direct information sources identified then as the most relevant to the design context, the research moved on to examine how these are actually utilised and the effect they have on design team interaction.

4.5 Study on design team information use

In order to better discern the use of information by a design team, a pair of controlled concept design sessions were designed based on the configuration shown in Figure 4.6. The three elements of concept design – analysis, synthesis and evaluation – described in Chapter 3 were used to broadly structure the design task, in which two groups were asked to develop design concepts. Both sessions used an identical design brief, but only one had access to information resources. The team interaction for both sessions was analysed by means of protocol analysis. This approach was deemed more appropriate than simply reviewing the design output (i.e. the concepts produced) as in this exploratory phase of research it provided a richer understanding of team behaviour. A briefing document with various requirements was provided which assumed the role of the PDS (the full briefing document can be found in Appendix I). The aim of this initial study can therefore be summarised as: *to understand how the introduction of information resources affects the concept generation process for a group of engineering designers.*

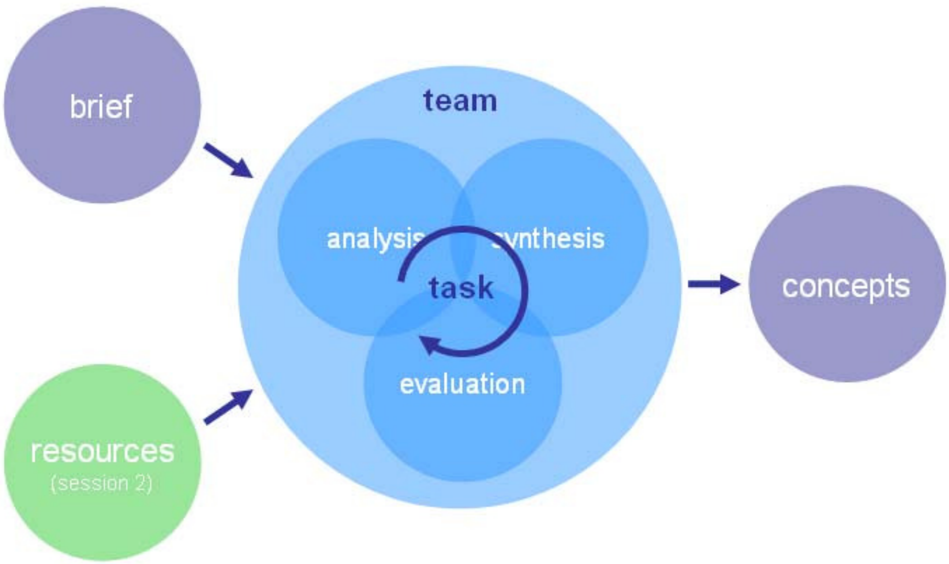

Figure 4.6: Integrating people and information in the concept design task

4.5.1 Structure

A pool of ten PG students and research staff with an engineering background were randomly formed into two teams, with one person in each team acting as a chairperson. The project brief was to develop concepts for a coffee cup holder, addressing the problem of transporting multiple coffee cups from the coffee shop to the office with a safe, easy-to-use and reusable product.

The teams were each given 30 minutes to assimilate the brief, develop concepts and identify one for further development. The two sessions were videotaped with a pair of cameras: one was positioned to capture the general conversation including body language and other conversational idiosyncrasies, the other mounted overhead and focused on the table to monitor sketching activity. The team in Session 2 had access to a range of resources, while the team in Session 1 had access only to the briefing document. Using the taxonomies above, these are all *fundamental* design concepts (after Vincenti) in that they are concerned with operation, configuration and structure, and *guided*, *direct* resources (after Howard) in that they are sourced from directly relevant industrial applications and relate to the specific design task.

Although the sessions were not formally structured, it was outlined that teams were expected to review the design brief, generate and develop concepts, and identify one for further development, with the chairperson taking responsibility for moving them through this process in good time. The sessions took place around a table with the chairperson at the head, as shown in Figure 4.7. The chairperson retained the copy of the briefing document and all other participants were issued with paper and drawing utensils.

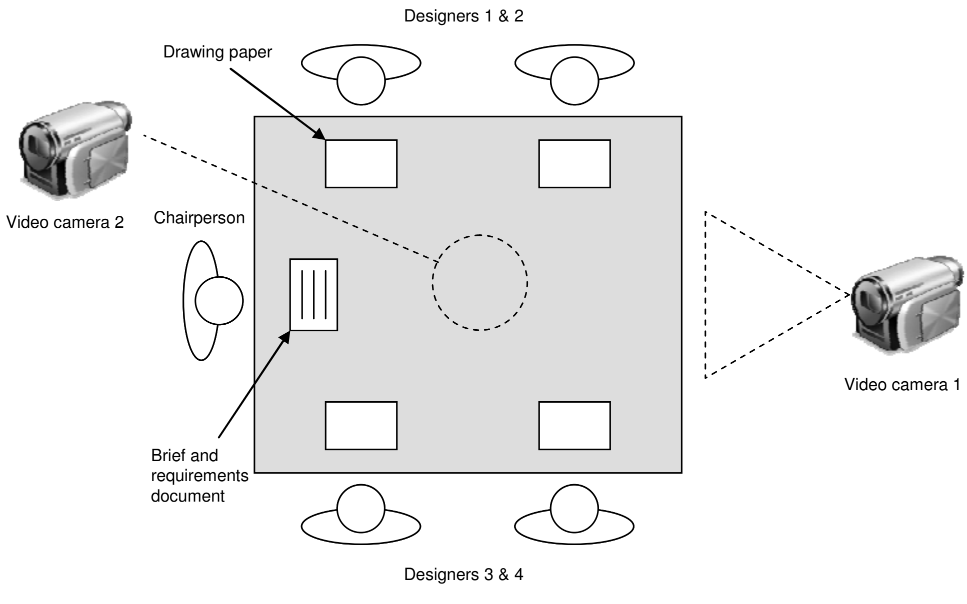

Figure 4.7: Physical layout of the concept design sessions

4.5.2 Protocol analysis

Protocol analysis involves recording and transcribing an event and categorising the resulting interactions using a designated schema. In this instance, a combination of the Transcript Coding Scheme (TCS) proposed by Huet (2006) and Badke-Schaub's Critical Situation Analysis (CSA) (2002; 1997) was used to frame and analyse the results. Huet has previously used the TCS in conjunction with the analysis of design reviews for Boeing to better understand how information is managed. Although the full coding scheme as described by Huet was used in the initial analysis, it emerged that Intervention Type (what kind of activity was happening) and Primary Media (what resources were being used) were the main elements of interest.

Much discussion during informal meetings can be classed as 'noise', when participants are chatting or moving off-topic. It was therefore deemed appropriate to identify at which points in the session there were important interactions taking place. Badke-Schaub's CSA was developed to simplify the documentation of design work to *routine* and *critical*, where critical situations are defined as ones where the design process 'takes a new direction on a conceptual or embodiment design level'. It consists of five variations: Goal-analysis and goal-decisions; Information and solution search; Analysis of solutions and decision-making; Disturbance-management; Conflict-management. The identification of critical situations is a three step process: the situations are identified, categorised, and then analysed for decision points and outcomes. This third step was not utilised in the analysis of this data, as the situations were being used only to highlight the important passages of design work. This then allowed the correlation of critical situations to the transcribed TCS results.

A sample of the documentation and analysis of a session is shown in Figure 4.8. This illustrates, from the left, the *identity* of the person contributing, a *transcription* of what was said, the *time* in the session when the contribution was made. The next five columns consist of elements of Huet's coding scheme, beginning with the *intervention type* (i.e. whether it was a statement, question, feeling etc.), the *exchange role* of this statement (whether it was for the purposes of informing, exploring, resolving problems, managing etc.), the *information type* (whether it was product, process or externally related), and the *media type* utilised in the exchange (encompassing gesture, speech, text and drawing as well as the utilisation of additional resources as described). Full transcripts and analysis can be found in Appendix I.

Meeting transcript — Huet's coding scheme — Badke-Schaub's situation mapping

ID	Transcript	Time	Type	Role	IT	Media	Item	Crit. Sit.
RZ	It also mentions that temperature must be maintained…which which is something these things wouldn't do they just help you carry it so that's quite an added an added feature…because these things help maintain the temperature and keep your fingers cool so that's like a dual purpose thing	09:24	S					
FG	Yeh yeh	09:27	S		RES	A2/B3		1
CS	Yeh	09:28	S					
[CS]	[Audio not clear	09:31	-					
CS	Yeh	09:36	S					
FG	Yeh	09:41	S					
CS	Yep	09:44	S	DEB				
	In in the reason why I've got my own coffee cup is because when i went to america about 10 15 year ago I got a Baskin's robin one and it was insulated and i thought would i bring that here and came home and got nicked and displaced or whatever and had to go and buy a new one out of ASDA…so that kind of idea brand loyalty and things	09:45	S		PROD	S	1	
CS	Uh huh	09:52	S					
CS	So you took your own cup so that the coffee stays hot	10:03	Q					
FG	Yes	10:06	A					
CS	Ok	10:07	S					
FG	Well in the morning I make em, fill it up its not one like that	10:07	S					
CS	Oh I see right		S					
RZ	You get one of these I think these quite chunky things almost like thermo they've got a lid on so that they keep it warm big	10:11	S	EXP	RES	A1		

Figure 4.8: Sample of Session 2 transcript analysis using Huet's coding scheme and Badke-Schaub's situation mapping

4.5.3 Experimental variables

The main independent experimental variable was access to design stimuli. In Session 1, the team only had access to the briefing document, which contained a set of design requirements. In Session 2, the team was given access to a total of twelve additional resources as well as the briefing document. These additional resources included existing products, coffee paraphernalia and design ideas in both model and sketch form: three coffee cups of different sizes; three existing coffee cup holders; three concept sketches for new holder designs; and three concept models for new holders.

4.5.3.1 Dependent variables

The primary dependent variable measured to discern the effect of introducing information resources to the concept design sessions was the profile of interactions, as indicated by the TCS and the CSA analyses. In addition, the instances of use of both the resources and the briefing document, and their correlation with the TCS and CSA profiles were of particular interest in helping to reveal the type of contributions by individuals and the internal dynamics of each team. Although the number of concepts produced was monitored, the quality of design output was not closely scrutinised, the workings of the design team being the main focus.

4.5.3.2 Controlled variables

Apart from the introduction of resources, the logistics of both sessions in terms of environment, duration and briefing were identical. The fact that two different groups of participants were used introduced a fundamental variation in terms of team personality and dynamics. It may have been useful for each team to have completed a 'marker' project for which their average output or similar could have been measured. By profiling the individual team members in the results, however, it was possible to develop a general sense of team performance. Additionally, the fact that a chairperson was assigned to each session assisted in ensuring that the team completed the work in good time and provided a measure of equalisation across the sessions.

4.5.4 Results

An equal number of design concepts were produced in each session (Session 1 – 10, Session 2 – 10) although as previously indicated the protocol analyses rather than the design output of the sessions were the focus of study. Figure 4.9 shows a sample of the tabulated results from Session 2 (the complete version can be found in Appendix I), with the transcribed conversations removed for reasons of space. The bottom row of the table shows the different participants who were speaking at a particular point during the session, with time elapsed shown above going from left to right. The exchange role is on the next row, with instances of the 'exploration' (EXP) role highlighted. These were identified as consisting of the synthesis and development of new ideas most closely associated with creative concept design work. The next row shows the media used in each exchange, with instances where the briefing document (T) or a provided resource (A, B, C, D) have been utilised highlighted. Finally, the top row shows different critical situations. Instances of critical situation type 2, (information and solution search) have been highlighted. In Session 2 the team had additional access to resources. The transcription analysis for Session 1 was identical.

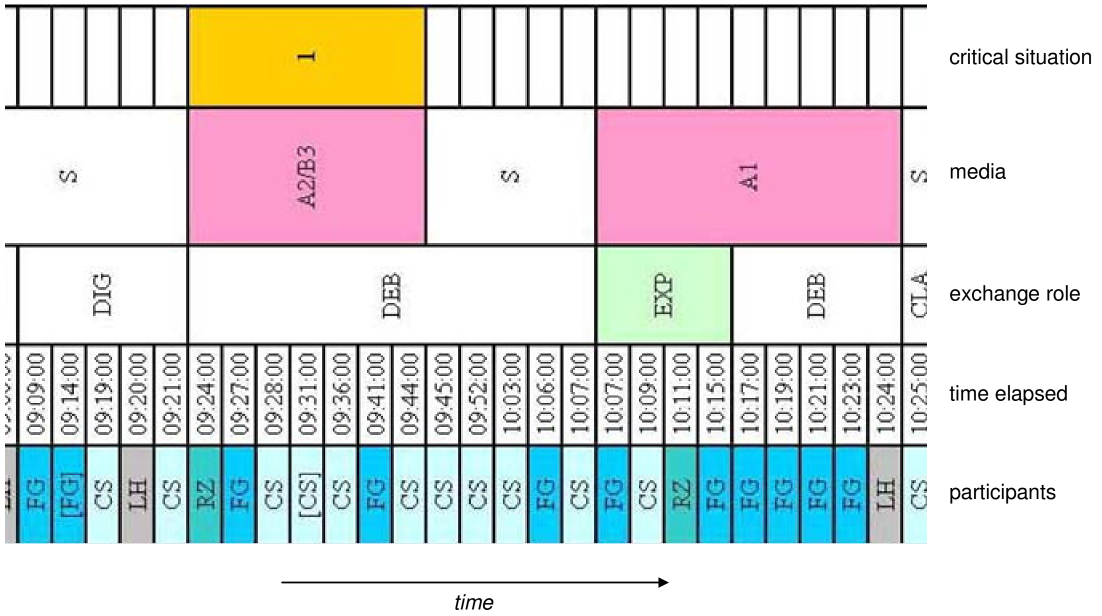

Figure 4.9: Sample of Session 2 analysis with relevant exchange roles, media and critical situations highlighted

4.5.4.1 Exchange role

Figure 4.10 illustrates the variation in types of interaction by session. In Session 1 it was noted that the discussion was fairly fractured, with a relatively high proportion formed by informing (INF), managing (MAN), and clarification (CLA) interactions. The majority of the exploring interactions were noted to occur during the middle passage of the session when ideas were being created, with another cluster towards the end when development of the final concept was taking place.

In Session 2, a greater proportion of the exchanges were made up of debating (DEB) and exploring interactions, and it was observed that the participants engaged in more lively anecdotal conversation than in Session 1. It was notable that an early period of exploration took place immediately after the use of resources, when the team were familiarising themselves with the problem. Additionally, the exploration and debating interactions were often supported by the props that were provided.

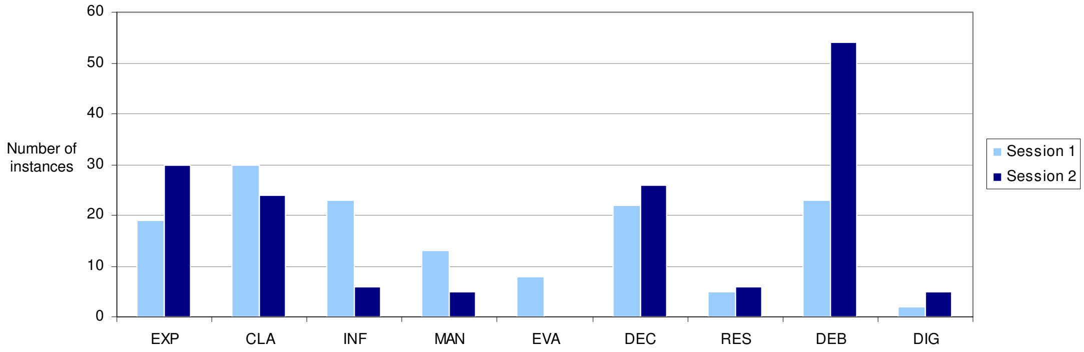

Figure 4.10: Types of interaction by session

4.5.4.2 Critical situations

Figure 4.11 illustrates the variation in critical situations by session. There were twenty critical situations identified in Session 1. Of these, four were related to goal-analysis, seven to information search and nine to analysis and decision making.

There were 36 critical situations identified in Session 2. Of these, 13 were related to goal-analysis (type 1), 12 to information and solution search (type 2) and 11 to analysis of solutions (type 3). The information and solution searches, which were of primary interest, were concentrated in the middle phase of the session. Again, there was evidence of a correlation between the use of resources and critical situations – use of resources often precluded or coincided with the emergence of critical situations during the session.

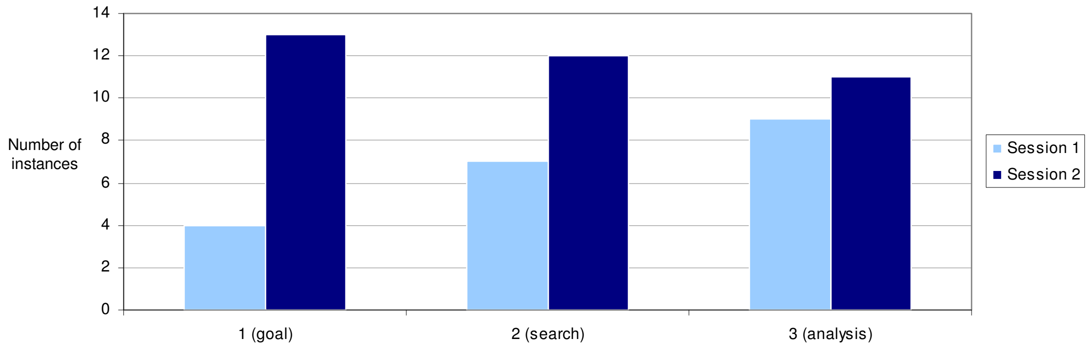

Figure 4.11: Critical situations by session

4.5.4.3 Use of media

Figure 4.12 illustrates the variation in use of media by session. In Session 1, the brief was the only resource available to the team and it was used repeatedly – on 30 occasions. Initially team seemed more comfortable having something to 'talk around' as they tried to reach as shared understanding of the design problem. It was also used frequently towards the end of the session when design decisions and choices were being made, to ensure these were in line with the given requirements. As ideas were being developed in more detail in the latter stages of the session, the brief was referred to in parallel with design exploration.

In Session 2 the resources other than the brief were used 42 times during the course of the session. Instances of use are particularly prevalent in the early and middle passages of the session. In the early phase, although a level of familiarisation was still taking place, the resources provided a forum in which to discuss thoughts and experiences of similar products – for example, people began to discuss frustrations with coffee cup designs and atypical use of coffee cup holders. In the middle phase, when the team was in a more exploratory role, the resources were used as props to compare and contrast concepts. The team referred to the brief and requirements document 9 times during Session 2. At times, certain words proved triggers for the team as they debated and clarified what they meant. These tended to lead to critical situations where there was an agreement on terminology or design direction.

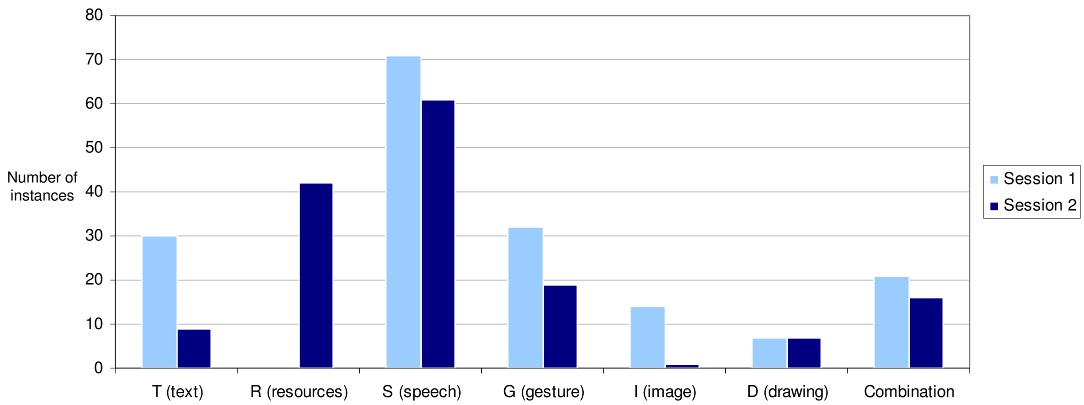

Figure 4.12: Use of media by session

4.5.4.4 Contribution of participants

Figure 4.13 illustrates the variation in contribution of participants by session. Although the composition of the groups was random, there was a very similar profile in both sessions. In both cases there was a dominant member who contributed more than the others (Session 1 – 37%, Session 2 – 37%) and a secondary contributor who also contributed above average (Session 1 – 25%, Session 2 – 29%) with the rest of the contributions being spread fairly evenly between the remaining participants (9-15%). The chairperson in both session was similar in contribution (Session 1 – 10%, Session 2 – 12%).

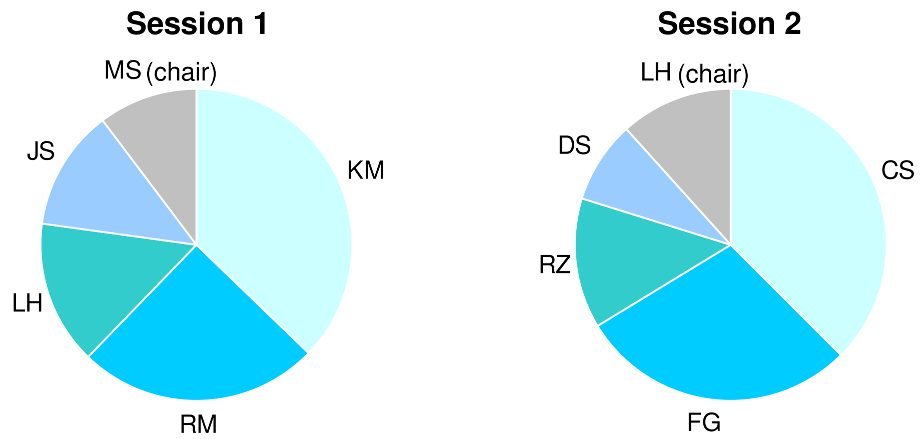

Figure 4.13: Contribution of participants by session

4.5.5 Analysis

The actual output in terms of design concepts was not used as a close indicator of the productivity of the sessions, and as it transpired the limited output would have made any inference on the quality of discussions difficult. This partly reflected in the fact that the teams were asked to arrive at a chosen design in a short space of time – a more open briefing document may have provided more variation and a greater volume of output. However, the purpose of using the protocol analysis was to reveal patterns in the information use of the team. An overview of the interaction types, critical situations and media uses, and the relationships between them, has allowed a more qualitative interpretation of how the sessions progressed.

4.5.5.1 Session 1

During the key exploratory passages, there was very little evidence of the brief being used in the team interactions. It was referred to intermittently throughout the session, but the instances of use correlated more closely to the start of the session when the team were trying to reach a shared understanding of the problem, and later in the session when they were attempting to evaluate the concepts they had developed. As an initial document to start discussion, the brief was useful as ‘warming up’ tool, and it is conceivable that it could be formally integrated into the early stages of such as session as a form of ice-breaker exercise – for example, having everyone discuss their past product experiences relating to specific requirements. It did not, however, particularly lead to or stimulate creative activity.

4.5.5.2 Session 2

For the majority of the creative passages in this session, the resources provided were used immediately prior to or during the interaction as a means to stimulate and support discussion. This suggests that the use of resources were an important factor when the team were generating and developing new concepts and was particularly apparent in the middle phase of the session, when a lot of resources were successively used and an extended period of critical solution searching took place. There was also a distinctive phase early in the session when the resources were used as a prop for clarification purposes in a similar way that the brief was used in Session 1. It may be that using models, sketches and products during this tentative phase of the session set a more creative tone than simply looking at requirements in a document – the overall results show that a greater amount of time was spent in the exploring mode in Session 2.

4.5.6 Discussion

The small sample size and comprehensive protocol analysis allowed a number of insights into the working patterns of the teams to be drawn. A larger number of sessions would have provided more scope for correlation of data but was not aligned with this qualitative approach. Running the sessions over a longer period of time may have allowed teams to explore ideas more fully, and assisted in the identification of underlying patterns of communication. It would not, however, necessarily have been representative of the short, intensive format of much early concept design work. In the analysis of the sessions, a number of issues have emerged relating to the themes of use of resources, use of brief and patterns of interaction, and these are reviewed below.

4.5.6.1 Resources

Although both sessions produced an equal number of concepts, the results show that Session 2 had a greater number of exploration interactions than Session 1 and it was observed that the team was more comfortable in progressing to the exploration of ideas and opinions with the aid of the resources as props and for stimuli. This indicates a higher level of performance of the team, despite the fact the discussions did not result in a greater number of concepts. In observing both sessions, it was striking how the resources provided in Session 2 created more animated discussions: on several occasions one of the resources was the trigger for someone to recall a coffee-related anecdote or a past experience related to the problem. This can be attributed as a factor in the increased exploratory activity of Session 2. The resources provided were all guided, direct sources, in line with those suggested by the literature. While these seemed appropriate for the problem context, sparking diverse but relevant discussion, the introduction of random or external stimuli may have had a different effect.

It was apparent from the observation of rapid exchanges between team members that any resources to be used as stimuli must be readily available. The focus of thoughts and ideas shifted focus quickly, and any information to support the process must be able to do the same. In this instance, the physical nature of the resources and the co-located, synchronous format of the session meant that this was not an issue, but if the teams were distributed or referring to other information sources, and especially digital resources such as the Internet, the effect on the 'flow' of the session would undoubtedly be a major problem.

Although the majority of current resources, such as those in the IDEO Tech Box discussed above, are physical there has been a massive shift in recent times to moving information into the digital arena. The benefits of this in terms of storage and access are tempered by the fact that resources are often difficult to find and in a format which is not vivid enough for the concept design team. The presentation and use of digital resources in such circumstances is therefore an area with significant potential for exploration.

4.5.6.2 Brief

A problem that the team seemed to suffer from in Session 1 was that they struggled to move beyond the requirements, using a large amount of time to debate at length the finer points of these. They eventually managed to develop a number of ideas but it was noticeable in Session 2 that when the team discussed the sketches, models and competitor products, ideas for new designs immediately started to flow. The problem of being 'limited by requirements' is one often cited by designers, but in this case the issue was the team being too focussed on what the requirements were rather than how they could be addressed. For the team in Session 2, the resources provided a means to do so by stimulating exploratory discussions.

It was also apparent in both sessions that the brief was used heavily towards the end, when the teams were attempting to analyse, evaluate and develop design concepts. Again this would be expected: it is necessary to compare the designs against the design requirements. The fact that Session 1 had a higher proportion of analysis and decision making critical situations than Session 2 (45% vs. 31%) suggests that Session 1 was generally more requirements-focussed. This is particularly apparent in the phase towards the end of Session 1 when the brief was frequently revisited. Despite this, in both sessions pockets of exploration continued to take place during predominantly analysis-related phases, highlighting the importance of using requirements not only in the evaluation of concepts, but also to assist with focussed and targeted development of concepts.

In Session 1 there was a tendency to revisit the brief as it was the one tangible document the team had to share, stifling their creative thinking somewhat. It did, however, prove extremely useful when teams were trying to analyse and develop their concepts in a focussed way. Therefore, it may be desirable to try and 'informalise' the PDS and introduce it to the concept exploration task in a regular and non-obtrusive manner to focus team creativity, rather than just using it to validate (or eliminate) the concepts developed. The other advantage of the brief was as a document to develop a shared understanding of the design problem and as a form of ice-breaker. It may be possible to formally integrate the brief into this critical part of a concept generation session help 'set the tone' for the remainder.

4.5.6.3 Interaction

The overall profile of interactions for both sessions shows rapid variation in the mode of exchange throughout. Although at a very high level the discussion moved from analysis to synthesis to evaluation, in terms of actual exchanges exploring, resolving, debating and evaluating happened from start to finish. This highlighted that while the discussions flowed smoothly, the participants were regularly changing their mode of thinking with apparent ease. This seems to support the suggestion that designers, when not constrained by prescribed techniques such as brainstorming, are comfortable with the 'co-evolution of problem and solution' (Cross, 2004).

In both sessions there was a markedly similar pattern of contribution by individuals across the team. Far from being even, the most vocal individuals contributed significantly more exchanges than the quietest. In a randomly selected group such as those used in these sessions, there are always likely to be quieter and more dominant personalities. It was also apparent, however, that there was no clear correlation between the number of times someone contributed and the number of ideas they actually produced. The quietest member of Session 2 and second quietest of Session 1 both produced a significant number of concepts.

Additionally, it was observed that on occasion a participant might 'break off' from the conversation in order to sketch or develop an idea they had. They would then re-engage with the group and discuss what they had been thinking in the intervening period. Whether the idea they had was sparked by the preceding discussion or was something which just 'came' to them is unclear, but studies have shown the value sketches to support design thinking (Schutze, Sachse, & Romer, 2003) and there is little doubt that a mixture of the two modes of working is desirable.

4.5.7 Conclusions of study

The stated aim of this preliminary study was: *to understand how the introduction of information resources affects the concept generation process for a group of engineering designers.* The use of protocol analysis was successful in allowing different types of interaction to be identified and nuances in behaviour of individuals to be discerned. Although the studies had a number of limitations – no strong conclusions could be drawn on design output, only two teams were examined, the sessions were of limited duration, the participants were not necessarily representative of experienced designers – it was nevertheless possible to make a number of inferences on how access to resources affected team interaction.

The introduction of information resources led to more exploratory activity. Using existing information and products proved an effective means to share thoughts and experiences. In both sessions, the rapidity with which individuals moved between types of exchange (from informing, to exploring, to debating etc) was striking. There was no period where one mode of exchange was consistently used, despite the fixed aims of the session. Although the overall patterns of interaction were inconclusive, the access to the resources provided in Session 2 also saw more exploratory discussion and debate. The resources provided were of a preselected, practical and immediate (physical) nature. If design teams in complex product development contexts are to effectively utilise the vast information resources at their disposal, careful consideration must be given as to how these can be accessed and shared by the team in a rapid and informal way that allows the shift of interaction modes described at the end of Chapter 3 (3.4.1, p.46).

As a particular type of information resource, the project brief was used primarily for analytical and evaluative, rather than exploratory, interactions. The teams tended to enter more creative design discussions when they did not refer to the project brief. It performed a valuable function in the early stages of the session as an icebreaker and focus for discussion, but use at inopportune moments acted as an inhibitor to concept exploration. As a fundamental information source, careful consideration is necessary as to how the briefing documentation can be framed to set the correct tone for the concept design session, and how it can be utilised to focus the topics of discussion without reducing the opportunity for creative thinking.

The number of interventions varied greatly between individuals for both sessions. It was found that there was a similar contribution profile for the sessions, consisting of a primary and secondary member dominating discussion – though these were not necessarily the participants with the greatest number of ideas. Structuring the team interaction in such a way to ensure contribution is as even as possible, without forcing individuals to work in a way which is uncomfortable to them, would seem to be preferential for such scenarios. Also, mixing individual and team modes of working within an information-rich framework provides an ideal opportunity to utilise the recognised benefits of each of these modes.

4.6 Summary

This chapter has highlighted the importance of information to the concept design process. A number of taxonomies have been reviewed, with a categorisation based on location suggested as most appropriate for identifying relevant design information. A study was subsequently conducted to better understand the effect access to guided, direct resources has on concept design activity. This indicated increased exploratory activity and rapids shifts in modes of interaction. While the results suggest that access to information has tangible benefits, in contemporary product development digital media is central to the delivery of information. The potential benefits are considerable, with vast amounts of information continuing to be made instantly accessible through the Internet and other digital resources, and rapid advances in communication support available through software and hardware. They are, however, less tangible than the resources utilised in the studies described in this chapter and introduce a new set of issues in terms of access and use. The following chapter therefore explores how digital resources and communication tools can be configured to best support concept design and integrate with the methods described.

Chapter 5 Digital support

The previous chapter explored the benefits of information use in concept design and the effect of access to physical resources on design team activity. This chapter focuses on the digitisation of such information to create more possibilities in its effective capture, storage and use in contemporary industry. Digital libraries and groupware are explored as relevant literature areas, and an argument for better integration of these two technologies to support the creative nature of concept generation is presented. The development of the LauLima learning environment and digital library is consequently outlined, and the results of a class study where it was used by a student cohort in a design project presented. Despite its attempts to integrate the designers' digital resources and working space, continuing issues with utilisation are highlighted. New models of interaction to increase information use are therefore suggested.

5.1 Background

The rapid evolution of IT has in recent times enabled us to move beyond the limitations of paper records in the management of complex data sets and to enable the co-ordination of large teams on a scale that was previously impossible (Liu & Xu, 2001). The digitisation of information associated with product development has numerous advantages: it can be conveniently accessed, revised and edited easily, stored with minimal physical overheads, and communicated instantly across distance. Even in the production of small-scale products, the management of digital information is today integral to the development process.

In the context of concept design, it has been suggested that harnessing this potential can enhance creativity (Kappel & Rubenstein, 1999) and that computer supported collaborative environments provide a promising innovation to facilitate teamwork. Progressive discourse interactions can take place as teams build on information stored and shared, allowing problems, design ideas and solutions to be constructed and promoting a deep understanding (Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2004). As advances in computer hardware and software continue apace, and with the exponential growth of the Internet meaning previously arcane information is now readily available, the challenge is to find effective approaches to presenting and using digital information.

For the purposes of supporting groups in conceptual design work it is not sufficient to simply recreate traditional library structures in digital form (Nicol, Littlejohn, & Grierson, 2005). Navigation through hierarchical lists and exacting search dialogue boxes are unsuited to the rapid exchanges of ideas during concept design and these demands are reflected in the relatively limited number of digital tools used in this design phase despite, being one of the most information-intensive and impactful during the product development cycle (Wang, et al., 2002). This chapter examines these specific challenges through the study of a digital library developed for design students, and subsequently suggests new approaches to integrating digital information use into the team concept design activity.

5.1.1 Digital tools throughout design process

Figure 5.1 shows a product development cycle using the first five of Ulrich and Eppinger's six overarching design phases and a range of digital tools used therein. The purpose of this diagram is to illustrate the range of information which is created, shared and used in the digital arena, and while it has been developed as generic overview, this is clearly only one of many ways in which the tools and process can be organised. In this case, it is based on the experience by the author working for a large technology consultancy.

The focus of the diagram is on the relationship and movement of information between the programs used in a development cycle. Rather than organisational approaches or design techniques, only the main software tool categories have been illustrated. For each of these, examples of typical industry-standard tools have been shown (e.g. Pro/ENGINEER for engineering design) but these could equally well be replaced by appropriate alternatives. The transfer of information between tools has been illustrated by 'information flows'. As the primary area of consideration in the design cycle, the Concept Development phase has been highlighted, but the integrated nature of the design process and associated information flows makes it worthwhile to provide a complete overview.

At the *Project Planning* stage, business software such as the Microsoft Office[4] suite is typically used to write briefing documents, prepare presentations and capture design requirements. These tools are used throughout the development process in co-ordinating activities and information. As well as information generated internally by the team, external sources must also be integrated. The Internet, generally accessed through search engines, provides a key information source that is utilised in initial research and as required at subsequent stages. In addition to this, information from specific tools, for example a marketing program utilised by a client, may also be included in the initial project stages.

At the *Concept Development* stage design tools are listed, consisting principally of the Adobe[5] suite. At this stage of development, most work is in the form of sketchwork or very rough models, and these programs provide support for presenting such design information. Computer Aided Industrial Design (CAID) tools have also become prevalent over the last few years, and these allow designers to quickly create CAD models which will not necessarily have accurate dimensions or details, but help to convey a concept through a convincing CAD rendering. These are more specialised and may still require work using Adobe-type tools in the development of presentation boards.

At the *System Level* and *Detail Design* stages, parametric CAD systems are typically used to create a robust 3D CAD assembly with part information that can ultimately be used for manufacture. These parts will have dimensional accuracy and be a first attempt at a final design. The parametric nature of systems such as Pro/ENGINEER[6] mean that the model can be constructed but amended if necessary as the detailed design work continues.

During *Testing and Refinement*, the information from the CAD model may be transferred to a specialist program or module, such as Pro/MECHANICA[7]. These allow various types of analyses (such as static, bucking and thermal analyses) to be carried out on the CAD model constructed. Final changes can then be made to the design based on the results of these analyses. The final information set would then go

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[4] http://office.microsoft.com (Accessed: 6th January 2010)
[5] http://www.adobe.com/products/creativesuite (Accessed 6th January 2010)
[6] http://www.ptc.com/products/proengineer (Accessed: 5th January 2010)

to the manufacture stage (not shown on diagram), but also back into drawings or documentation which can convey to the management team or client that the design satisfies all requirements.

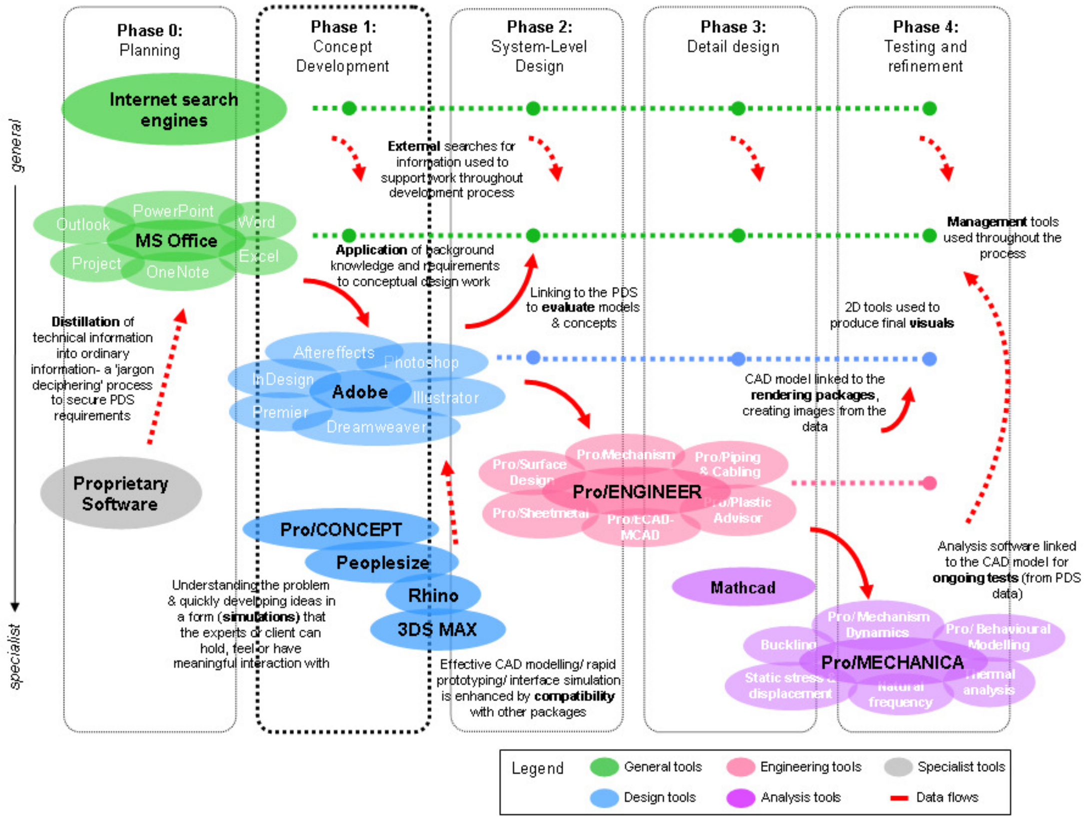

Figure 5.1: Digital tools and information flows through design process

5.2 Digital information support

The interlinked range of digital packages used in the design process have been shown to have a complex associated network of information flows. To manage these information flows, specific knowledge and tools have emerged. The two main topics identified as relevant to supporting the design process from conception to completion were Computer Supported Co-operative Work (CSCW) and Knowledge Management (KM). These have been considered in relation to concept design, with the primary technologies associated with each highlighted as shown in Figure 5.2. CSCW is concerned with the effective utilisation of computer technologies to support the way people work in groups. In this context, the use of groupware

[7] http://www.ptc.com/products/proengineer/mechanica (Accessed: 6th January 2010)

(software to help groups collaborate) is the means of collaborative access and use of information, as well as communication across a common interface. KM generally relates to the capture, organisation and storing of information in a knowledge base to enhance organisational performance. Digital libraries have been identified as the most relevant technology in this field with regards to how a collection of resources can be logistically stored in digital form and accessed by the group via computers. Each of these areas is explored in more detail in relation to concept design activity below.

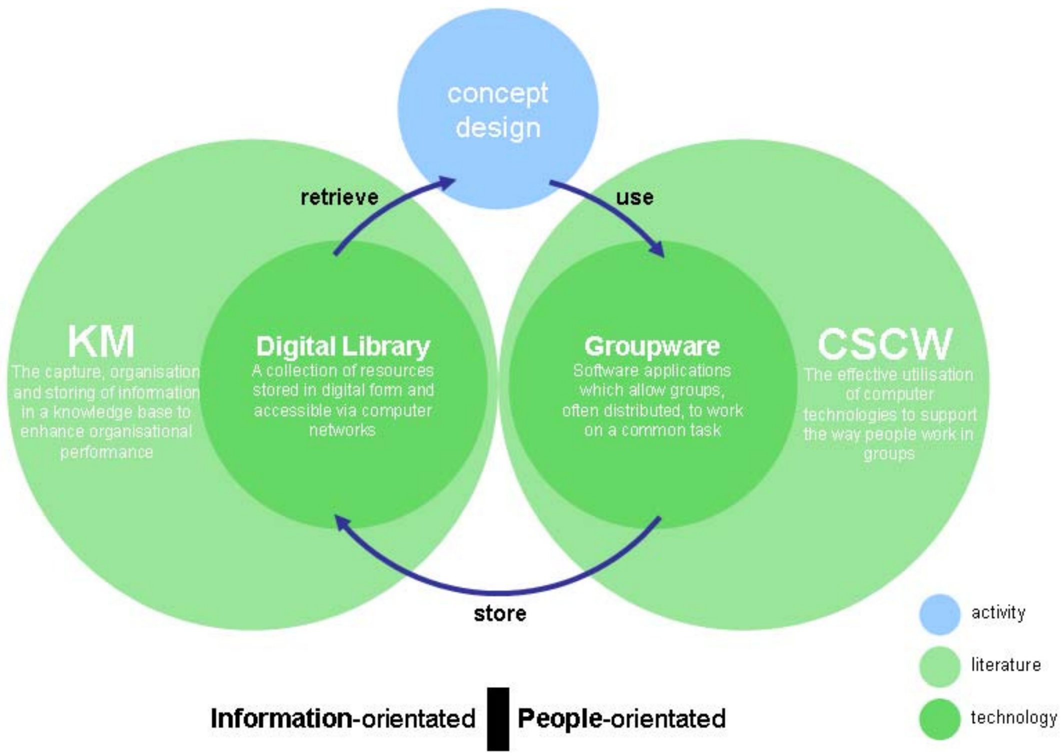

Figure 5.2: Literature relating to use of digital information in conceptual design

5.2.1 Computer Supported Co-operative Work (CSCW)

CSCW is an umbrella term encompassing all digital support for collaboration. It came to prominence with the increasing prevalence of computers in the 1980s, and despite often being concerned with issues relating to groupware it also addresses the broad psychological and social issues which drive team work and impinge on these support systems.

Using digital tools provides significant opportunities for distributed work, and the issues raised by this are a major area of investigation in the field. When teams are working remotely, as is often the case in today's global, multi-disciplinary design projects, access to an information space where teams can store, organise and share project information is even more crucial (Nicol & MacLeod, 2004). However, as illustrated in Figure 5.3, teams working across distances using computer-based communication media can often suffer from inhibited interaction (Broadbent, Cross, Rodgers, Huxor, & Caldwell, 1999; Rogers & Lea, 2005) and in concept design the loss of dynamism and rapid interaction makes brainstorming-type activity difficult to realise effectively.

Providing a technologically rich environment in this instance is therefore crucial to facilitate the multiple modes of communication used by designers, as described by projects such as the iLoft project at Stanford University (Milne & Winograd, 2003). Expressive means such as sketching, conversation and gesture are essential for designers to communicate the subtleties of their ideas in a vivid way (Žavbi & Tavčar, 2005). The vision of a completely immersive virtual environment is, however, some way off and in the meantime developing team management frameworks and approaches that take account of these limitations has been a major concern (Coates, Duffy, Whitfield, & Hills, 1999; MacGregor, 2002; Mark, 2002). The development of mechanisms of interaction for distributed design teams does not, however, preclude their use in co-located situations where access to digital media can augment the group activity. This research focuses on the interactions between the users and the digital support environment, with the assumption that any insights or approaches suggested based on co-located work have good potential for application to the distributed mode of working.

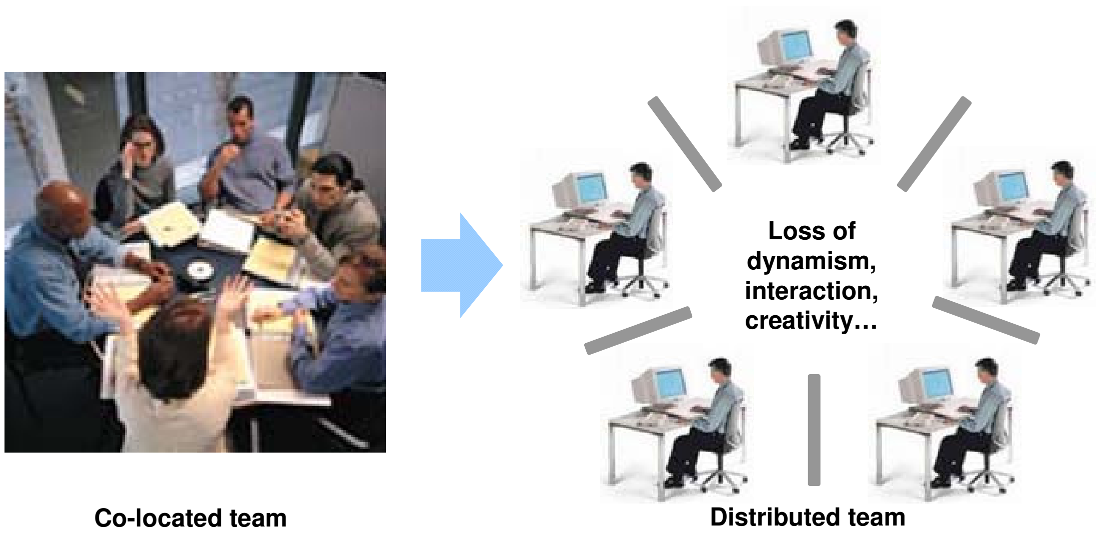

Figure 5.3: Inhibited communication in the distributed setting

5.2.1.1 Groupware

Groupware has been shown to provide a supportive environment for collaboration (Nicol & MacLeod, 2004; Sclater, Grierson, Ion, & MacGregor, 2001). This can be particularly useful in an educational setting, as highlighted by the NetPBL (Lee & Tsai, 2004) and ITCOLE (Rubens, Emans, Leinonen, Skarmeta, & Simons, 2005) systems developed to assist students in design project work. These systems often provide significant information resources to assist decision making and guidance for less experienced designers. In the industrial realm there have been similar attempts to co-ordinate information flows through the design process to improve design team performance (Broadbent, et al., 1999; J. G. Davis, et al., 2001; Kleiner, Anderl, & Grab, 2003; Roller, Eck, & Dalakakis, 2002). Document-centric systems, such as the LIRÉ system (J. G. Davis, et al., 2001) developed at Carnegie Mellon University and based on an extensive information flow analysis in order to deduce design team workflow, attempt to utilise the undoubted potential of digital information storage for quick retrieval and utilisation but do not generally address the characteristics of team interaction, particularly during specialist tasks such as concept generation.

The concept design phase has been highlighted as having a particular profile in terms of information use, communication and creativity – aspects which do not necessarily lend themselves well to digitisation with current technological limitations. There have been continuing efforts to improve the real-time immersivity of groupware (Gutwin & Greenberg, 2002; Leinonen, Jarvela, & Hakkinen, 2005). Roy and Kodkanir (2000) describe a web-based system for conceptualisation that in addition to a digital sketch input provides link to the US Classifications patent database for convenient access to idea stimuli, with communication augmented through a shared whiteboard and chat. Another approach to creating a more immersive environment is the i-LAND system (Streitz, et al., 1999) which is based on an integration of information and architectural spaces. Some groupware solutions for conceptual design, however, use rule-based structures to help control interactions between participants. This has primarily involved building electronic versions of existing concept design methods such as morphological charts (Huang & Mak, 1999), Poolwriting (Aiken, Vanjani, & Paolillo, 1996) and the KJ Method (Munemori & Nagasawa, 1996) with certain benefits such as anonymity or speed of information exchange being highlighted as advantages of working in the digital mode.

A substantial range of proprietary idea management software systems, such as Ingenuity Bank[8], Jenni[9] and Goldfire Innovator[10] are available to support companies in their innovation processes. From their genesis as electronic imitations of the traditional suggestion box, these have developed into more sophisticated systems that support the capture, documentation and evaluation of ideas in the virtual environment. Programs have begun to address the issue of information use in the development of ideas, for example Flynn et al. (2003) discuss the development of the 'Creations' tool. This addresses different types of creative thinking, and includes an 'environmental scanning' mode which encourages new information to be obtained as stimuli. However, like other tools this element of the program remains demarcated from the act of sketching, requiring the designer to shift their attention to a drawing program or paper in order to apply the information in conceptual sketchwork.

Given the wide range of variables involved in the design of groupware, four suggested principles are: *maximise personal acceptance*; *minimise requirements*; *minimise constraints*; and *external integration* (Cockburn & Jones, 1995). These

[8] http://www.ingenuitybank.com (Accessed: 5th January 2010)
[9] http://www.jpb.com/jenni (Accessed: 5th January 2010)
[10] http://www.invention-machine.com (Accessed: 5th January 2010)

would suggest that is important to make any groupware system as easy to use as possible, and with the flexibility to allow users to work in a way they are comfortable. This is in contrast with the very particular task-based approaches at times utilised during concept design, for example when generating ideas or evaluating concepts. Given this dichotomy, it is particularly important that any system or mechanism proposed to support concept design is adequate tested to verify its usefulness in a practical setting (Pinelle & Gutwin, 2000).

5.2.2 Knowledge Management (KM)

In contemporary product development innovation consists primarily of re-interpretation of existing knowledge and applying it in new ways. The few inventions that are fundamentally new are often rooted in long-term R&D programmes, with the majority of conceptual design work instead residing in incremental improvement or new configurations of existing products and technologies. KM is concerned with how the vast array of knowledge available to organisations, both internally and externally, can be captured and utilised to provide a competitive advantage. Often studies in the field relate to large organisations in the design and development of complex products (Fruchter & Demian, 2002). In these circumstances, the expertise contained in the organisation and used in the long-term development of product lines is a critical asset that must be shared and re-used effectively. Knowledge, however, is generally regarded as being contained in the individual – when it is communicated through text, drawings or other means it becomes information. Some of the major challenges in KM are therefore less about creating knowledge – indeed in this instance the creation of knowledge through concepts is an intrinsic part of the process – but more in the capture and sharing of it (Alavi & Leidner, 1999). Knowledge can also be either *explicit* or *tacit*: explicit knowledge can be conveyed through databases, books, drawings etc. (such as calculations, facts and principles), whereas tacit knowledge represents what we know but cannot easily express (such as qualities, feelings and experiences). Partly a technology issue and partly a business strategy issue, it is easy for organisations to get aspects of KM confused and attempt to solve a non-technical problem with expensive software (Tiwana, 2001). It is therefore important that there is a clear understanding of the aims and objectives of any KM an organisation uses, and a clear strategy for implementation.

KM is typically orientated around knowledge items rather than mechanisms for knowledge use – Cormican and O'Sullivan (2003), for example, describe the eProduct Manager as a tool to help manage knowledge in the innovation of new products but do not address the mechanics of using this knowledge in the concept design process. In relation to conceptual design, participants are synthesising and combining available information resources, creating new conceptual ideas, and adding rationale and context. This knowledge content will be generated and reused intensely for a short period of time as the conceptual design process progresses, and then stored to be potentially re-applied in another context during future concept design activity. Understanding what information is useful, encouraging uptake, understanding how it affects subsequent design work, and capturing the rationale used are the major challenges for KM in this setting.

5.2.2.1 Digital Libraries

Digital libraries and digital repositories relate to the specific tools used for storing and retrieving information. Throughout the design process, large amounts of data must be managed by the design team. There remain, however, usability issues associated with the key aspects of uploading, accessing and sharing of information, and integrating these into typical design activity (Bederson, 2003; Koohang & Ondracek, 2005). This is reflected in the consistently low use of existing electronic resources (Komerath and Smith, 2002), such as subject gateways (e.g. Intute[11]) which provide loosely structured web resources on a particular subject that can be followed through hyperlinks, and portals (e.g. SMETE[12]) which provide similar facilities but with additional services and often include direct searching of information items (MacLeod, 2000).

The reluctance to engage with these interfaces can partly be attributed to the way in which digital information is commonly organised. There are several formal thesauri used by the digital library community, such as Dublin Core (2009) and

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[11] http://www.intute.ac.uk (Accessed: 6th January 2010)
[12] http://www.smete.org/smete (Accessed: 6th January 2010)

Inspec (2009). These are exhaustive lists of topics, typically numbering in the hundreds, which are used as tags for items. Suitable for very large information stores, these systems rely on search terms to trace relevant material: each item is tagged with the appropriate subject terms when being entered into the library and flagged up when the user conducts a search. Entering such 'information about information' is known as metadata. While extremely valuable for retrieval purposes, the time and effort required to add quality metadata is problematic (Baker, 2007), and this is especially pertinent during the conceptual design task given the rapid nature of communication and divergent modes of thinking employed. It is therefore necessary to carefully consider appropriate ways for participants to access and use the information library so it is not an inhibitor when undertaking creative design work (Csikszentmihalyi, 1997).

5.3 Development of an integrated environment

KM and CSCW have been highlighted as the areas most relevant to the information support of conceptual design work. In each of these, digital libraries and groupware have been highlighted as the important technologies to facilitate effective use of digital information. Groupware solutions facilitate rich communication between team members who may be working in distributed and asynchronous modes. Digital libraries support the effective utilisation of information through efficient capture, storage and retrieval. It is of critical importance that any system takes cognisance of both the social and logistical aspects to ensure the effective use of information by teams. Therefore, the integration of functionality from these different fields is necessary.

This section of the thesis reviews the implementation of a digital library developed at the University of Strathclyde as part of the JISC-NSF funded 'Digital Libraries for Global Distributed Innovative Design, Education and Teamwork' (DIDET) project (University of Strathclyde, 2008) of which the author was a contributing member. A collaboration between the University of Strathclyde, Stanford University and Olin College of Engineering, and with project members from design, pedagogical, ICT and information literacy backgrounds, the project aimed to support global, team-based design projects by combining digital libraries with virtual design studios, thus addressing directly the issues of integration outlined above. The following sections, therefore, describe the architecture and subsequent implementation of the library in an academic setting, with the results used to make further inferences on how digital tools, and in particular digital libraries, can better support information use in concept design.

5.3.1 Architecture of the LauLima system

The University of Strathclyde has a history of managed design environments that encompasses several research projects (William J Ion, Thomson, & Mailer, 1999; Littlejohn & Sclater, 1999; Whittington & Sclater, 1998). In light of this experience, it was decided at the outset to develop an integrated environment which, while supportive of the informal communication that is common in conceptual design work, would provide convenient access to appropriate information in an effort to make it more integral to the process. The result was LauLima (Polynesian for ‘group of people working together’), a wiki-based system that was a customised version of the open-source TikiWiki groupware. LauLima consists of a split architecture (Figure 5.4) allowing users to save, store, organise and share information in a flexible and informal way in the LauLima Learning Environment (LLE). In addition, there is a store of formal design information to search and browse called the LauLima Digital Library (LDL), which is added to over time using the best material from the LLE. Both these systems exist within the same environment, i.e. there is an integrated user interface and access to the library is presented as merely another function of the system.

The flow of information from one domain to the other is additionally highlighted in Figure 5.4. This process involved staff selecting materials stored in the LLE by student teams, which already had some basic metadata applied (name, author, description), to an approval gallery. At this point, staff flagged content for inclusion in the LDL and added more metadata, particularly with regard to educational context, before items were finally approved (ensuring that Intellectual Property Rights (IPR) and Digital Rights Management (DRM) were properly taken into account) and migrated to the LDL. This model removed the requirement to entice end users to take the time to upload quality information items, but did put an onus on the department to provide staff resources for the migration of material from the LLE to the LDL.

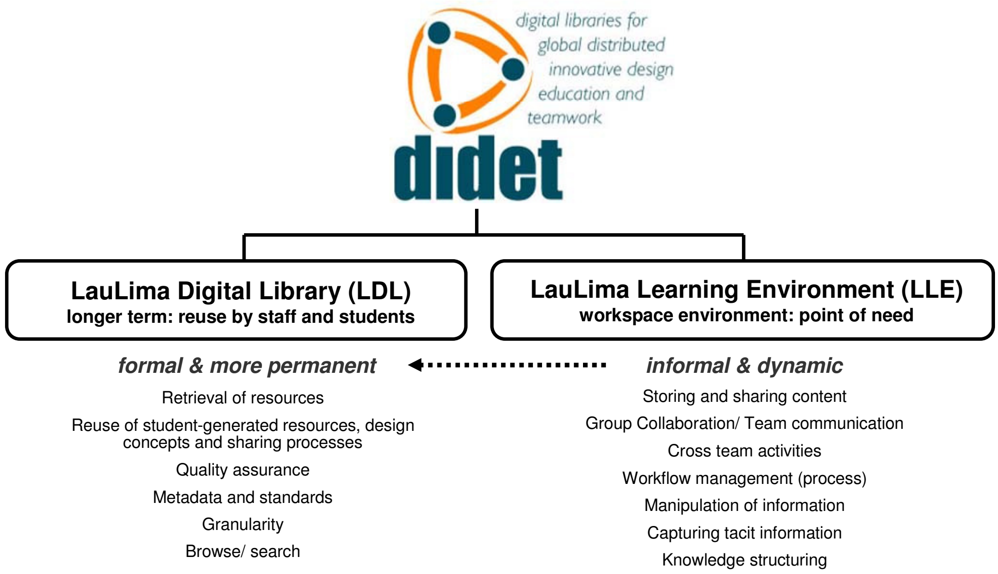

Figure 5.4: LauLima system

Design is a social activity, both in its process and application, with concept design typically taking place in studio-based environments where people exchange information and ideas in an informal manner. Strathclyde's physical working environment reflects this, with student teams encouraged to undertake design work in a space where they can get support from their peers as well as teaching staff. In recent years, there has been a significant increase in the use of laptops as tools to support group work (Figure 5.5) and this provides an ideal format to integrate the use of digital resources into the practical desktop nature of concept design activity.

The LLE was the first aspect of LauLima to be implemented, and feedback in the form of polls, questionnaires, and informal comment was positive from teams who showed a high level of utilisation (Grierson, Nicol, Littlejohn, & Wodehouse, 2004). They cited strong team management benefits from using the system, and it proved popular in terms of sharing and organising design work. The LDL was developed and introduced after the LLE was already embedded in project work. Material, primarily student generated in the form of sketches, photographs, models and reports but also some links and external resources, was gradually added and an interface developed to allow users to browse and search for resources. The remainder of this chapter addresses the issues in encouraging teams to make use of these resources during concept design work.

Figure 5.5: The informal and social studio space

5.4 Project study on digital library utilisation

Although the LDL was similar in construction to other digital libraries, it benefitted from the integration with a groupware system that was responsive to the needs of design teams. Despite the documented problems in engaging undergraduate engineering students with digital repositories (Komerath & Smith, 2002), it was hoped that this would be sufficient to ensure significant levels of utilisation. To examine in more detail the levels and patterns of information use during concept design, a study of an undergraduate design project was carried out. The students, who were using the LLE to organise their team and document their design process, were given access to the LDL to support their work.

5.4.1 Format of project

The Integrating Design Project was a 6-week project where students were working in twenty teams of four. The brief was to design a fruit squeezer for use in the domestic kitchen. Students had to search for relevant information (Phase 1), develop and select a concept (Phase 2) and prototype and evaluate it (Phase 3). Teams made use of the groupware to search, store, share and organise their information and design work, and were asked to represent the development of the product using linked wiki pages

(Figure 5.6). These wiki pages were intended to help students develop a shared understanding of their design problem and solution.

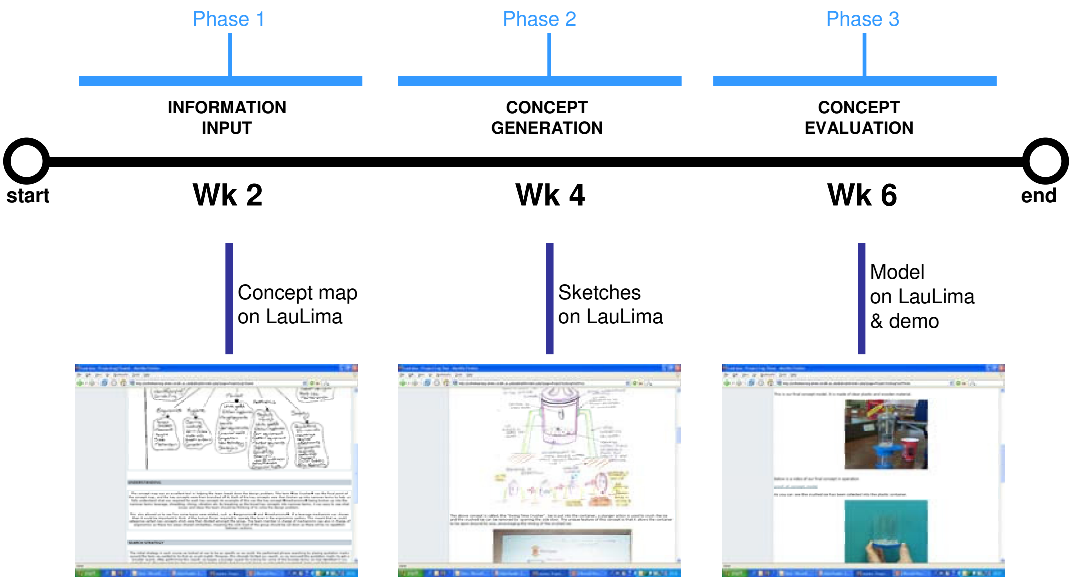

Figure 5.6: Student teams documented their work on linked wiki pages

5.4.2 Digital library

The students were given an introduction and access to the LDL. This was through the same environment they were using to share and document their design work in the LLE. When opened, the LDL is a conventional digital library in that it is based on hierarchical lists and various metadata fields to facilitate browsing and searching. Items were categorised in a number of ways allowing users to browse by Inspec and Stanford subject terms, the project the item was harvested from, the year it was added, and the resource type (content, graphical representation, textual representation, project related). When a category was selected, it was possible to browse a set of thumbnail images and accompanying metadata to give users a clear overview of content (Figure 5.7). Additionally, a search interface which included features similar to those in Google's Advanced Search functions (AND, OR and NOT, search by field etc.) allowed users to target specific information. Again, thumbnail and metadata results were displayed in results lists. When items of interest were identified, users could either view them online or download them to their computer for further perusal. There were 495 items in the library, the majority of them harvested from previous student projects relating to crushing devices (can crushers and ice crushers had been previous topics).

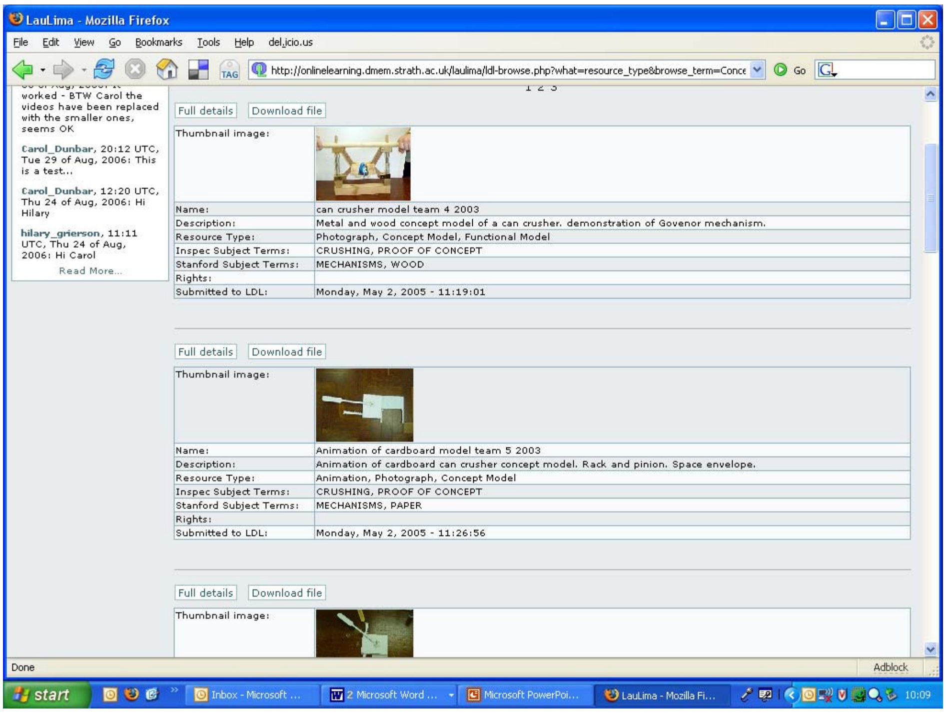

Figure 5.7: Screenshot of the LauLima digital library

5.5 Results

Throughout the project, all interactions with the digital library were logged by the system, allowing research and teaching staff to monitor activity. In addition, questionnaires were distributed to garner opinion on the usability and usefulness of the library at the end of the project. Full documentation of the data logs and questionnaire results can be found Appendix II, with the results summarised below.

5.5.1 Data logs

Throughout the project, student interactions with the digital library were logged by the system, allowing research and teaching staff to monitor search, browse and download activities in detail. Figure 5.8 illustrates the accumulated instances of each activity across all teams. There was a relatively low overall level of usage, but with considerable variance through the project. The peak of system activity was in Week 3 when information gathering was being concluded. It then dropped off as concept generation took place, and increased again towards the end of the concept development phase. The results followed the pattern of previous research (Hertzum & Pejtersen, 2000; Sonalkar, Mabogunje, Leifer, Eris, & Jung, 2007) in that a preference for browsing over searching was in evidence for the duration of the project.

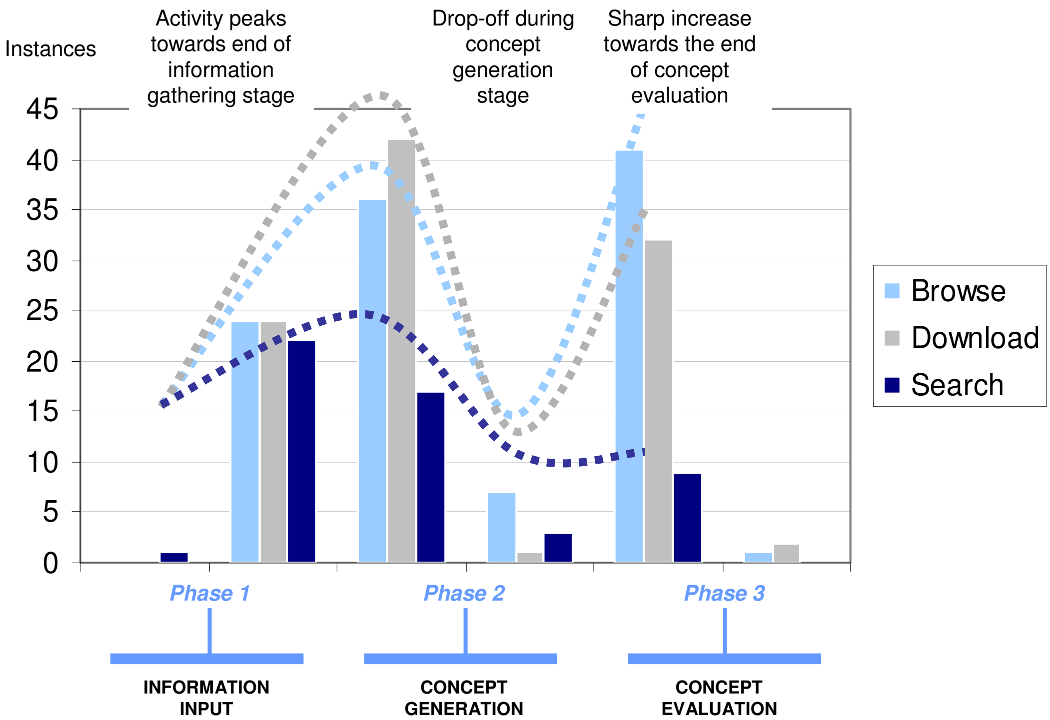

Figure 5.8: System logs for the 6-week project

5.5.2 Questionnaires

Questionnaires were distributed to garner feedback on the level usability and perceived usefulness of the library. This included factors such as preferred mode of navigation, quality of resources and ease of use.

The low level of usage by students of the digital library was reflected in the questionnaire responses. Various reasons were given, the main one being the perceived convenience of the system. 'Easier' resources were cited as being more useful and more readily available, in particular Google or other web searches. These were regarded as 'quicker to access' and 'sufficient' for the needs of the project. This was generally not reflected in the quality of material gathered by the teams in their wiki pages, which was on the whole variable, with only a couple of teams producing excellent resource repositories. Generally, feedback reiterated that students accessed the library mainly during the research phase, with a limited number using it toward the end at the project hand-in. No-one responded that they used it in the second project phase.

The resources available in the library drew a mixed response. The students who had spent more time doing searches and browses found the material was useful and relevant to the project – there was one comment that pertinent information was there ‘without having to search’ i.e. the material was closely related to the project being undertaken. There was additional feedback that being able to view exemplars provided ‘insight’, and was useful for identifying and stimulating ideas. There were, however, observations that specific searches proved problematic, giving unexpected or unwanted results. Also, some students felt that the library contained insufficient material, and again the Internet was cited as a bigger resource where material could be found more easily. The time needed to access and use the library was additionally highlighted as a problem given the compressed project timescales.

5.6 Analysis

The results of the data logs and questionnaires were analysed and a number of key topics identified regarding use of the digital library. These included *utilisation*, *accessibility*, *navigation*, and *content*, and are addressed in turn below.

5.6.1 Utilisation

The relatively low overall level of utilisation of the LDL was disappointing, with observation and questionnaire responses revealing that although they generally recognised the importance of finding good quality and relevant information, students often preferred to browse the Internet rather than engage with the LDL. This may have been for a number of reasons, including the library interface, the size of the library and the nature of the items contained within it. Based on the questionnaire responses, however, students who engaged with the library found the content and breadth of material useful in their design work and the majority did acknowledge that it had advantages over web searches in convenience, relevance and the quality of resources returned.

System logs showed the library was used principally at the start of the project and again towards the end, with a significant drop when teams were engaged in concept generation work. From observation of studio sessions, the corresponding level of use of non-LDL sources (such as Google searches, textbooks, catalogues etc.) followed a similar pattern. The gathering of resources at the beginning of the project allowed students to familiarise themselves with other fruit squeezers, kitchen appliances and crushing devices in general. When moving into the conceptual phase, however, little of this information manifested itself in the designs produced. The students engaged in their conceptual design by sketching on paper, often comparing and developing ideas in conjunction with other group members, with the information gathered during their research largely neglected.

Despite the emergence of Computer Aided Industrial Design (CAID) tools to support sketchwork, particularly in areas such as the automotive industry, and the digitisation of systematic approaches such as TRIZ (Rantanen & Domb, 2002) to formally tackle problems, a paper-based, informal and collaborative approach remains common for many companies engaging in generative design thinking. In terms of integrating digital information with the designs created, a more homogenised environment where information previously gathered is presented in a useful way at the point of conceptual sketchwork, and greater ease in moving from research to conceptual modes, may facilitate more effective use of digital information. The flurry of LDL activity as the project deadline approached suggests that examples of past work were being used for comparative and reflective purposes. In terms of industry practice, such information may be applicable to project review and concept evaluation meetings when such comparisons are particularly relevant.

A number of teams with initial resistance to using the system, and who did not reach a 'critical usage' level, did not use the LLE groupware element for managing their work at all, uploading only what was necessary for assessment at the end of the project. Reasons cited for this included frustration at the tedious process of having to apply metadata when uploading items to the system and difficulty in organising their file stores in a way which made it easy to refer to and share. This was disappointing, as these issues were specifically considered in the design of the LauLima architecture. It was wiki-based, giving the teams a great deal of control and flexibility in how their resources were organised, and because of the anticipated resistance to adding metadata, users were required only to add a bare minimum, with additional context added later by staff to items selected for migration to the long-term library. These problems are similar to those faced by organisations attempting to introduce any groupware system. Conscious of the cost in terms of time and effort, if both short and long-term benefits are not obvious to the designer there is a real danger of lack of uptake. This is critical for such systems as they only become effective when they are being used across the organisation. If they are not, the result is that information is never fully integrated with the design process. Consequently, stronger mechanisms are required to encourage users to engage with the resources available to them during the concept design activity itself.

5.6.2 Accessibility

The common perception that the Internet, and Google in particular, was a more convenient way to access information than the LDL was perhaps confused with familiarity as when searching for specific resources there was little evidence of teams finding relevant and useful information they could use in their conceptual design work – much of it was high level information such as on-line retailers. It was noticeable that there was a general failure to make use of any of Google's advanced search features to optimise their searches. The LDL search facility was deliberately designed with these advanced search features on the main interface to encourage their use. It was found, however, that the number of options served to make the page intimidating and actually led to less use of the library. In light of this, a strategy similar to Google's, i.e. providing a basic search as default and calling up more advanced features as required, was considered more appropriate. The LDL's browse feature, too, had accessibility issues. It contained a high number of categories and terminologies which were not very transparent, requiring further investigation to reveal content. A better approach may be to have a flatter branch structure with fewer categories and simpler terms, and relying on the effective presentation of summary metadata to ensure effective browsing.

5.6.3 Navigation

When using the system, browse was favoured over the search feature. This could be attributed to a lack of knowledge of information literacy and searching strategies, with browsing preferred to having to identify and combine appropriate search terms. Parallels can also be drawn to the visual and non-linear nature of creative design work – browsing through category lists and thumbnails is a convenient way to view diverse material and can spark new directions of thinking. Another contributing factor was the relatively small size of the library, meaning it remained feasible to browse through lists rather than conduct a search. Although there were no statistics for the particular types of browse activity, general observation revealed the resource type categorisation to be the most useful. Items were described in a practical, descriptive way (with terms such as 'chart' and 'animation') and grouped into only four main categories whereas the standard thesauri had extremely long and specific lists that were somewhat intimidating. For larger digital collections, the granularity offered by such thesauri is necessary, but in this context with a smaller and more specialised library they were not particularly beneficial. As the project progressed, it was assumed that students would search for the more precise, often technical, information required during design embodiment and detailing. Instead, the proportion of browse to search instances remained fairly constant. This indicates that content does not necessarily have a strong effect on the method of retrieval, but the limited data set means this issue would benefit from further investigation.

5.6.4 Content

As the library was mainly populated with material from similar projects, the bulk of it was closely related to crushing devices. Although this ensured the relevancy of the material in the library it was not enough in itself to entice significant utilisation. The user-generated material in the library was chosen to encourage learning from examples, by mistakes, and by building on existing ideas. In an organisational setting the value of specialised resources developed over a period of time can be expected to support brand consistency and product line continuity in detailed design and manufacture. In the rapid development of new concepts, however, inspiration and diverse resources to spur creative thinking are also desirable. Although the library contained a mix of different materials to support this type of activity, it remained underused. Given that much of the content was associated with the work of previous students, the sense of resistance perhaps reflected a desire to demonstrate original thinking, with the inference that looking at others' ideas would not stimulate but rather detract from this. It may therefore be necessary to consider other formats of presentation of such material – it was shown to be beneficial in the latter stages of the project as exemplars for benchmarking work prior to submission but may not be suited to acting as neutral stimuli or technical references for generative or developmental design work. The size of the library, at almost 500 items, was a significant but not exhaustive resource, and users highlighted that the Internet afforded far more expansive searching and browsing opportunities. This is countered by the fact that the library provided richer resources that were more easily located, but the flexibility of using web browsers remains appealing to the explorative mindset adopted through informal design work. Digital libraries for such applications should therefore be large enough to be considered suitable for this type of research or facilitate the acquisition of new information from external sources as required.

5.6.5 Conclusions of study

The study highlighted a number of issues regarding the use of digital information through the early stages of the design process by a student cohort. Although it took place in a controlled educational setting and did not address the more systematic methods that may be employed (particularly in larger organisations), it did replicate an informal, team-based approach to concept design work that is common in many industrial situations. In general the digital library was underused, with time, convenience and perceived usefulness being the biggest obstacles to use, and Internet searches instead being the preferred mode of research. Students who engaged with the library, however, found its content and relevance useful, and there was a broad appreciation for the importance of good information to the design process. Observation showed that overall peaks and troughs of information utilisation through the design project applied to both Internet searches and LDL use, and that there was a general lack of direct utilisation of this information in the concept design work produced. While these results could be interpreted in a number of ways, there is an indication that better mechanisms are required to encourage users to engage with digital resources during conceptual design work, and that the presentation of information in a more sympathetic way could result in better substantiated design concepts.

5.7 Developing interaction with information

The literature and protocol studies in Chapter 4 illustrated that information is important to the concept design team, with the use of resources encouraging explorative activity. This chapter has gone on to outline the importance of an effective shared digital information resource in supporting conceptual design. The development of the LauLima Digital Library as part of an integrated design environment and subsequent evaluation of its use in project work has, however, illustrated continuing problems regarding user engagement with digital resources during concept design. To address this, it is necessary to consider new ways to increase the team engagement with information during this activity. If the groupware environment is considered the interface through which digital resources are accessed, then the research problem can be summarised, as shown in Figure 5.9, as trying to develop mechanisms to integrate the activity and information more effectively.

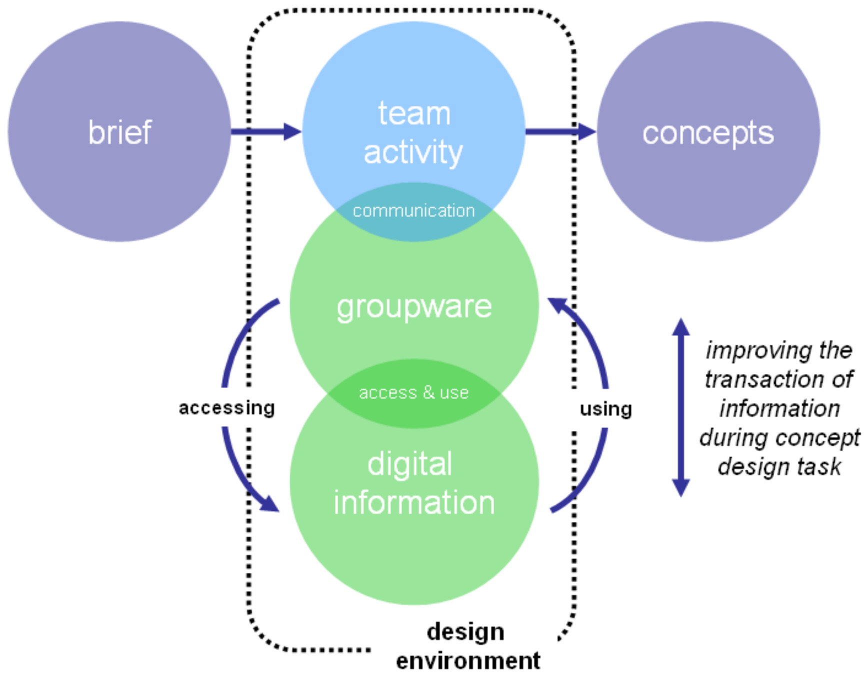

Figure 5.9: Integrated approach to digital support for conceptual design

Although the LauLima system aimed to integrate a highly contextualised digital library within the working groupware environment, the temptation remained for users to conduct quick Google searches when they required an item of information. To understand why this is, it is necessary to consider the nature and role of the digital library. Although the Internet provides access to a vast amount of material it is completely unstructured, and despite the consequent ineffectiveness of many high-level search engine searches it appeals to users in its flexibility and freedom to explore. On the other hand, digital information systems have largely emerged from the field of librarianship rather than design, and the typical hierarchical lists and search interfaces do not lend themselves to creating an explorative experience. Witten and Bainbridge (2002) recognise this issue when they discuss the 'in'-ness of a library as being critical: since digital libraries do not have a physical structure, some notion of boundary is required so that it envelops the user in an intellectual if not a physical sense. Rather than considering digital libraries to be representations of traditional library structures, it may be appropriate to consider them 'discrete small-scale projects which embody different approaches to information storage and manipulation, but which are linked together to form a wider resource' (Carpenter, Shaw, & Prescott, 1998, p. 21). This is essentially the same model used by the Internet – when specific pages are identified as being particularly useful they can then easily be bookmarked and used consistently. Given the focussed nature of concept design, it may be that a series of smaller, more specialised information resources selected as appropriate for the particular design context would be more effective in supporting the particular interaction structures of the team.

Indeed, it may be that the analogy of a library is in fact not appropriate for the concept design environment at all. Sketching is a fundamental means for the designer to internally develop ideas as well as to communicate them with others (Schutze, et al., 2003) and given its key role in the concept design process, it must have a major bearing on the information use of the team. Rather than filing information items in a systematic way, making them visible in the same environment as the groupware or sharing element of the system may be a more appropriate approach to allow the information to be used freely as stimuli in the generation of ideas. An analogy akin to a designer's sketchbook may be more applicable, with annotation, notes and ideas marked directly onto or alongside the items of information which have been used to inspire or inform a particular concept. The LauLima system went some way towards this by having the library in proximity to the environment of use, but this requires further extension to provide a more vivid interface that is actually part of the concept design process rather than a separate entity which must consciously be visited.

The tactile quality of physical resources such as models allows them to be effectively used as prompts for explorative discussions, often acting as a centrepiece as they are touched, operated and manipulated. This is not easily replicated in the digital environment but if information resources are made vivid, with their benefits explicit, it may lead to a greater willingness to engage through the digital interface. To help achieve this, mechanisms to integrate creative design work with exploratory information searching tasks could be utilised, the concurrent nature of the activities helping to ensure that the information being retrieved is relevant to the task at hand, and the information handling at the very point of concept generation compelling its use in the creation of new ideas. Additionally, forms of tagging or tracing could be used to highlight the applications and uses of resources, meaning each time a concept is referenced, the corresponding resources are also highlighted – thereby encouraging others to explore how it was used and to exploit it themselves. This potentially creates a more dynamic sharing and creating environment, and a higher turnover of information. Such prescriptive mechanics must be carefully considered – although they offer the possibility to curb the personality-driven approaches (such as brainstorming) which have proven impractical in current digital environments, those which inhibit the 'flow' of concept design work are unsatisfactory.

Perhaps the biggest disparity between information and concept design is a chronological one: information gathering is often completed prior to the design team engaging in conceptual work. This introduces the possibility that information can be discarded, forgotten or overlooked as attention shifts to a new phase of activity. This applies to information generated in the concept design process as well as information gathered beforehand. Vincenti (1990, p. 225) stresses that given the practical, problem-solving nature of engineering design, knowledge emerges continually as work progresses:

> 'The growth of engineering design knowledge originate[s] primarily out of prior engineering activities and [is] achieved primarily by engineering activities.'

This emphasis on knowledge generation in the *process* of designing, whether through sketches of new concepts, the application of raw data, or the contextualisation of design principles, suggests that the usual sequential split in information-related, research activity and concept-related, creative activity may not be optimal. Although increasing the proximity of information and the design environment supports the transfer between these two domains to an extent, by actually encouraging the adding and enhancing the information resources *as concept design activity progresses*, it may be possible to further increase the effectiveness of information for design as the work progresses. This move from a phase-based model to an activity-based model is similar to that suggested in Chapter 3 (Figure 3.3, p.48) for the purposes of increasing team creativity.

5.8 Summary

This chapter has outlined the importance of digital information systems to conceptual design work. An integrated groupware and digital library system has been presented, and the results of a project study outlined. Continued problems with ensuring adequate interaction with information during the concept design activity have been highlighted, along with observations on the suitability of libraries as an information format. It is concluded that new structures are required to improve interaction with digital information, but these should be of a nature that does not inhibit the flow of concept design. This chapter also marks the end of Phase a (*exploration*) of the research. Two descriptive studies have been undertaken in exploration of the role of information and digital tools in the support of concept design. The main output of the phase is an understanding of the effect of information on concept design activity, and the problems of integrating digital tools to support information use. In moving to the development phase of the research (*Phase c*), the following chapter examines how techniques from the arena of computer games can be adapted and used in new, more integrated approaches to concept design.

Chapter 6 Techniques for the enhancement of information use

As the first chapter in Phase c (*development*) of the research, it is at this point in the thesis that the exploration of existing methods and management of concept design (Phase b) ends, with new approaches introduced and developed. While a number of approaches such as social networking and crowdsourcing point to new ways of interacting in the digital arena, this chapter explores computer gaming as a viable means to structure the interaction of the design team. With its strong emphasis on vivid and engaging content, it was identified as offering exciting possibilities for increasing design information use and thereby leading to improved concept generation work. Consequently, literature on the emergence of games and computer gaming for productive task environments is reviewed as a means to provide highly interactive content in the design setting. A first-hand evaluation of a range of computer games from different genres is then presented with a view to their possible utilisation in support of the concept design. Four scenarios for implementation of gaming methods are proposed, with one identified for further development. Game Theory and in particular the Prisoner's Dilemma, are then introduced as a means to further optimise team interaction, concluding with a revised scenario of interaction.

6.1 Background

The review of computer support for conceptual design in Chapter 5 illustrated the problems with encouraging effective use of digital libraries. To increase the level of user engagement with the information resources to the point where it becomes a useful shared tool, it is necessary to look beyond typical productivity software to more dynamic and desirable environments. While social networks such as Facebook[13] and Twitter[14], and crowdsourcing (Marco, Leimeister, Huber, Bretschneider, & Krcmar, 2009; Whitla, 2009) point to new ways to co-ordinate networks of people, computer gaming currently offers the most immersive digital experiences. In this rapidly evolving sector, vivid and engaging digital content are

[13] http://www.facebook.com (Accessed: 8th May 2010)
[14] http://twitter.com (Accessed: 8th May 2010)

fundamental, with games consisting of high levels of motivation, interaction and structure. There are many elements which could be applicable to a team-based design scenario, including co-operative or competitive elements, use of avatars and analogy, exploration of virtual worlds, and other recognised devices regularly used by game designers.

Today's society is more computer literate than ever, with a generation having grown up playing computer games. The world market for games and edutainment software grew to $18.2 billion in 2003, up from $16.9 billion in 2002 and it was predicted that by 2007, the global market would be worth $21.1 billion (DTI, 2005). This has led to vast resources being spent on the creation of interfaces which are rich, engaging and fun, and provides a strong indicator of how people can best interact with digital information and each other in the future (Friedman, 2006).

According to Manninen (2003), the interactive experience can be made more rich using forms which are 'large, versatile, flexible and focused on the content' – precisely the area where the computer games industry has garnered vast expertise and in which innovative techniques could be implemented. Although computer games have attracted a measure of negative publicity for violence, misogyny and anti-social behaviour, more people are starting to realise their benefits: recent studies have shown that gaming simulation can enhance understanding of organisational culture, structure, and processes (Kriz, 2003), and that the playing of computer games can be helpful in establishing procedural habits (Gee, 2003). In addition to this, the increased penetration of broadband Internet access has led to the rise of Massive Multiplayer Online Games (MMORPG), with subscriptions estimated to reach £1.3bn by 2013 (BBC News, 2009), with the World of Warcraft title now boasting more than 8 million subscribers worldwide.

The shift towards using games constructively is reflected in the burgeoning area of game-based learning, which has been expanding rapidly in recent years (Prensky, 2001), primarily in the corporate area, where the main applications are of a business or task orientated nature. Simulation games, in particular, are becoming increasingly common in business and teaching business (Faria & Wellington, 2004). McDaniel et al. (2006) suggest that the designing of games as well as their playing lend themselves to the learning of project management, providing contrast between theory and practice. Projects such as the Microsoft-MIT funded Games-to-Teach project (MIT and Microsoft Corporation, 2005) indicate that this will be applied to many other areas of learning as the field evolves.

Despite this movement to utilising their obvious potential, until now there has been relatively little study into how some of the qualities of computer games could be applied to the context of design (Ip & Jacobs, 2004; Squire, 2002). The chapter therefore seeks to address two main research questions:

- How can computer gaming techniques and strategies be used to enhance information use in product development teams?
- What framework or methods can be used to combine and utilise the most desirable features of these games?

6.2 Characteristics of computer games

The playing of games is an innate human trait, and is apparent in many aspects of society from the imaginary games played by children in the playground to sports spectacles played out in front thousands. Prensky (2001, p. 106) emphasises the important social function of games, and highlights several key advantages to explain this:

- Games give us *enjoyment*
- Games spark our *creativity*
- Games give us *doing*
- Games give us *learning*
- Games give us *adrenaline*
- Games give us *structure*
- Games give us *involvement*
- Games give us *motivation*
- Games give us *flow*
- Games give us *ego gratification*
- Games give us *social groups*
- Games give us *emotion*

After Prensky (2001)

The traditional forms of game played by small groups, such as chess, cards or board games all have rule sets that allow participants to interact in a structured way. While these forms of game remain hugely popular, it is in the digital arena where radical innovation is pushing the boundaries of what can be achieved in complex worlds where large amounts of information are discovered and shared in the user experience. Further, the mode of interactivity engendered by digital communication is part of the modern mindset, with computer users demanding a higher and more sophisticated level of engagement in these environments than ever before (Gee, 2003). Prensky coined the term 'digital natives' for the first generation to grow up immersed in a digital world, highlighting the fact that they 'think and process information fundamentally differently'.

He points to a characteristic preference for: speed of information; parallel processing and multi-tasking; graphics over text; random access as afforded by hypertext and links; networks; instant gratification and rewards; and games and gameplay. As a result, digital natives expect digital environments not to just emulate traditional forms (web pages replicating newspapers, Solitaire computer game replicating the card game etc) but to provide a platform for them to engage and interact in profound ways with both information and ideas. This is described in the shift from Web 1.0 to Web 2.0 (O'Reilly, 2005) where static web pages as information sources have been replaced by more interactive sites where the emphasis is on user participation, and is illustrated by success stories such as wikis (Wikipedia[15], Moodle[16] etc) and social networking (Facebook[17], MySpace[18] etc). While Web 2.0 brands such as YouTube[19] and Flickr[20] have now penetrated the mainstream, many have their eye on the next phase of development, dubbed Web 3.0 or the 'Semantic Web' (Berners-Lee, Hendler, & Lassila, 2001). In this vision, computers will become a kind of personal assistant, connecting aspects of our digital lives with innate intelligence, and trawling the Internet to respond to our information, social and entertainment needs.

These general trends suggest that users will expect similarly interactive experiences in the use of information. To better understand the particular characteristics of computer games which could be relevant, they have been reviewed with respect to concept design. The areas of *motivation*, *structure* and *interaction* have been identified as distinct aspects which can lead to better information use and are summarised below.

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15 http://en.wikipedia.org (Accessed: 5th January 2010)
16 http://moodle.org (Accessed: 5th January 2010)
17 http://www.facebook.com (Accessed 5th January 2010)
18 http://www.myspace.com (Accessed 5th January 2010)
19 http://www.youtube.com (Accessed 5th January 2010)
20 http://www.flickr.com (Accessed 5th January 2010)

6.2.1 Motivation

The motivation engendered by computer games is one of its primary attractions for use in the design context: if using information stored in a digital library can be made even remotely as attractive as playing a computer game, there would be a huge increase in uptake. The concerns of parents whose children spend endless hours trying to master the latest games are indicative of the hold they can exert over players. Davis and Carini (2004) emphasise the strong link between fun and engagement in their work developing heuristics for designing fun into video games, and this is clearly a desirable element for any interaction proposed. Considering the interaction purely as 'fun', however, is not altogether appropriate for the business and productivity context – an overly-relaxed approach to a task is not sustainable in arenas where deadlines and targets continue to define the pace of work.

Csikszentmihalyi (1997, p. 31) has developed the concept of *flow* to describe how individuals are motivated by particular tasks. He describes the normal, relaxed condition of the mind as one of 'informal disorder', and emphasises the need for focus in order to 'pursue mental operations to any depth'. When this level of concentration is attained, we find that we can lose ourselves in a task. Most people have experienced this, usually when undertaking an activity they enjoy. It is particularly common when engaging in something creative, such as drawing, when time can seem to disappear. Csikszentmihalyi identifies the quality of this experience when undertaking a task as a function of the relationship between its challenge and the skill required. The optimal experience, or flow, occurs when both variables are high (Figure 6.1).

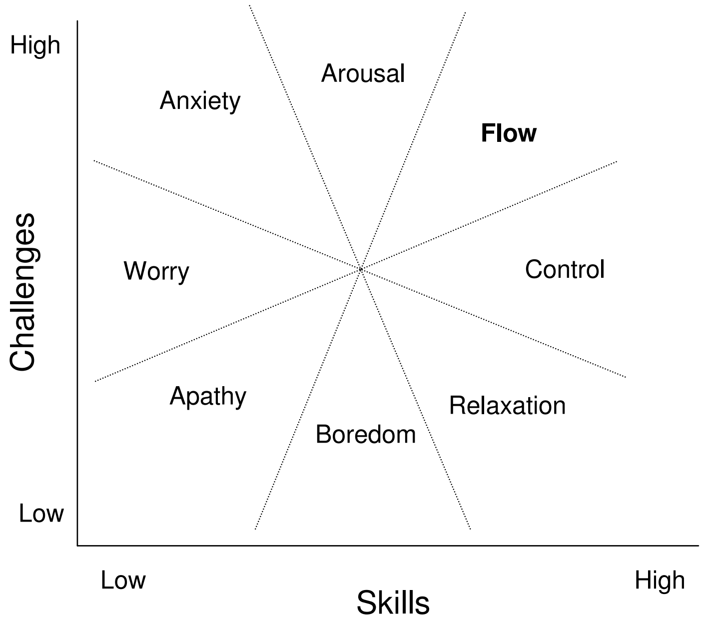

Figure 6.1: Finding flow (Csikszentmihalyi, 1997)

Malone (1981) suggests that challenge depends on ‘goals with uncertain outcomes’, describing fantasy and curiosity as elements of intrinsically motivating games. Sweetser and Wyeth (2005) highlight that challenge is often identified as the most important aspect of computer game design: it should have a suitable level of challenge ‘not discouragingly hard or boringly easy’. They have developed a method of analysing the enjoyment of computer games by relating them to Csikszentmihalyi’s concept of flow called GameFlow – a model for evaluating player enjoyment in games. Chen (2007) also applies Csikszentmihalyi’s ideas to the field of computer games, suggesting that many games follow a prescriptive path too challenging for the novice or too easy for the expert, taking them out of their respective flow zones. She, like Malone, suggests that this can be overcome by incorporating choices for the player during the game. However, it is also stressed that these choices are embedded inside the core activities to ensure the flow is never interrupted - too many choices for the player or computer to deal with can lead to an interrupted or fragmented experience.

This can be further extended to the challenges faced in the concept design. Chapter 3 (Section 3.4.1, p.46) highlighted analysis, synthesis and evaluation as the main constituent tasks of this activity. Figure 6.2, developed from a diagram by Chen (2007), illustrates these as separate areas where flow can be achieved, with analysis equating to background knowledge and information skills, synthesis to sketching and imagination, and evaluation to judgement and background knowledge. The purpose of a gaming interaction is then to provide a framework for moving in and across these flow areas. By maintaining an appropriate level of challenge and providing as cohesive an experience as possible, participants can be expected to engage in a productive work mode.

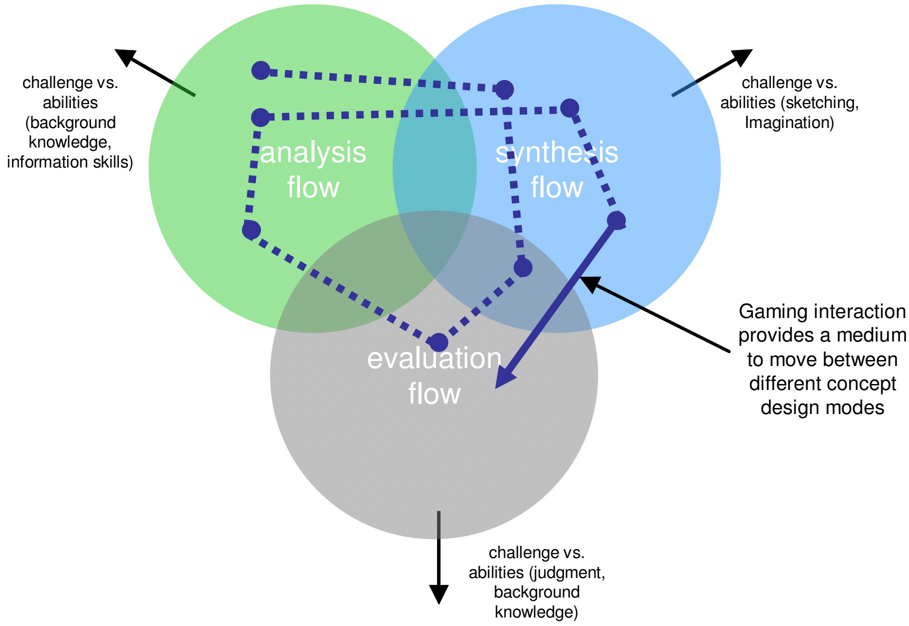

Figure 6.2: Flow zones for concept design task (after Chen)

If the role of a gaming element is to assist participants in actually reaching the flow state when undertaking a task, it is desirable that it is integrated into the task itself rather than being an incongruous addition that moves players from one task to the next. For example, in The Monkey Wrench Conspiracy (Prensky, 2001), the player designs implements in a CAD program to help them complete an adventure in space. The incentive of using the implements for the gaming element is the motivation for completing the CAD tutorials in good time. It is necessary to ensure these elements are carefully balanced to ensure the user is not simply offered chunks of ‘fun’ play as a carrot to endure tedious tasks. In this example, attention could be given to the process of actually designing the implements to make it more appealing.

6.2.2 Interaction

As Apperley (2006) notes, interactivity is a very broad term that cannot be applied equally to all computer games. There is very little structural and organisational commonality between different games, particularly in terms of the aesthetic look and feel. Additionally, completely different paradigms of gameplay, graphics, scoring and strategies may be required, even within genres. Manninen (2001) has attempted to identify and categorise the main forms of interaction involved in the playing of computer games in an 'Interaction Taxonomy' (Figure 6.3). As well as providing a loose framework to categorise the forms of interaction in multiplayer games, these individual categories draw attention to the different ways information can be communicated in the game environment.

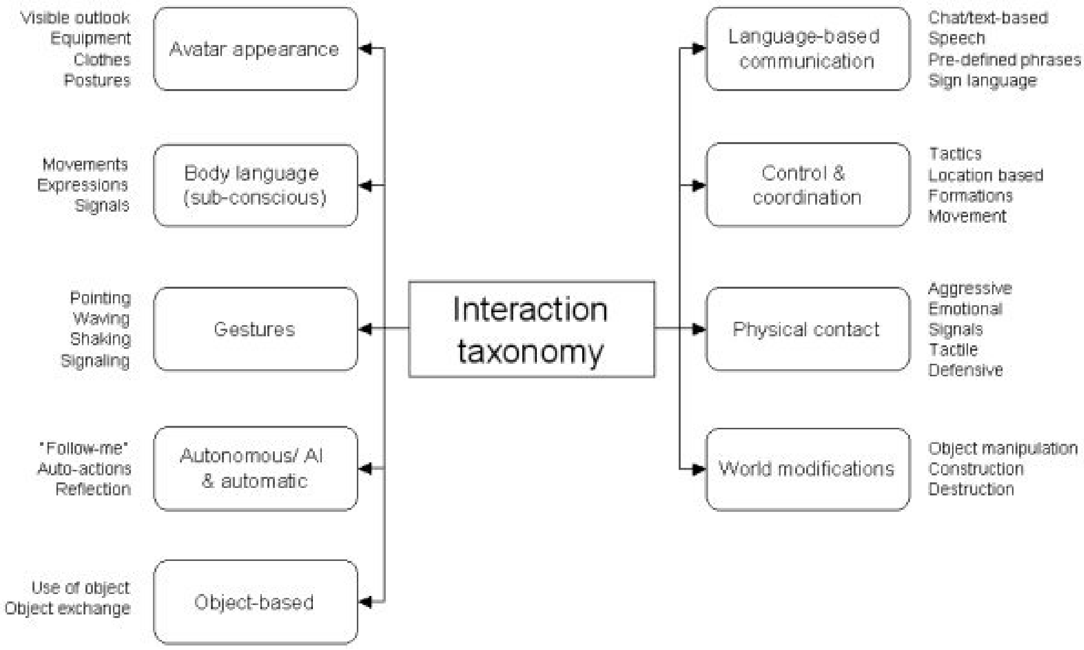

Figure 6.3: Taxonomy of interaction forms (Manninen, 2001)

Although factual information can be effectively communicated through speech and the written word, much emotional and contextual communication relies on the reading of more subtle signs and clues. Mehrabian's (1981) commonly quoted '7%-38%-55% Rule' suggests that in any face-to-face communication there are three elements: words, tone of voice and body language, with the importance of each being 7%, 38% and 55% respectively. Although these findings were in the context of people talking about feelings and emotions, it highlights the fact that words spoken are only a component part of any interaction. Communicating in the virtual environment of computer games presents obstacles in conveying the nuances of tone of voice and especially body language given the current limitations in technology and for any platform to be successful it must provide the adequate means for participants to communicate the information required to complete tasks. For different concept design approaches, different forms of communication have precedence. For example, brainstorming is often verbal in nature, whereas the 6-3-5 Method relies on sketchwork to share ideas. It is therefore necessary for any gaming intervention to be attuned to the information required to be shared by participants using a particular design approach.

In their studies of MMORPGs, Ducheneaut and Moore (2004) use the term 'macroing' for players progressing through the online world on autopilot, completing the tasks necessary to advance in the game and not bothering to interact with the hundreds of other players present in the game's social areas. They suggest that the overwhelming number of people and information were imporant factors in this. On the other hand, they also observed players who engaged in rich interaction. They go on to highlight issues such as space in the virtual environment, the level of information presented, and appropriate rewards as ways to encourage strong social behaviour in MMORPGs. It is necessary, then, to use the design activity and any gaming element as the focus of the group. From a CSCW perspective, Gutwin and Greenberg's (2002) examination of how small groups perform concept design work in medium-sized groupware environments focussed on the importance of an 'awareness of others', emphasising how individuals move regularly between individual and shared activities.

The opportunities provided by the virtual gaming world for participants to use avatars and take on roles can potentially be a powerful way to address this need for 'workspace awareness'. Westecott (2003) emphasises the importance of roles in gameplay and describes how in games, the player can be regarded as a 'first-person actor' where they must take the role of a character and interact with environments and other players. This provides the opportunity to build and support social structures in a game space that can be task-orientated. Similar analogies describing the design of the game experience as a stage for characters to interact (Laurel, 2004) have also been applied. Given the personal nature of creativity and idea generation, the management and use of such avatars can potentially be used to provide different levels of anonymity or shielding from criticism where necessary or desired.

While competition has been cited as a key element in the enjoyment of playing computer games (Vorderer, et al., 2003), the achievement orientation and perceived competence of individuals has been highlighted as a significant factor in how well players respond (Tauer & Harackiewicz, 1999). Given that the concept design task is fundamentally co-operative in nature, the idea of introducing competition is attractive in the sense that if all individuals are motivated, confident and engaged it could further stimulate and subsequently enhance their work. If this is not the case, however, there is the risk of alienating individuals within the task, and in the virtual setting it is easy for players to withdraw from engaging as suggested by the macroing phenomenon in MMORPGs.

6.2.3 Structure

Computer games provide a structured framework through which players must navigate, but unlike the strictly linear narrative of a film or book, each game is played in a different manner. Players are repeatedly presented with a wide range of concepts and scenarios which they must rapidly assimilate and select from in order to progress, and although games vary in their linearity and narrative scope, in all of them participation by the player is fundamental. Newman (2002) describes how in the virtual environment, the act of interfacing with the system is a part of a continuous feedback loop where the player must be seen as 'both implied by, and implicated in, the construction and composition of the experience'.

The decisions, whether they be the split-second choices in the midst of an action game or a strategic choice associated with a Sim game, made by the player make each experience unique. It has been suggested that controlling the allowable inputs and outputs of games could allow action and reflection to be configured for optimal decision making (Manninen, 2003). The decisions made by players can be inhibited by an imbalance in game variables such as time restrictions vs. information load, action components vs. strategy interludes, and narrative thread vs. flexibility. Structuring the game to balance these various elements and ensure players remain in the 'flow' state is integral to the gaming experience. Similarly in engineering design, the overall process structure has periods of divergence and convergence during which information and ideas are generated and evaluated accordingly. If these are imbalanced it is likely to result in a compromised output. How this balance is achieved for different game genres is, then, particularly relevant to understanding how an optimised flow experience can be obtained for the concept design task.

For the team situation, the lack of facility for vivid communication can be problematic. It has been suggested that existing design teams using groupware to facilitate collaboration should build compensatory structures into the design process to allow teams to overcome these barriers (Mark & Wulf, 1999). These compensatory structures, however, should not interfere with the flow of a design session – if they can be absorbed into the structure of gameplay, the team potentially benefits from better engagement as well as more controlled information exchange.

Modern computer games often consist of vastly complex worlds that contain huge amounts of information. With rules of gameplay often being very involved, it is interesting to note how game developers have addressed the issue of conveying these key information elements to players in an engaging way. Gee (2003) describes the experience of opening the instructions or manual for a new game that on first examination can seem impenetrable. After spending a while playing the game, however, the attention of the player is captured, motivation increases and they are more likely to engage with what was previously difficult material. In addition, the manual can be used in a number of different ways, such as referring to it for details to enhance their play. As the industry evolves, however, instruction manuals are being eschewed altogether in favour of integrated starter levels, introductory characters and cut-away sequences that prime the player and teach different aspects of the game as it is actually played. In the design context, the requirement to find and apply information that is related to the conceptual development of a gestating or recently formed idea is likely to be more productive than generic searches on a particular topic.

As the field of game studies develops, an argument that has recently emerged is between *ludolology* and *narratology* as approaches for the analysis of games (Frasca, 1999). Ludologists focus on game mechanics and the element of play as the essence of the game, whereas narratologists argue that games are closely linked to stories and emphasise their importance in giving games meaning. There has been continuing debate on the merits of this delineation (Frasca, 2003; Pearce, 2005) with a general consensus emerging that most games have a blend of these two elements, particularly in the realm of computer games where complex combinations of avatars, animation and immersion are used (Apperley, 2006). Regarding concept design, the element of narratology lends itself well to the contextualisation of the design problem and in assisting with navigating through the various stages expected of the designer to reach a design solution. Integrating engaging ludological elements that will potentially enhance levels of information use by participants, however, presents a greater challenge. In essence, can designing truly be a game?

6.2.4 Summary of characteristics of computer games

The review of literature has shown computer games to have a number of potential benefits for team utilisation of information during the concept design task. Three key characteristics of computer games are increased *motivation* of participants, controlled *interaction* during collaboration, and adding *structure* to the completion of tasks. To better understand how these characteristics are manifested in typical computer games, a selection were systematically evaluated.

6.3 Review of computer games

Games from four main genres (Apperley, 2006) were identified and tested to identify ways in which they could be used in the context of concept design. These included *strategy, simulation, role playing* and *action* games. Table 6.1 lists the games which were selected for closer examination, and also provides a synopsis of each. Recognised as being games of excellence and/or popularity in their respective genres, they were selected as examples where the gameplay and information-rich environments have been tightly interwoven to provide an engaging user experience.

Genre	Game	Description
Strategy	Age of Empires III	Conquer other civilisations by building and defending empires, accumulate wealth by trading and diplomacy. Armies and population must be assigned

		tasks in real time to manage progess.
Simulation	Sim City 4	Build houses, shops and amenities to create a city and then manage utilities and resources to help it develop. The city and its inhabitants will respond to every decision made.
Role-playing	Oblivion: The Elder Scrolls IV	Interact with a richly coloured environment and a large cast of characters through structured dialogue. Based around a series of puzzles, and features drama, intrigue and humour.
Action	Super Mario Bros. 3	Navigate a fast-moving 2D cartoon environment by running and jumping over various obstacles. Completing each stage moves the player closer to achieving the mission to stop the evil Bowser.

Table 6.1: Games selected for evaluation

A number of approaches to evaluation of the games were considered. Through a literature review on usability and user experience in games, Sweetser and Wyeth (2005) developed a method for analysing the enjoyment of computer games. Its criteria included: The Game; Concentration; Challenge; Player Skills; Control; Clear goals; Feedback; Immersion; Social Interaction. A number of criteria were derived for each, relating to aspects of the flow state, and the system is illustrated in the review of two games. Similarly, in their development of usability heuristics, Pinelle et al. (2008) analysed reviews of 108 different games and identified twelve common classes of usability problems which consistently appeared. From this, they developed ten usability heuristics based on these problem categories and suggest that these can be avoided by following certain principles. While these review-based approaches are useful in identifying trends across the field, Barr et al. (2006) emphasise the need for first-hand, in-depth studies of games, suggesting this is an approach which has been lacking in recent studies. Their work highlights the fact that computer games are fundamentally different from productivity software and must be analysed as such. Games, for example, are not aiming for consistent product output.

It was therefore decided that first-hand evaluation by the author was most appropriate for the review of computer gaming in this context. The broad categories of *motivation*, *interaction* and *structure* used in the review of gaming literature were combined with more specific criteria derived from the literature on previous evaluations of computer games. The games were then played to the point where it was felt that a reasonably complete overview of its characteristics was obtained. Impressions were recorded while playing the games, and then augmented during reflection, with records of the evaluation documented in Appendix III. While acknowledged as subjective indicators, evaluation was conducted from a practical design perspective rather than that of an expert gamer, allowing them to be considered with respect to how they could usefully impact on typical concept design activity, and in particular how they could enhance information use. A summary of the findings for each game has been formulated and captured in the following sections.

6.3.1 Strategy

Real-time strategy (RTS) games (as opposed to traditional turn-based games) progress in real time, with players making continuous decisions. Teams are required to engage in the micro- and macro-management of an often complex set of variables to achieve a fixed goal. It is a dynamic gaming environment which requires players to respond quickly to changing circumstances. *Age of Empires III*[21] was selected for evaluation as an archetypal RTS game. Set during the colonial era, players develop an empire by progressing through phases of technological development and destroying enemy bases. The two main elements of gameplay are collecting resources and engaging in military activity. There are three game modes: story-based campaigns, single player skirmishes and online multiplayer skirmishes.

6.3.1.1 Motivation

The mix of strategy and action are what motivate players in the RTS environment. In *Age of Empires,* players have a bird's eye view of the landscape and control settlers to gather resources and soldiers to undertake military operations. Continually monitoring activity across the gameboard, developing your community and deciding when and where to engage in battles ensure the player is always occupied. The presentation of information is such that the player is anxious to ensure they are always up to speed with the latest statistics.

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[21] ©2007 Microsoft Corporation. All rights reserved. http://www.ageofempires3.com (Accessed: 5th January 2010)

6.3.1.2 Interaction

The game can be played in single-player mode or in small groups. Information is not generally shared across players in the same team, although chat facilities can be used to co-ordinate certain actions. The rules of the game generally become apparent through engagement with the environment, and all game-related information is presented through a series of toolbar interfaces on the periphery of the main game board. Additional statistical information can be accessed outside of the main gaming environment. To attain higher levels of performance, it is necessary for the player to engage with these statistics in plotting strategy.

6.3.1.3 Structure

Although game lengths can vary greatly, the evolving environment demands that players take cognisance of the developing infrastructure and absorb information on what buildings, equipment and technologies are appropriate for different phases. The blend of high-level strategy and ongoing task management in a dynamic environment has established RTS games as an effective format not only in single player mode but for engaging a group of people in a controlled environment.

6.3.2 Simulation

A simulation (Sim) game is a mixture of skill, chance and strategy which results in the complex representation of a system, such as a stock exchange or a civilization. Although an important sub-genre is the representation of physical experiences such as driving or flying games, the focus in this instance was on complex systems. The *Sim City* series has emerged as an important title in the genre and although *Sim City 4*[22] (the game tested in this instance) includes better graphics and more complex parameters to manage, the objective is the same as previous instalments of the game – to design, build and maintain a city. The player controls parameters such as land zones, tax rates, transportation and infrastructure in order to ensure its smooth development. Disasters such as flooding, tornadoes and fire also force the player to adjust. There are no specific goals except to develop a successful city, and players have a great deal of control of how they chose to allocate and use their resources.

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[22] ©2009 Electronic Arts Inc. All rights reserved. http://simcitysocieties.ea.com (Accessed: 5th January 2010)

6.3.2.1 Motivation

The game consists of a large number of micro-decisions, combined with overall strategies on how to develop your city. Many decisions are repetitious but the context is constantly shifting, and the game is broken up by intermittent emergencies such as fires or union strikes. How well the player copes with these depends on the quality of the city infrastructure they have created. The reward of the game is to see a large, thriving city and the longer the game goes on, the greater the emotional attachment the player develops.

6.3.2.2 Interaction

The game is primarily single player, although online multiplayer options have become available with the latest releases which allow participants to operate within the same landmass. This mode of gameplay was not evaluated. There is continuous communication with the game AI in the form of pop-ups and advisors. The advisors have stored threads of recommendations so that players can review historical decisions and plan strategy.

6.3.2.3 Structure

The pace of the game is fairly sedate, with the emphasis instead being on absorbing information and making decisions. The interface is a good example of how to manage the presentation of large data sets, with toolbars, dialogue boxes and traceable history all used to make the use of information as understandable as possible. In playing the game, the player does learn of the various trade-offs faced by city officials, such as deciding the level of taxes, the amenities to be offered to citizens and a raft of other factors. Theoretical concepts behind city planning are, however, never overtly explored.

6.3.3 Role playing

Role playing games (RPGs) are forms of interactive and collaborative storytelling games, which tend to focus on the role-playing aspect of behaviour. Derived from traditional role playing games such as *Dungeons & Dragons*, games often feature a fantasy-inspired quest to achieve a particular goal where the player encounters many challenges, developing their skills and attributes as they do so. *Oblivion: The Elder Scrolls IV*[23] is an acclaimed single player game in the realm of typical RPG fantasy. Set in an imaginary city called Cyrodiil, the player is an escaped prisoner who must thwart a fanatical cult by finding the hidden heir to the throne of the kingdom. The player explores the 3D world, solving puzzles and interacting with a world of characters, and intermittently engages in basic fighting. The game is fairly open-ended, allowing the player to interact with the storyline with a degree of flexibility.

6.3.3.1 Motivation

The game is woven into a complex story which unfolds as the game progresses. The general game mode is exploratory, with navigation and character encounters gradually revealing a complex world, though puzzles and challenges form small sequences of action within this. Information must be pieced together from the various cast of characters and clues in the playing environment, with the focus being on the cerebral challenges of finding a way through the web of intrigue.

6.3.3.2 Interaction

As a single player only game, the programmers have been able to carefully pace the game. Interacting with the AI characters through multiple choices as well as having the opportunity to bribe and manipulate based on visual feedback, is effective in the setting but lacks the complexity of human-to-human conversation. A large amount of information in the form of conversations, maps, personal inventories, game tips and so on is active during the game. These are consulted in game mode as well as through various statistical screens.

6.3.3.3 Structure

Oblivion unfolds slowly. As the game progresses, the player builds the profile of their character to tackle the challenges ahead. The world is a rich tapestry and contains a large amount of information on the story, environment and people in it. These must be absorbed and used as the game progresses, and in addition the statistical screens (sorcery, weapons, health, maps etc.) must continually be

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[23] © 2009 Bethesda Softworks. All Rights Reserved. http://www.elderscrolls.com (Accessed: 5th January 2010)

monitored and adjusted to suit the game. It is, however, based purely on fantasy – set in an accurate historical setting, it would be a potentially powerful way to learn about the way that society functioned.

6.3.4 Action

Action games are primarily concerned with using reflexes and timing to undertake fast-moving challenges. While one of the most fundamental of gaming genres, it is broad in scope, with shooting, driving, platform and sports and maze games all prominent examples. Recent games have tended to push the limits of graphical representation, bringing more realism than ever to the genre. At its most basic, however, it is the gameplay, or 'fun', element of action games which is critical to their success. On this basis, a title from the iconic *Super Mario* series of platform games (*Super Mario Bros. 3*[24]) was selected for evaluation. When playing the game, the player navigates a 2D cartoon-like environment controlling Mario the plumber (his brother Luigi joins him in two-player games) running and jumping over various obstacles and enemy monsters. Completing each stage moves the player closer to achieving the mission on behalf of Princess Toadstool to stop the evil Bowser.

6.3.4.1 Motivation

The side scrolling, 2D platform environment demands fast had eye co-ordination. There is a bonus for reaching the end of each stage as quickly as possible, and at the end of each level there is a 'boss' to defeat. The game AI is very basic: each game plays identically, i.e. the enemies appear at exactly the same place, and if a player fails to complete the same stage consistently, they soon have the advantage of knowing where and when the characters will appear. It does, however, gradually get harder, with more complex platforms to navigate, more enemies to deal with and greater time pressures. The control of the character's movement is simple, but has a mesmeric effect – the nuances in jumping dictate the success in navigating the environment.

[24] © 1991 Nintendo. All Rights Reserved. http://www.nintendo.com (Accessed: 5th January 2010)

6.3.4.2 Interaction

There is very little communication during the playing of *Super Mario*. Two-player mode would typically be side-by-side at a console and independently within the game, rendering any meaningful interaction unnecessary. Information is occasionally presented to the player regarding how many points they have collected in bonuses etc. but this is fleeting, with focus being on the action unfolding. The intrinsic rules of the game world – how different enemies function, how certain tools can be used and so on – are simple and easy to pick up through playing the game.

6.3.4.3 Structure

The game involves limited use of information. Certain statistics are displayed at the top of the screen, including the number of lives left, the points earned, the money collected, the current stage, and the time remaining. These are simple status indicators to support gameplay. In addition, there are a number of basic messages presented during gameplay on bonuses collected but these are only in support of the action on the screen and limited in depth. The simplicity of working through consistent levels of increasing difficulty is appropriate for the nature of the game.

6.4 Development of new interactions

In reviewing the games it was found that each while genre had particular characteristics, strict delineation was not always straightforward as attributes, particularly in modern games, tended to overlap. To better understand these characteristics could be applied in the design context, it was decided to use a speculative, scenario-based approach that provided a range of suggestions on how interaction with information could be improved in each instance.

For each of the gaming genres, evidence of practical applications of that genre in business or engineering contexts has been reviewed. These existing examples have been used as points of departure for embodied scenarios that detail game formats, interfaces and mechanics of interaction for use in the activity of concept design. The subsequent review of these scenarios provided a tangible understanding of how the cross-application of gaming techniques could actually be achieved and a clear understanding of what the potential issues with each may be. The scenarios have been realised in storyboard format, with each of these included in a reduced form in the body of the thesis and full-size reproductions contained in Appendix III.

6.4.1 Scenario 1

RTS games have been shown to provide a mixture of action and strategy-based gameplay, involving a number of people in a shared, dynamic environment, and therefore have great potential to be adapted to the overall management of a design team. BusinessLab[25] is a research consultancy specialising in organisational learning. They have previously explored how RTS games can be used in a commercial context to facilitate the growth and development of teams by augmenting the dynamic gaming environment with existing collaboration software. Stakeholders were set a number of team challenges in the *Age of Empires* setting, requiring them to work together to achieve game objectives, using in parallel software like *Microsoft Groove*[26] to develop a strategy that will allow them to work together to achieve a common goal. RTS games generally involve the manipulation of avatars within situations of medium to high pressure demanding both micro- and macro-management strategies to successfully complete them, making them well-suited to such settings. The interface can be designed in a way sympathetic to the information content, allowing the player to monitor progress at a high-level strategy environment. Particular activities can then be nested within this as discrete elements.

As outlined above, in this vein a strategy-based game scenario was then developed as shown in Figure 6.4 and reproduced (as are the following scenarios) on a larger scale in Appendix III. In the scenario, design team members are represented by avatars and the concept design process by islands around which they must navigate. The islands align with the various tasks highlighted by Ulrich and Eppinger, with specific activities relevant to the task being located on each. The team is required to co-operate to build and develop their raft in order to move from island to island. Each island contains a number of elements, for example on the Idea Generation Island players must catch different animals – these represent information items and must be used to create a concept. When a sufficient number have been caught and

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[25] http://www.businesslab.co.uk (Accessed: 5th January 2010)
[26] http://office.microsoft.com/en-us/groove (Accessed: 5th January 2010)

used, the players can progress. Other islands contain similar tasks based on interaction with the environment.

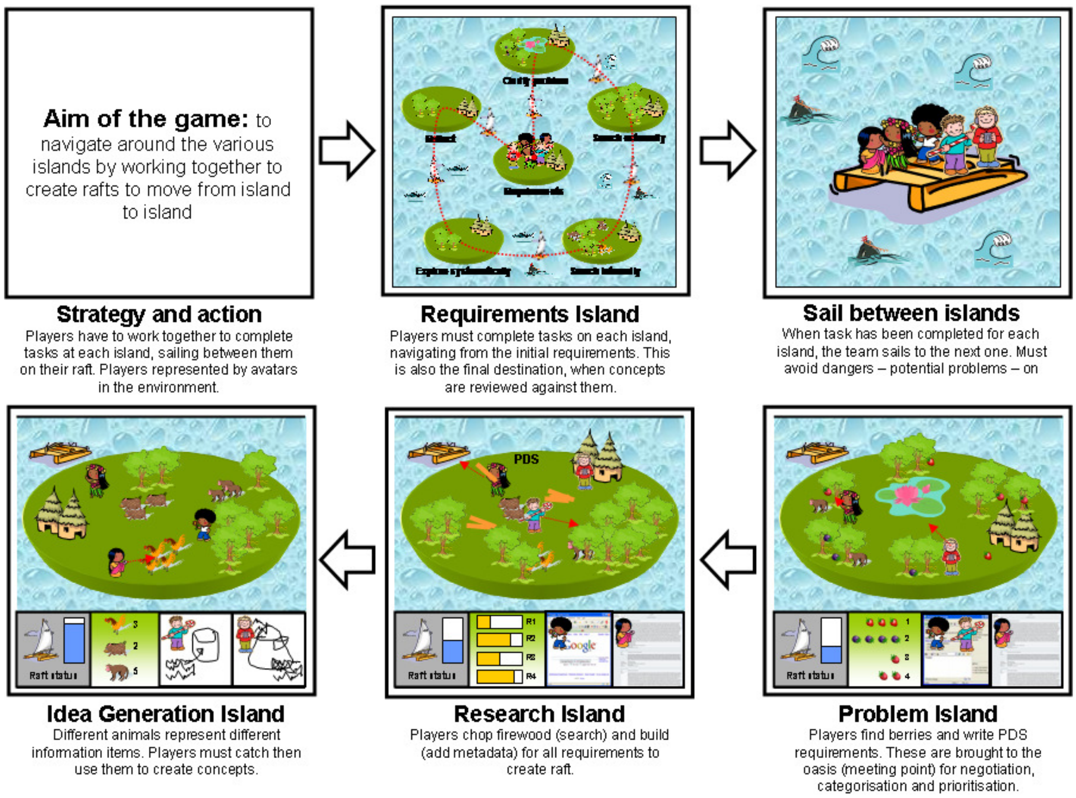

Figure 6.4: Scenario 1 (full-size version in Appendix III)

6.4.2 Scenario 2

Sim games set up scenarios and explore under what conditions they might work. They rely less on pressure and risk and more on engagement and interaction: decisions are continually being made as an intricate simulation builds, with the player becoming more and more involved. An example of use of Sim games for practical use is the Supercharged! Game (Jenkins, Squire, & Tan, 2003), a joint effort by MIT and Microsoft as part of the Games-to-Teach project which aimed to teach students about electrostatics. They saw clear opportunities for using simulation and games to 'engage students in engineering or architectural design processes'. The simulation in this case is guiding a ship through electromagnetic mazes, with obstacles affecting the player's movement according to the laws of electromagnetism. The most obvious application of the sim genre to the design context is in using information-rich systems to familiarise participants with a particular design problem, and with the subsequent setting and adjustment of appropriate design constraints prior to the concept generation task.

Figure 6.5 shows a scenario based on a continually changing situation. Although in this instance it has been rendered somewhat crudely as a board with squares and circles, it could be simulated in a more complex way similar to games such as *Sim City*. Players attempt to cross the board from one side to the other by linking boxes (information items) to circles (concepts). Other players' squares can be destroyed using 'requirement bombs' – players must consider how best to prevent others crossing while they make progress themselves. Different game modes are entered depending on the task being undertaking, but players continually return to the game board as the situation evolves. Communication with other players is also possible through the information panel at the bottom.

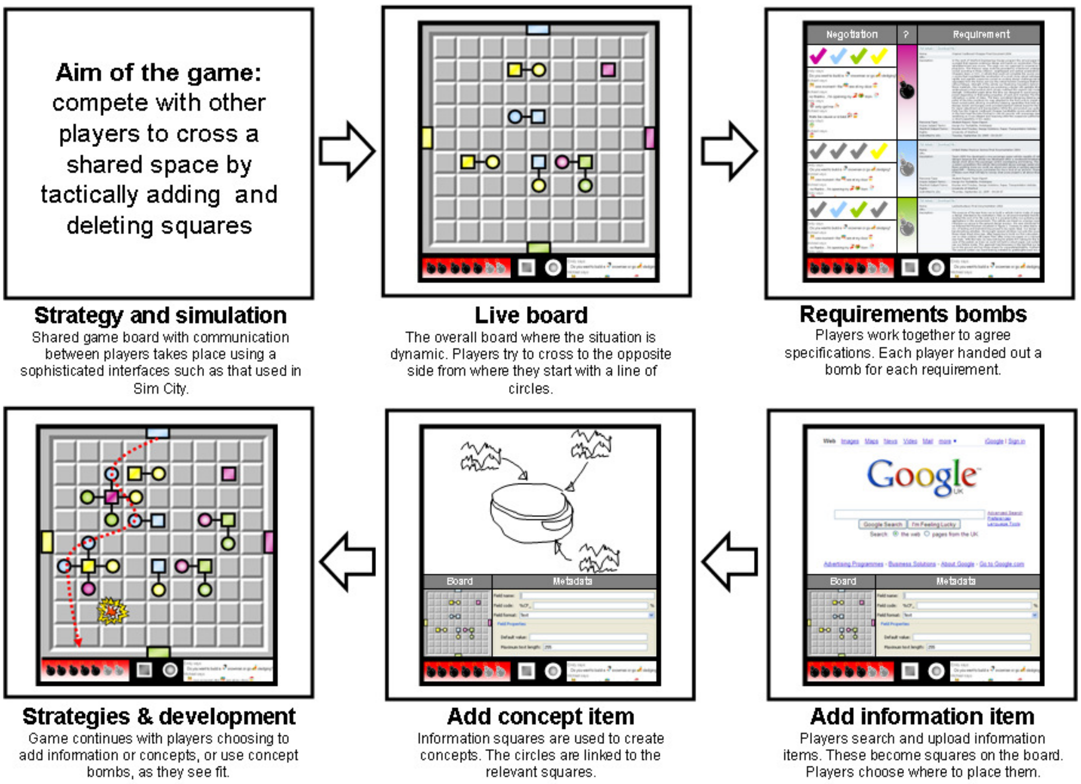

Figure 6.5: Scenario 2 (full-size version in Appendix III)

6.4.3 Scenario 3

RPG games allow players to develop their characters as they explore a virtual world. They tend to consist of a high degree of contextualisation, with the player progressing through a fictitious situation which requires imagination, response and perseverance in a loose narrative framework. The key to success in many creative activities is a relaxed environment where people feel they can contribute freely. From this point of view, the fantasy environment provided by RPG games may be useful in liberating participants from the usual constraints of the workplace – individuals can assume other personalities or use environments to stimulate new ideas and ways of looking at a problem. Gee (2003, p. 90) discusses the learning procedure in the *Deus Ex*[27] RPG game in terms of probing, reflecting, reprobing and rethinking on problems, artefacts and behaviours in the virtual world. This relates strongly to the ideas on reflection in- and on-action as described by educationalists such as Schön (1985) and Cowan (1998). During concept design, 'learning' in this sense takes place during certain activities such as information gathering, but not necessarily at other points such as concept generation. The ability to use the virtual world as an overarching framework in which specific activities and types of thinking can be embedded is, nevertheless, a potentially powerful way to engage participants. In many current RPGs, there are action or strategy based interludes where the player engages in specific activities, such as lock-picking or bribery in *Oblivion*. If a similar approach is applied to tasks within the concept design process, the virtual environment then becomes a framework for a range of more prescriptive activities.

Figure 6.6 illustrates a scenario where a conventional RPG game such as *Deus Ex* can be adapted to the conceptual design activity in a more structured approach. If players begin the game in a particular zone and have to work their way through various rooms to reach their destination, specific tasks can be incorporated within each. In this case, an Information Room and a Concepts Room require participants to undertake searches and create concepts before they finally meet with the other players in an Evaluation Room. Virtual environments can be onerous to develop, but there are an increasing number of free, open-source editors such as OGRE[28] and Horde3D[29] that can be used in their construction. In this case, it may be that a generic game structure can be used in multiple design contexts.

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[27] © 2000 Eidos Interactive. All Rights Reserved. http://www.eidos.com (Accessed: 7th January 2010)
[28] http://www.ogre3d.org (Accessed: 7th January 2010)
[29] http://www.horde3d.org (Accessed: 7th January 2010)

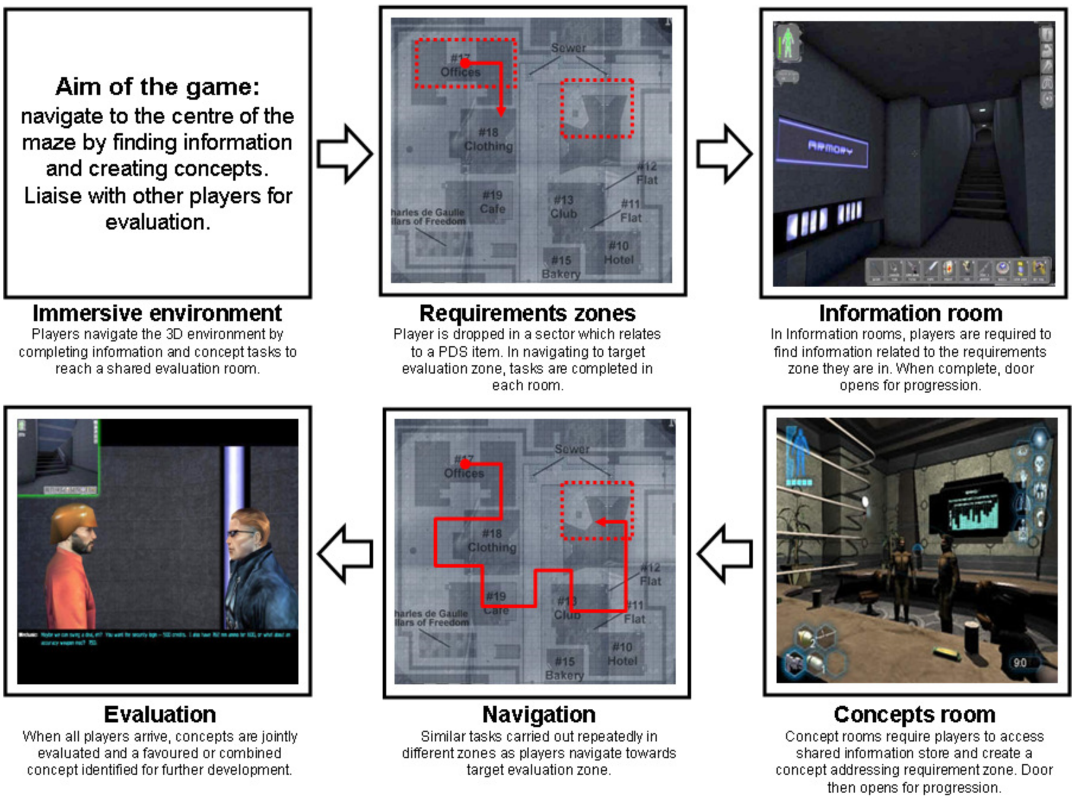

Figure 6.6: Scenario 3 (full-size version in Appendix III)

6.4.4 Scenario 4

Action games, despite being generally regarded as exciting and fun to play, are generally reliant on challenges of dexterity and highly context specific, making the integration of productive content difficult. The rapid task completion it generally entails, however, could be effective as an incentive for further activities providing it is strongly integrated into the overall context. If, for example, a game such as *Grand Thef Auto*[30] was used with an accurate city map, it could be used as a tool to teach taxi drivers navigation strategies. Strategic elements such as traffic conditions and roadworks could be used as variables in identifying appropriate routes, with the action sequence providing a 'reward' for undertaking this task and allowing them to actually try the route, ableit in game form. Although attractive, this requires huge overheads in terms of programming an entire city accurately. Despite this, action games do not necessarily have to be realistic to be successful. Gameplay, which is a combination of game control, environment, and challenge, is the critical factor in an

[30] © 1997 Rockstar Games. All Rights Reserved. www.rockstargames.com (Accessed: 7th January 2010)

action game's success. It is therefore appropriate to consider how engaging action-based sequences can be used in concept design in a way which is repeatable (i.e. not project-specific) but still meaningfully integrated to the process.

Figure 6.7 illustrates a scenario that integrates two action-based sequences into the concept design process. Players are firstly required to search for information items, which are represented as balls. They are motivated to collect as much information as possible in order to have more balls to drop on other players in the following game sequence. They are then required to create an idea correlating to each of the information balls they were struck by. The motivation to develop concepts is to allow players to drop these in the form of boxes on other players, requiring those struck by a box to develop the concept further. The task and game sequence repeats, with the aim of providing a strong link between the different elements.

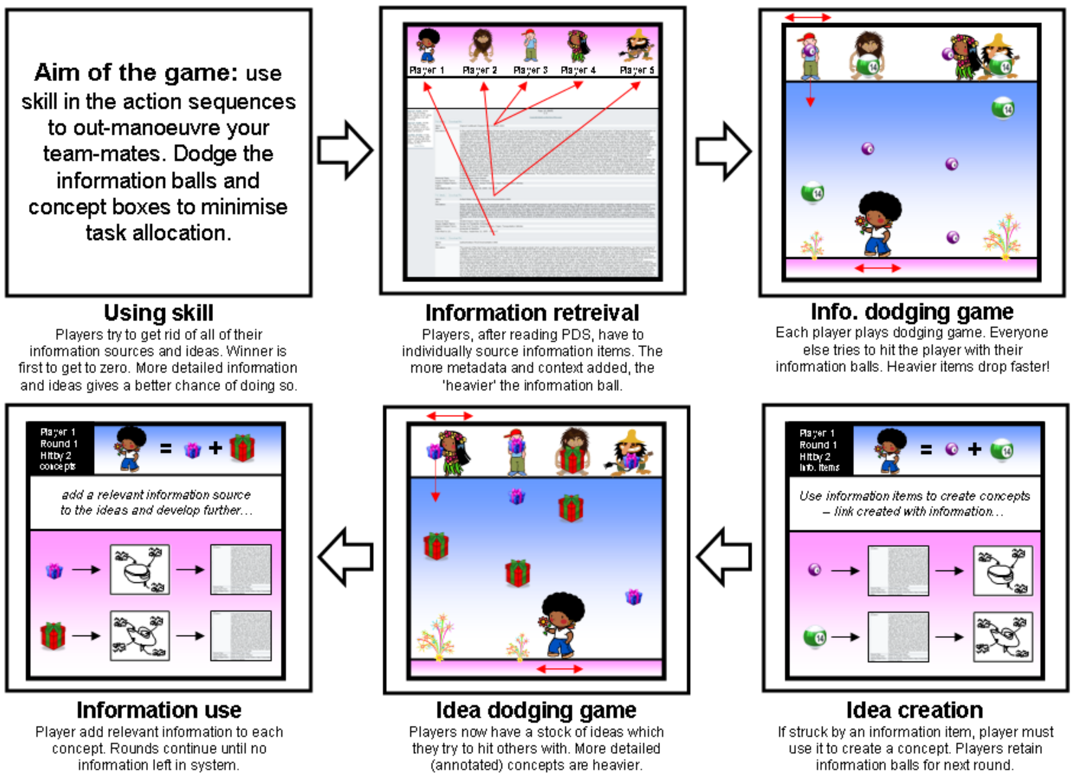

Figure 6.7: Scenario 4 (full-size version in Appendix III)

6.5 Development of design interaction

Using these initial conceptualisations of enhanced interaction with information, a more detailed development was undertaken. This required the four scenarios to be reviewed before refining a proposed approach.

6.5.1 Evaluating the game scenarios

Given their conceptual nature, a detailed formal analysis was not appropriate for the scenarios. Instead, the broad game characteristics explored at the beginning of this chapter and used in the game evaluation (*motivation, interaction* and *structure*) again utilised. In addition to these gaming characteristics, two further evaluation criteria were added: *implementation* and *innovation. Implementation* was included to consider the practicality of prototyping and programming any system identified for development within the constraints of the programme of research, as the ability to validate any proposed approach was a necessity. In addition, *innovation* was considered important as a measure of the novelty of approach and the potential for contribution to existing knowledge in the use of design information. Based on the author's own interpretation, a Likert Scale was used (1- poor to 5- good) to rate the scenarios. Table 6.2 shows the assessment criteria and scoring.

Criteria	Scenario 1 RTS	Scenario 2 Sim	Scenario 3 RPG	Scenario 4 Action
Motivation	3	3	2	5
Interaction	3	4	3	3
Structure	4	5	2	3
Implementation	2	4	1	2
Innovation	3	4	2	4
TOTAL	**15**	**20**	**10**	**17**

Table 6.2: Assessment of games

The aim of this initial evaluation was to identify a general direction for development, with ideas and features from other scenarios incorporated as appropriate. The result was that the Sim-based scenario (Scenario 2) scored highest, primarily due to the controlled and on-going interactions of the game being most suited to the design context. However, there were a number of aspects of the scenario which required strengthening, particularly regarding motivation to engage with the game through characteristics such as risk and pressure: it remained somewhat limited in terms of the forced interaction and motivation between players, and it was felt the board did not sufficiently integrate information and ideas between players. Although the action-based scenario (Scenario 4) was felt to be particularly promising in terms of user engagement, concerns persisted about the feasibility of these being meaningful parts of the player experience rather than appendages to the actual design tasks. To address this issue, and to ensure the interaction was a truly vivid experience for participants, game theory was explored with a view to integrating it more fully with the design activity.

6.5.2 Prisoner's Dilemma

Game theory has, over the last fifty years, emerged as a major interdisciplinary approach to studying the way people interact (Hamburger, 1979). Although its origins are in the field of mathematics, its ideas have come to be applied in a range of areas such as economics and other behavioural sciences (R. Matthews, 2005). It is primarily concerned with the decisions made and strategies used by individuals as they pursue their own interests, leading to conflict or competitions within groups or social structures. Some games, such as chess, are by their nature very competitive as the players' interests are in direct conflict. Such games are called *zero-sum* games, because if we add up the wins and losses, with losses being negative (i.e. +1 for the winner, -1 for the loser, 0 for a draw) we find that the end result will always be zero. In a *non-zero-sum* game, however, players' interests are not always in direct conflict so there is the opportunity for mutual gain. Probably the most famous example of a game where this is the case is the Prisoner's Dilemma, developed by Flood and Dresher when working at RAND Corporation in the early 1950s (Herdt, 2003).

The name Prisoner's Dilemma comes from the original scenario for the problem: it consists of two prisoners who are held in separate cells, accused of being complicit in a particular crime. The aim for the captors is to convince one of the prisoners to implicate the other by giving evidence against them. If both prisoners choose to give evidence (*defect*) then the judge is in no doubt of their guilt and sentences them to three years in prison each. If neither prisoner gives evidence (*co-operate*) then the judge has less clear indication of guilt and sentences them to only one year each. If one prisoner, however, defects and the other does not the judge will allow the defector to go free while sentencing the other prisoner to five years. The reward structure for the game is summarised in Table 6.3.

		Player B	
		Cooperate	Defect
Player A	Cooperate	R=3, R=3 Reward (R) for mutual cooperation	S=0, T=5 Sucker's Payoff (S), and Temptation (T) to defect
	Defect	T=5, S=0 Temptation (T) to defect and Sucker's Payoff (S)	P=1, P=1 Punishment (P) for mutual defection

NB: The payoffs to Player A are listed first

Table 6.3: Reward structure for Prisoner's Dilemma

In his seminal book on the subject 'The Evolution of Co-operation', Axelrod (1990) outlines how this model can be used to help describe human patterns of co-operation. He describes how he invited researchers worldwide to submit a computer program to play an iterated version of the Prisoner's Dilemma, and uses this as the basis of discussion on society and human collaboration in general, citing examples from trench warfare in World War I to biological systems. The fact that many of the elements in conceptual design are typically individual tasks within a group or organisational context (e.g. finding relevant information or creating a concept sketch) suggests there is potential for harnessing the strategies associated with the Prisoner's Dilemma.

Although game theory has not yet been widely embraced by the design community, there are a few relevant instances. Matthews and Chesters have developed an 'Information Pump' (2006) using modified Prisoner's Dilemma interaction. This is a method for extracting feedback from product users that awards participants points for the information they supply. The interaction is fairly involved, consisting of 'encoders' who have knowledge of the product in question and 'dummies' who do not. The encoders make statements about the product and the other participants then make judgements on their validity and how others will react. Despite the complexity of the approach, the authors report positive feedback to their initial studies.

It has also been suggested how the Prisoner's Dilemma could motivate learning in the design studio (Shih, Hu, & Chen, 2006). In this instance, it was used to model the interaction between students assessed individually but working in the social studio space. The dilemma was whether a student would choose to share information they had sourced individually with their colleagues or not. Even though this was a theoretical proposition, the authors suggest that structuring and restructuring of learning groups will take place based on the effectiveness of cooperation between individuals. In both these examples, this tension between cooperation and competition of participants was attractive, and ways to incorporate similar mechanisms in the context of concept design teams were subsequently explored.

6.5.3 Revised scenario

A revised version of Scenario 2 was constructed incorporating aspects of the Prisoner's Dilemma. Players were required to create concepts before going head-to-head, with the dilemma reframed by asking players whether to share or keep their concept. The overall aim was for players to collect the most concepts while having had to complete the fewest searching tasks. The reward structure was equated to search tasks and reversed so that the Sucker's Payoff was to conduct five search tasks and the Temptation was to do nothing. The search tasks were to either source new information items or to upload existing information to the digital library for use by other players. The storyboard for the interaction is shown in Figure 6.8.

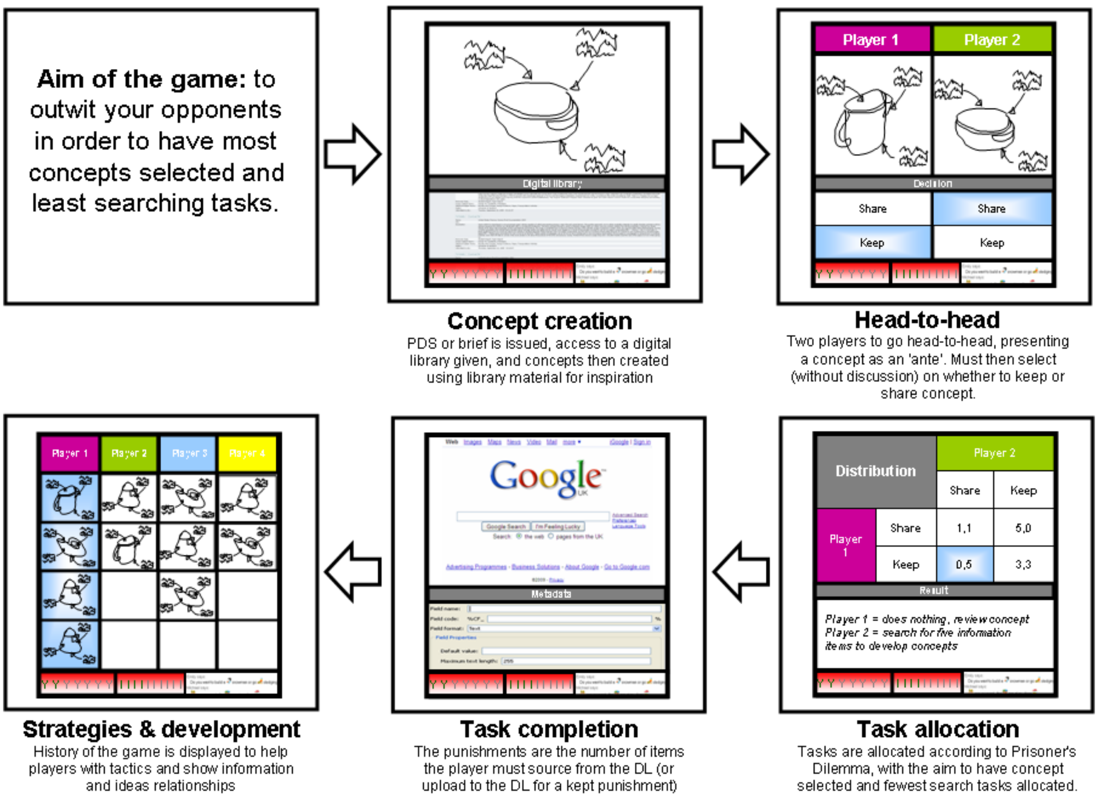

Figure 6.8: Revised scenario incorporating Prisoner's Dilemma (full-size version in Appendix III)

6.6 Summary

The stated aims of this chapter were to explore how computer gaming techniques could be used to enhance information use in product development teams, and to suggest frameworks for their application. A review of relevant gaming literature and an examination of computer gaming genres (including the evaluation of four titles) revealed a number of characteristics in motivation, interaction and structure that are applicable to the design team. These were developed to a storyboard level in scenarios visualising the implementation of these characteristics, and deliver a number of tangible suggestions on how gaming interventions can facilitate interaction with information. Based on a systematic evaluation, a scenario using Sim game characteristics was selected for further development. Augmented with additional ideas from game theory to optimise team engagement, a refined proposal for the implementation of a structured concept design approach to enhance information use has been outlined.

Chapter 7 Development of a structured interaction

This chapter reviews the development of a set of interaction mechanics for the improved use of information by design teams. After Chapter 6’s identification of computer gaming elements appropriate for use in the concept development process, and the Prisoner’s Dilemma as a potential means to facilitate team interaction, this chapter documents how a set of interaction parameters were defined and modified incrementally over a 6-month period. An iterative, paper-based approach was adopted, with the interaction defined, tested and revised a total of six times. A set of criteria (motivation, continuity, simplicity, flow, information management, concept management, scoring, and task allocation) were used to track changes made to the interaction during these revisions. The method was then formalised, with its three components (inform, create, reflect) linked to the three modes of concept design (analysis, synthesis and evaluation). A name and visual identity were then assigned to the method in preparation for formal evaluation.

7.1 Developmental approach

The acknowledged importance of prototyping in verifying the usability of games in development, and the particular effectiveness of paper prototyping as a means to achieve this (Federoff, 2002), was fundamental in refining the mechanics of interaction. As a result, a highly iterative approach was used with each increment tested in a controlled setting to ensure the outcome would be a robust and practical way for design teams to interact. The development was split into four main stages:

1) Initial form – An initial form for the interaction was constructed which utilised the primary features of the Prisoner’s Dilemma approach to co-operation, and which addressed the main requirements established for effective concept design.

2) One-on-one pilots – Two pilot tests were carried out to clarify basic interaction mechanics, based on the use of a wiki page as the means of collaboration. An informal approach allowed comments to be collected and necessary adjustments made.

3) Co-located tests – A series of concept generation sessions were developed for a co-located scenario. A paper-based system was used to focus on the mechanics of the game and issues of team dynamics rather than technological issues. Again, informal feedback and comments were gathered to further refine the interaction.

4) Formalisation– The interaction mechanics were finalised for evaluation in controlled experimental conditions.

7.2 Initial form

The previous chapter outlined the basic principles of the Prisoner's Dilemma as a way to encourage participants to interact by evaluating each others' concepts and linking this to a reward structure requiring participants to search for and add information to concepts. This initial approach was then developed into a set of workable rules for team-based concept design. The approach works on the premise that all participants aim to make their concepts as well-developed, well-informed and attractive as possible during the concept generation stage in the hope it will be selected as the concept for further development. It provides a mechanism where players go 'head-to-head' with their concepts using the *co-operate* or *defect* choice presented by the dilemma.

This is the major difference from a traditional Prisoner's Dilemma situation – it is usually simply a choice to either co-operate or defect with no consideration of information that the other player has presented. This makes the interaction less pure in the sense that it is no longer just about iterations of co-operation and defection, but also about players' judgement of additional material. This shift is reflected in the terminology used in the thesis: *interaction* (as opposed to *game*), and *participants* (as opposed to *players*) are used from this point onwards in referring to the activity of the team. The interaction consists of rounds, and for each round all participants must have produced a concept. After examining each others' concepts, the participants are presented with a variation of the Prisoner's Dilemma where they have to decide whether to co-operate or defect, i.e. rate the concept. The choice to co-operate indicates that they think it is a good idea, defect indicates they think it is a poor idea.

The motivation of the interaction relies on the reward structure outlined in the previous chapter (Table 6.3, p130). In the traditional Prisoner's Dilemma, these usually score points for the player. For the adapted interaction, however, the payoffs were used to allocate tasks to the participants. This is where tasks relating to finding and using information would be introduced, and these were ordered anticipating that participants would gravitate towards sketching and 'ideator' activity over research and 'collector' activity (Puccio, 1999). It was expected from the outset, however, that this reward structure would be one of the main items for adjustment in the developmental iterations of the interaction.

The Prisoner's Dilemma is typically played in very large numbers with a long history of moves. There is a discount parameter (ω) for multiple rounds, meaning that rounds diminish in importance as the game progresses. In this case the discount parameter was not considered appropriate (i.e. a value of 1 was used) as the relatively low number of rounds meant that they were all equally important. An alternative that was briefly considered was weighting the rounds according to the PDS, and this element can be seen in the 4th iteration of the co-located tests (below).

Also, ideally there is usually an unpredictable game length, as a fixed length can logically lead to a pattern of defection: on the last move, there is no incentive to co-operate as there are no future implications. On the next-to-last move neither player has a strong incentive to co-operate as it is likely their opponent will defect on the next move. This reasoning can be followed back to the first move of the game. It was assumed in this case, however, that participants would not be so absolute in the use of such tactics, even if they were aware of the number of rounds left in the session.

7.3 One-on-one pilot studies

Two initial pilot studies were carried out using just two people (the author plus one other) to develop the basic mechanics of interaction. The intention was to conduct as much of the interaction as possible using wiki pages to try and emulate the virtual environment envisaged for the final system. The storyboard for the interaction is shown in Figure 7.1.

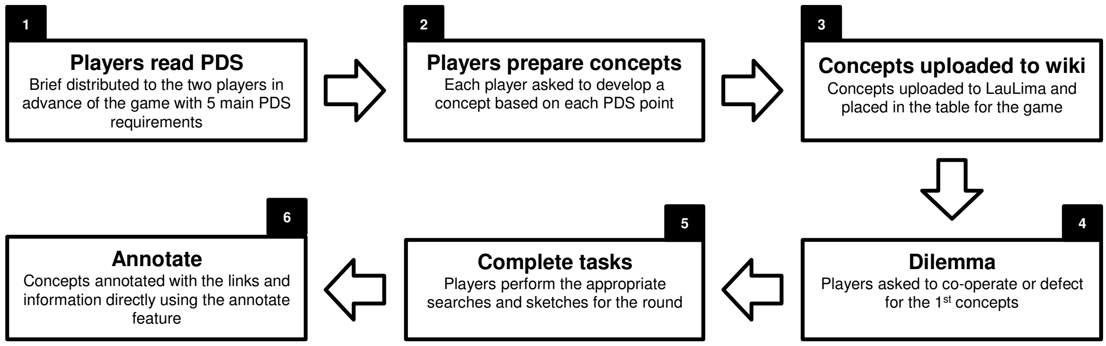

Figure 7.1: Storyboard for pilot studies

First, a wiki page was constructed and all the relevant information required for the session uploaded. This included the participants' sketches as well as the PDS documents, to minimise the inconvenience of uploading during the interactions. The studies took place in a co-located setting with participants analysing the other person's concepts before simultaneously turning over cards to reveal their decisions in each round. Each of these interactions resulted in tasks being allocated according to the Prisoner's Dilemma matrix. The outcome for each of these is illustrated in Table 7.1. On the distribution of tasks, participants searched for appropriate items, uploaded them to the wiki page, and developed them directly using an annotation feature.

Payoff	Rank	Outcome
Temptation (T)	4	You must make 3 interventions to enhance your opponent's concept based on digital library items (opponent does nothing).
Reward (R)	3	Both participants must search externally and upload 2 items to the digital library related to the PDS point.
Punishment (P)	2	You must make an intervention to both your own and your opponent's concept based on digital library items. Your opponent does the same.
Sucker's Payoff (S)	1	Do nothing.

Table 7.1: Revised reward structure for one-on-one pilot study

7.3.1 Summary

Although the pilot studies were useful in understanding the Prisoner's Dilemma and motivations for making various decisions, the terminology and associated technology associated meant that they did not run as smoothly as was hoped. Uploading links and annotating sketches on the wiki page (shown in Figure 7.2) was overly laborious, seriously inhibiting the flow of the session, and there were frustrations in waiting for others to complete tasks. It became difficult to discern whether if played faster the interaction would have had the fun element that was desired. Additionally, the preliminary library supplied to participants had only eight initial items, and it was felt that this inhibited the suggestions made to develop concepts further. Although there was some evidence that the interaction provided a forum to enhance concepts and the sessions resulted in some promising output, it was necessary to address the fundamental technological issues associated with scanning and uploading to wiki pages for the interaction to be workable on a larger scale.

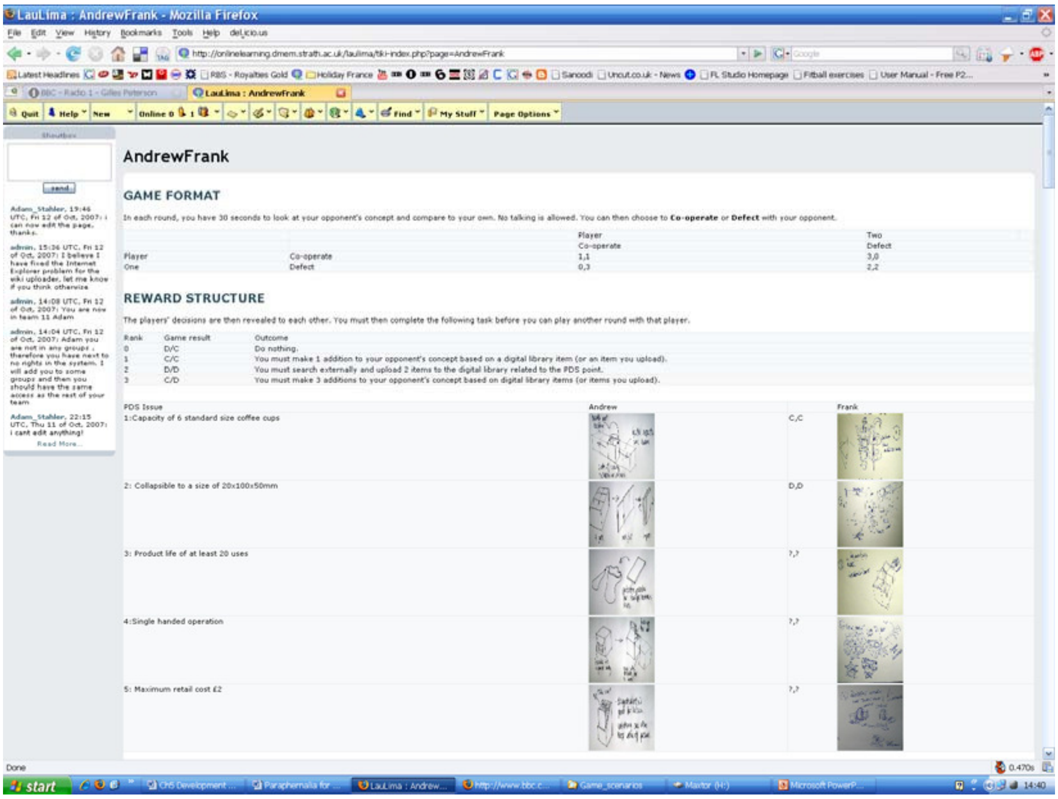

Figure 7.2: Screenshot of the wiki used for one-on-one pilots

7.4 Three-way co-located tests

After completion and review of the pilot studies, development of the interaction then moved to a second level based on tests using groups of three participants in a co-located situation. Although the mechanics of the approach could be scaled up to larger numbers, groups of three were used to keep the logistics as simple as possible. In order to avoid the technological issues experienced in the pilot studies, and to focus further on the mechanics of the interaction, it was decided to utilise a paper-based set-up augmented by use of laptops for information searching. The physical environment is shown in Figure 7.3 – each participant was provided with pens and paper templates to document the creation of concepts, information searches and the addition of annotations, with all the output from the sessions collated and presented on a board at the front of the room.

Figure 7.3: Physical environment for co-located tests

The primary form of communication for participants was through the content of their concept sketches. Verbal communication was not eliminated completely – participants could still talk regarding the information they had found and make suggestions for improving concepts – but they were asked to judge concepts based purely on observation so as to prevent personalities and powers of persuasion becoming a factor. This focussed efforts on the concepts and using information in a concentrated way. Given the more considered format of the approach, it was unrealistic to expect a quantitative output similar to that of rapid generative approaches such as brainstorming. It was anticipated, however, that the resulting concepts would be more robust and have higher levels of embodiment. This aligned the interaction more closely with the 6-3-5 Method and other more progressive techniques where concepts are developed within the concept design session.

The reward system was critical to the success of the approach, and based on the results of the pilot studies an initial mechanism was developed to allow three participants to exchange concepts and ideas using the Prisoner's Dilemma as a way to evaluate each others' ideas while maintaining an ultimately collaborative approach to the concept generation task. A storyboard outlining the procedure for participants is illustrated in Figure 7.4. Since the concept generation team have a common goal and a natural tendency to co-operate, the structured interaction of the dilemma acted as a stage-gate moment for comments and judgements to introduce some light relief. It was intended to help the team bond while utilising a mildly competitive element to increase productivity.

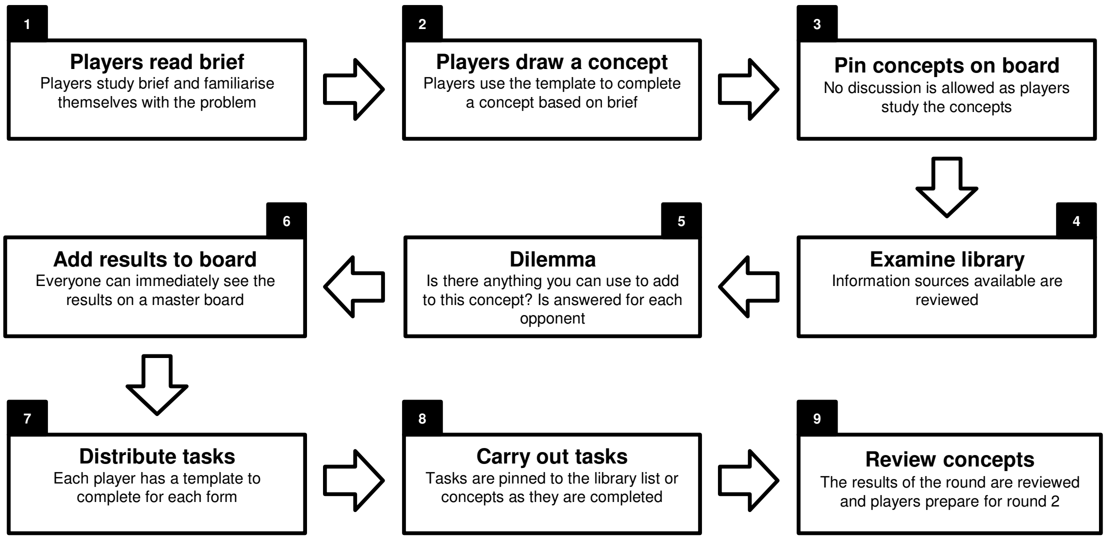

Figure 7.4: Storyboard for co-located tests

Participants in the tests were researchers and academic staff with a background in design engineering. After each iteration, feedback was acquired and, in conjunction with observation of session progress and analysis of output, changes were made to the interaction format. In order to track the changes through these revisions, it was necessary to quantify characteristics relevant to the usability of the approach (Ip & Jacobs, 2004; Pinelle, et al., 2008). These key characteristics included: *game motivation, concept threads, reflection, pace, digital library, sketching & annotation,* and *task distribution*. The changes made from revision to revision are summarised in Table 7.2 and are described in more detail below.

Feature	Issue	Revision I	Revision II	Revision III	Revision IV	Revision V
Game motivation	*The rationale for utilising a game mechanism was that it could be tailored to blend engaging co-operative and competitive behaviour.*	Ranking of outcomes and changed from 0-3 rather than 1-4, with 0 being the 'best' outcome. Task allocations reversed to encourage players not to consistently choose design rather than search option.	0 task altered to review own concept rather than develop new ones. Scores written on board at end of each round to increase visibility.	Score allocation shifted from the decisions made to judgement from other players. Three outcomes, with two 'yes' votes being most desirable – develop your own concept.	Crossing the game board from left to right introduced as a motivating element, with scoring system discarded. Allowed players with two yes votes to jump to next category.	Positive judgement scores, concept perseverance scores, search task scores Players can score for positive judgement, concept perseverance and searching.
Concept threads	*Ensuring that developmental threads between concepts of merit emerged was a key component of the approach.*	Players created and retained their own concepts – other players asked to provide feedback or developmental suggestions.	Concepts passed to the next player if they are going to be developed. Concepts with two negative votes dropped.	Identical to previous session.	Board layout changed so concepts move horizontally across board and again retained by participants. Interactivity assured by concept evaluation and developmental tasks	Reverted to rotating concepts around participants in each round. Fixed path for creation of concepts and adding relevant information based on decisions.
Reflection	*The Prisoner's Dilemma required optimisation so that it was meaningful and easy to grasp for participants.*	Dilemma decision changed from 'defect/co-operate' to 'yes/no'. Players circled decision on table rather than turning cards.	Dilemma question changed to 'do you think this idea is worth developing?' and more onus put on concept evaluation.	The same dilemma question used, but decision rationale improved by the fact that judgement has no effect on individual's own task allocation.	Task allocation moved back to player's own judgement decisions and simplified to yes means sketch and no means search.	Head-to-head element removed completely - participants instead reflect individually on the concepts passed to them.
Pace	*The time allocated for tasks during the sessions was an important factor: the aim was to maintain 'flow' while ensuring that quality was maintained.*	Simplifications to sketching, annotation and dilemma implemented to try to increase speed marginally, allowing for more rounds in given timeframe.	Displayed fixed time intervals on a clock to ensure better timekeeping. Limited the amount of metadata to be added for each new information item.	Similar in format to previous session but greater allocation of tasks within similar timeframe.	Two different round lengths introduced – five minutes for a sketch round, three minutes for a reflect and develop (search or add) round.	Round lengths equalised at four minutes per concept sketch and four minutes per reflect and develop, allowing six rounds in 44 minutes for three participants.
Digital library	*Library composition, including preliminary and generated items, was monitored for impact on the concepts produced.*	Information from previous pilot tests added to increase number of preliminary items in library to 9 for increased diversity.	New project brief (can crusher) developed and number of preliminary items increased further to 12.	Information item template simplified and matched to task annotation template. Identical project brief and library items as previous session.	Coffee cup brief utilised again. Library expanded to 14 items and printouts of front pages included for participants' information.	Three items provided tailored for product, six more generic items appropriate for both briefs. The mechanics of the game should ensure that it grows significantly. OneNote used to share.
Sketching & annotation	*The manner in which participants were expected to sketch, annotate and alter concepts required to be simplified as far as possible.*	Sketches created as game progressed and pinned on board rather than uploaded to wiki page.	Improved the annotation template to make it simpler to use. Asked players to pin annotations for concepts on the board themselves.	Round allocation increased to two searches, a search and annotation or two annotations (i.e. always two elements) to try and increase activity during session.	Round allocation decreased to one search or one sketch depending on other participants' judgements.	Participants issued with 'books' in which to sketch concepts and add information reference. Digital items captured in electronic format using OneNote.
Task distribution	*It was necessary to refine the allocation of tasks according to decisions made during the game to ensure the session ran smoothly.*	Players scoring 0 asked to check library and develop new ideas during task period.	Increased visibility of timings. If a task is not completed by the end of the round, players asked to carry it forward to next round.	Simplified to three possible task outcomes depending on scores from other participants.	Additional variation in payoffs meaning that players can move two squares for two yes votes, one for one yes and remain on same square for two no's.	Simplified to one vote per round with two possible outcomes – yes develop using new information, no develop using existing information.

Table 7.2: Summary table of interaction development

7.4.1 Revision I

A project brief to design a coffee cup holder for transporting multiple cups from the coffee shop to the office or workplace was developed and an accompanying digital library created. One of the main observations from the pilot studies was that participants were uncomfortable with some of the overtly competitive terminology used. As a result, the wording of the dilemma was changed to '*are you prepared to add to this concept using information from the library*?' when evaluating concepts. Additionally, yes or no answers were used as alternative to co-operate or defect. The reward structure was revised on the assumption that designers would rather focus on the creation concepts than searching for information. Tasks were allocated to participants based on the judgement they made on concepts in the dilemma. This meant there was a temptation to refuse to add to their colleagues' ideas, adding a measure of intrigue. The 'winner' was the participant who had the lowest score at the end of the rounds, having had the most time to spend develop their ideas and use information found by others. Given the tendency of designers to favour modes of creative synthesis (Owen, 2007) this was viewed as suitably desirable for participants. The reward structure was therefore revised, and tasks allocated to the rankings as set out in Table 7.3.

Rank (score)	Outcome
0	Do nothing (check library, develop new ideas)
1	Add 1 annotation to your opponent's concept based on an item from the library
2	Add 1 item to the wiki page by searching externally
3	Add 1 annotation to your opponent's concept based on information searched for externally (and added to the library)

Table 7.3: Reward structure for Revision I

The results board, shown in Figure 7.5 and reproduced on a larger scale in Appendix IV, was split into three areas: the library at the left, concepts in the centre and scores at the right. The rounds of the interaction formed horizontal bands across the board, and the participants' concepts were split into columns. As participants found additional material for the library, this was added at the left hand side. Unlike the pilot studies, the concepts were formulated at the beginning of each round prior to search and development activities taking place. The decisions and scores for each round were then entered and totalled at the right hand side.

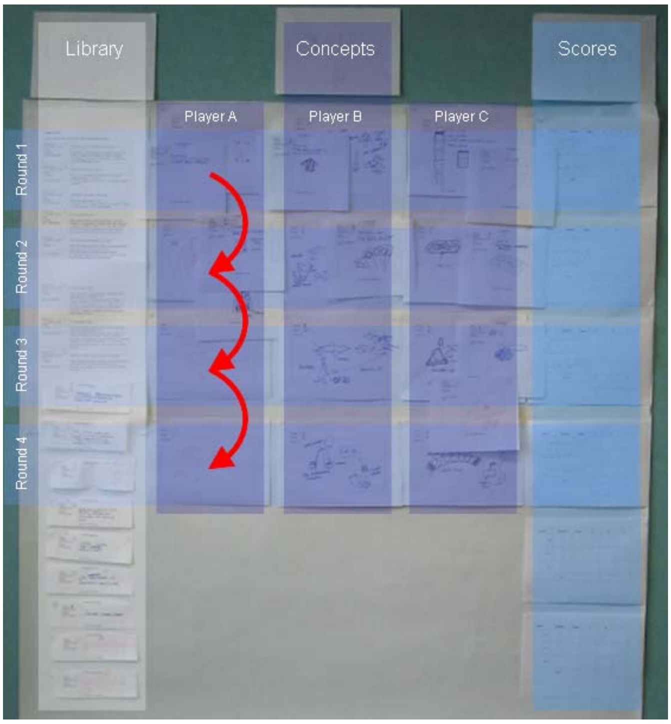

Figure 7.5: Results board for Revision I (full-page version in Appendix IV)

7.4.2 Revision II

A new project brief to design a can crusher and a new set of digital library items were created. The reward structure was altered slightly so that participants who were allocated a 0 task were asked to review their concept rather than do nothing. Additionally, it was decided that if a concept received two negative judgements from the other participants then it would drop out of the session and a new concept thread started in its place in the following round. The task allocations are shown in Table 7.4.

Rank	Outcome	Task
0	Review	Review your own concept
1	Add	Add 1 annotation to your opponent's concept based on an item from the library
2	Find	Add 1 item to the wiki page by searching externally
3	Find & Add	Add 1 annotation to your opponent's concept based on information searched for externally (and added to the library)

Table 7.4: Reward structure for Revision II

The results board for Revision II is shown in Figure 7.6. The major change made to the interaction structure was that instead of participants working only on their own concepts, they were now moved across the results board during each round. This meant that concepts were rotated at the end of each round, and rather than just make suggestions for other participants' concepts, they would actually take them on and develop them.

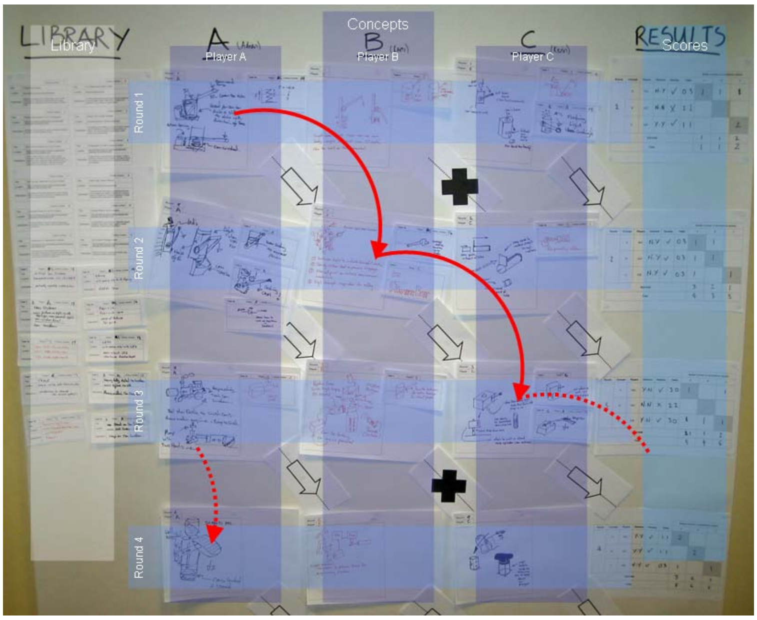

Figure 7.6: Results board for Revision II (full-page version in Appendix IV)

7.4.3 Revision III

In this revision, participants from Revision I were again invited to take part. They were, however, using the can crusher brief developed for Revision II which they had not seen. This meant that despite having some experience of the interaction and how it worked, they would be working on a new design challenge. A fundamental change was made to the reward structure for this iteration, with the task allocation being based on the concept judgement received from other participants rather than the judgement made by the participant themselves. It was hoped this would result in a more rational analysis of concepts. The reward structure was also simplified so that two tasks were always issued to participants. It again worked on the basis that participants would rather spend time developing their concepts than searching for information, and the allocations (as shown in Table 7.5) reflect this.

Decision	Develop?	Outcome	Task
Y, Y	Yes	Add, add	The best outcome. Add 2 annotations to your concept using items from the digital library.
Y, N	Yes	Add, search	A mixed result. Add 1 appropriate item to the digital library and use it to add 1 annotation to your concept.
N, N	No	Search, search	The worst outcome. Idea will not be developed. Find two appropriate items to add to the digital library.

Table 7.5: Reward structure for Revision III

The results board for Revision III is shown in Figure 7.7. The structure of the interaction was similar to the previous session in that participants rotated ideas as the rounds progressed. Some effort was made to rationalise the format of the library, simplifying the template for when participants added new information items.

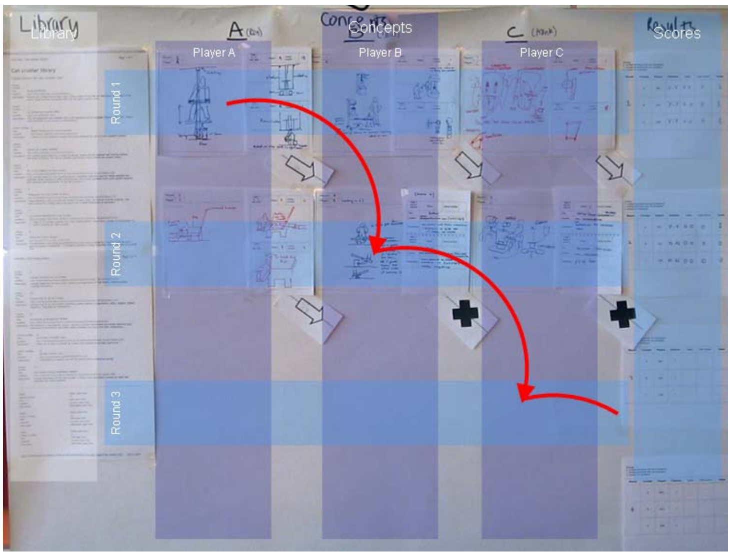

Figure 7.7: Results board for Revision III (full-page version in Appendix IV)

7.4.4 Revision IV

For Revision IV, task allocations were again moved back to the participants' own judgement decisions (i.e. as with Revisions I and II, the judgement passed by a participant related directly to the type of task they had to do). However, this was simplified to a yes answer equating to a sketch task and a no answer equating to a search task, and moving the reward structure away from the classic Prisoner's Dilemma format to a more basic reward structure, as shown in Table 7.6. This was intended to make the approach easier to understand, but depended on participants making appropriate critical judgements on concepts for new information items to be introduced to the session.

Decision	Develop?	Outcome	Task	Board move
Y,Y	Yes	Add, add	A and B do a sketch for the concept	Move two spaces, or next category
Y,N	Yes	Add, search	A does a sketch for the concept, B does a search for the concept	Move one space
N,N	No	Search, search	A and B do a search for the concept	Stay on same space and draw again

Table 7.6: Reward structure for Revision IV

The structure of the results board, shown in Figure 7.8, was altered significantly, with participants now working their way from left to right across it. In doing so, participants were asked to address specific requirements from the PDS to focus creativity and ensure that all major elements were address during the session. Library items were categorised according to these PDS requirements and placed below the concepts on the board. The primary goal was altered from trying to achieve the highest score to trying to move across the board the fastest. To this end, board moves were added to the reward structure, so if a concept received two positive reviews the player in question would jump a square to the right.

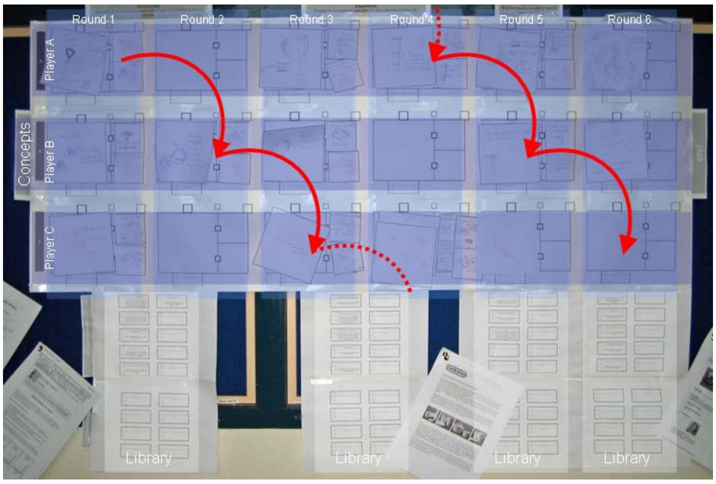

Figure 7.8: Results board for Revision IV (full-page version in Appendix IV)

7.4.5 Revision V

It was decided that in order to simplify the mechanics of the interaction still further the dilemma aspect would again have to be reconfigured. Rather than using the ‘head-to-head’ format, it was decided instead to allow participants to make individual assessments based on the concept passed to them. If a participant made a yes decision, they would develop the concept with a new library source, if they made a no decision they would develop it with an existing library source (Table 7.7). This encouraged participants to vote no if it was appropriate, as any yes vote would require a search task to be undertaken.

Decision	Rank	Outcome	Task
Y	1	Search	Develop existing concept with new library source
N	1	Sketch	Develop now idea from existing library source

Table 7.7: Reward structure for Revision V

The horizontal layout of board progression was retained, however the concept of ‘racing’ across it was abandoned. Instead, a basic scoring system was introduced based on the number of positive concept votes and information items uses for each participant. This pushed the competitive element into the background and moved the mechanics further towards a 6-3-5-type approach in the progressive generation of ideas. Also, the way in which the sketching templates were presented to participants was altered – a ‘book’ was used which clearly outlined the ‘inform, create, reflect’ path taken as decisions were made during the session, and were also easily passed around the group at the end of each round. The digital library was managed entirely through the Microsoft OneNote program (described in more detail in Section 8.2.3, p.155), with participants finding and sharing their sources in a dynamic document accessed through the laptops issued.

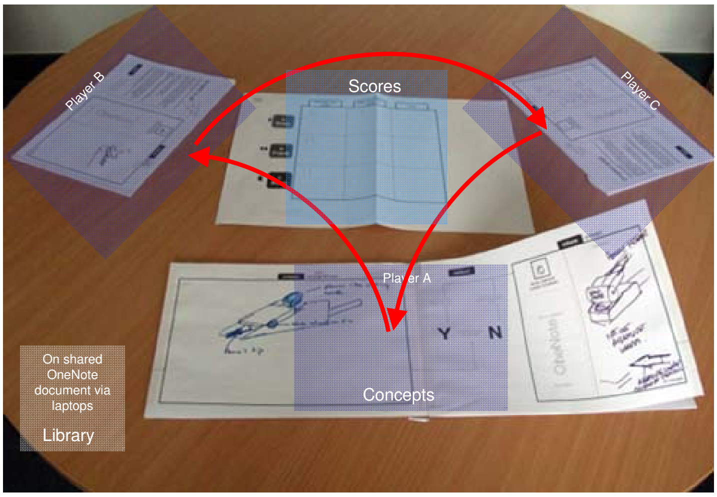

Figure 7.9: Results board for Revision V (full-page version in Appendix IV)

7.4.6 Formalisation

The design approach was finalised in preparation for formal evaluation. The format of rotating concepts and asking participants to assess them individually was deemed successful: despite removing some of the competitive aspects, it simplified the interaction mechanics considerably and maintained a good level of engagement. The reward structure was refined so that a yes decision equated to a search task and a no decision equated to a sketch task for the concept reviewer (Table 7.8). This counterbalanced the tendency for participants to vote yes with the fact that such a decision required them to search rather than sketch.

Decision	Rank	Outcome	Task
Y	1	Search	Find a new, relevant information source
N	1	Sketch	Browse library for inspiration, create new concept

Table 7.8: Reward structure for final version

The separation of searching and sketching tasks meant that the rotation of information and ideas was clearer than in previous revisions. Each task was allocated five minutes to ensure that a significant amount of material would be generated and rotated around the group in a thirty minute session. The implementation of OneNote was developed further with the table for depositing information items refined for ease of use. It was decided to eliminate the preliminary items altogether, with the entire focus on the creation and use of new items as appropriate for the design context. Finally, the concept books were further simplified to clarify the tasks undertaken by each participant as a result of the decisions made during the session. The overall interaction – when fulfilling its function in the design process appropriately referred to as a method – in its final form is summarised in the form of a flowchart (Figure 7.10).

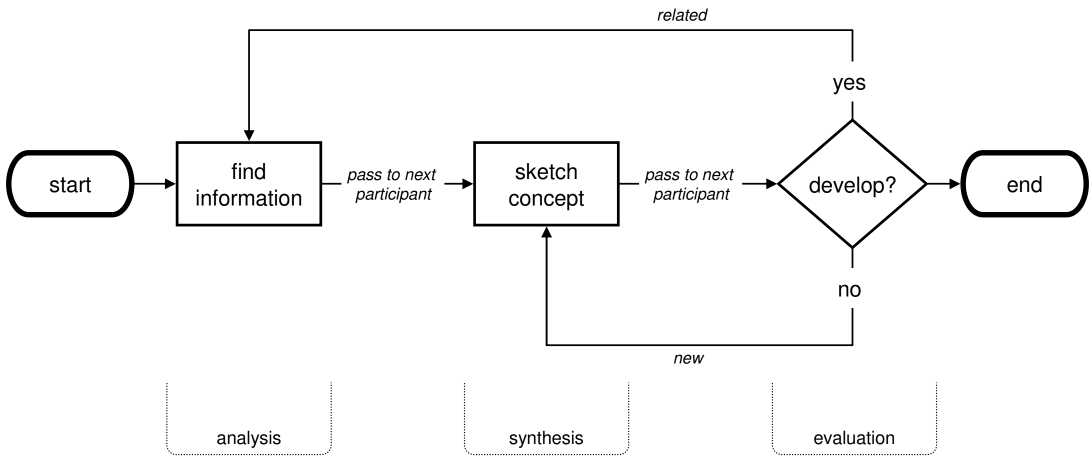

Figure 7.10: Flowchart for final interaction

Evolving from the studies on gaming techniques, the integrated method facilitates the continual shift from *informing* to *creating* to *reflecting* as concepts are developed. The emergence of three discrete elements experienced repeatedly relate closely to the movement between the three modes of creative design – analysis, synthesis and evaluation – discussed at length in Chapter 3 and illustrated in Figure 3.3, p.48. This cyclical, activity-based method encapsulates the elements of the phase-based, linear concept design process while increasing their integration. The name selected for the method was the 'ICR Grid', standing for 'Inform, Create, Reflect' and indicating the way that concepts and information are integrated in a grid structure. The graphic identity for the ICR Grid is shown in Figure 7.11.

Figure 7.11: Graphic identity for the ICR Grid

The graphic identity was inspired by the 1956 lithography 'Prententententoonstelling' *(The Print Gallery)* by the Dutch graphic artist lithograph by M.C. Escher (Figure 7.12). It shows a man viewing a print of a Mediterranean seaport in a gallery. As his eyes follow the print from left to right, the buildings in the scene become part of the gallery in which he is standing. The mathematical grid Escher used to create this blurring of the internal and external world was based on an elliptic curve to provide a seemingly seamless transition (de Smit & Lenstra Jr., 2003). This 'cyclic expansion… without beginning or end' provides inspiration for the ICR Grid: its assimilation of the abstract, pictorial representation into the real world is loosely analogous to how information items are utilised to create tangible concepts through the integrating structures of the method.

Figure 7.12: 'Prententententoonstelling' by M.C. Escher (© Cordon Art-Baarn-the Netherlands)

7.5 Conclusions

As shown by Table 7.2 (p.140), the interaction went through significant changes during its development phase. The gradual shift from the classic Prisoner's Dilemma to an *inform, create, reflect* cycle (Figure 7.13) was driven by an intention to simplify the interaction as far as possible. This process was based on feedback from participants during the series of tests conducted, and resulted in a method which encapsulates the main elements of conceptual design thinking (analysis, synthesis, evaluation) in a cyclical framework. Additionally, it enhances interaction with information by supporting retrieval and application in parallel with concept creation and development. This results in the output of a linked information resource alongside concept sketches, making it distinct from other concept design methods.

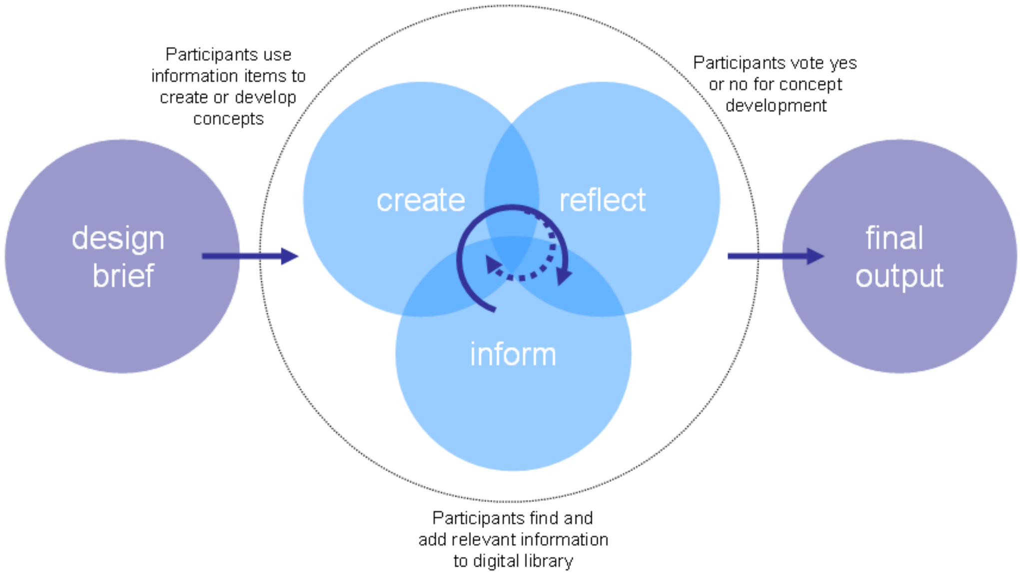

Figure 7.13: Overview of the ICR Grid

While there was a consensus that the proposed approach introduced new and interesting parameters into the concept design sessions, the mechanics were initially too complex. They required significant facilitation by the author to progress satisfactorily, preventing participants from finding a state of flow. The many refinements to the reward structures and task allocations aimed to address this by making the interaction as clear and robust as possible. By the sixth iteration (Finalisation) it was felt that this was achieved to a satisfactory level. Although testing took place with groups of three, the final form is scalable for larger (or smaller) groups and it was planned to experiment with this during evaluation.

7.6 Summary

This chapter has documented the iterative development of a new concept design method. This was achieved through paper-based tests where the mechanisms of interaction were refined until they were considered robust enough for formal evaluation. The method has been named the ICR Grid in light of the way it encapsulates the three main elements of concept design while integrating information and ideas in a grid-like structure. This chapter additionally marks the end of Phase c (*development*), with Chapters 6 and 7 having outlined the adoption of gaming techniques and traced the development of a feasible design method. The following chapters are concerned with the evaluation and application of the ICR Grid.

Chapter 8 Comparison of 6-3-5 Method and ICR Grid

This chapter marks the beginning of the final phase of the research, Phase d (*application & reflection*). Having developed and refined the ICR Grid to a suitable level, a sequence of evaluation and application began. This chapter begins the process by describing a comparative study between the 6-3-5 Method and the ICR Grid. The ICR Grid can be considered an evolved variant of 6-3-5, intended to better integrate information into the concept generation process. Unlike a conventional 6-3-5 process where participants continually sketch concepts, using the ICR Grid participants are additionally required to undertake information search tasks, use specific information items for concept development, and reflect on the merit of concepts as the session progresses. A quasi-experimental evaluation using eight different teams and two different design briefs were used, with the aim of establishing whether the interaction led to enhanced conceptual output. The results indicate that although the quantity of concepts was lower, the use of information had a positive effect in a number of areas, principally the quality and variety of output.

8.1 Comparative study

Since the main element being examined was the use of information to improve concepts, it was decided that the ICR Grid should be compared to Rohrbach's 6-3-5 Method (1969) as they share many similarities in terms of individuals exchanging sketched concepts in a structured way, with the ICR Grid differing principally in that participants are required to find and use information, and to reflect on concepts produced by others. A comparison of the two approaches, then, afforded the opportunity to examine in detail the effect these elements had on the concept design output.

As the name implies, the 6-3-5 format involves a team of six participants who each sketch three ideas every five minutes. After each five minute round, the concepts are passed round to the adjacent participant. The team is then able to draw on others' ideas for inspiration as they wish. If all participants complete the session properly, a 30-minute session should produce 108 ideas with the most promising results used for further concept development and evaluation. In this instance, the sessions actually utilised a ‘3-X-5’ approach: the teams consisted of only three members, and rather than demanding three concepts per round, it was emphasised that participants should create as many concepts as they felt they comfortably could in the time.

This alternative approach provided a better comparison with the ICR Grid, and additionally allowing the rate of concept creation to be reviewed as a variable of the sessions. Although it was envisaged that the final version of the ICR Grid would be applicable – with a number of amendments – to the distributed situation, it was decided that these would, as with the pilot and development studies, be conducted in the co-located format to ensure better mimicking and control of the interaction mechanics. A mixture of off-the-shelf software, available hardware and physical media such as paper and pens were used where appropriate as an alternative to programming a fully realised version of the method. This would have absorbed a significant amount of developmental time, when the focus of the research was on the interactions of the design team rather than the software itself.

8.1.1 Aim

The aim of the experiments was to establish the effectiveness of a controlled interaction in improving the overall quality of design concepts. The studies in Chapter 4 regarding the use of information sources as stimuli showed how *team concept design can be positively affected by access to appropriate information*. Chapter 5 went on to propose that the *use of information sources can be optimised through a structured team interaction*. Chapters 6 and 7 have documented the development of the mechanics of a new approach to concept generation. The study in this chapter aims to *evaluate the effectiveness* of the method using a comparison with the 3-X-5 Method. This is achieved by analysing how information use in the ICR Grid affects the conceptual output of the team using a variety of established metrics (quantity, detail, novelty, variety and quality) and reviewing questionnaire feedback from participants. In addition, use of design requirements and team communication, which were previously highlighted as important additional factors in the concept design task, have been monitored for their effect on the concepts produced.

8.2 Structure

Teams of three were formed randomly from a pool of twenty four senior undergraduate MEng students and postgraduate MSc students, all with an engineering background. This provided eight teams, which on reviewing the results was deemed sufficient by the author in providing clear indicators and patterns across sessions. In each session, the team had to undertake two 30-minute concept design tasks: one using the 3-X-5 Method and one using the ICR Grid. The overall format is shown in Table 8.1. In each session, teams used the 3-X-5 Method first. This allowed participants to become familiar with the general principle of passing concepts around the team prior to undertaking the more complex workflow of the ICR Grid.

Brief A was to design an ice cream scoop, Brief B was to design a chisel-edge pencil sharpener. These were chosen by the author as familiar problem contexts of similar complexity. They were also deemed to provide sufficient scope for basic mechanical innovation. The brief for each task specified three key requirements for each design, e.g. suitable for one-handed operation, easy to wash etc. to force participants to consider some design parameters when undertaking the tasks. In order to ensure that the brief was not an unbalancing factor, half the teams used the ICR Grid to tackle Brief A and half used it to tackle Brief B. This allowed discrepancies caused by the brief to be examined.

It was recognised that the dynamics created by personalities would inevitably result in variations in performance across the teams. In addition to having eight sessions to compare, having two tasks allowed internal comparison on how team productivity was affected, i.e. if a team had a high level of productivity in relation to others, a comparison could still be made between the ICR Grid and 3-X-5 Method.

Session	Task 1 Using 3-X-5	Task 2 Using ICR
1 2 3 4	Brief A	Brief B
5 6 7 8	Brief B	Brief A

Table 8.1: Format of sessions

8.2.1 Physical set-up

The experiments took place in a co-located setting similar to the previous developmental tests, with participants working face-to-face. Although an important potential application for the structured concept generation approach is the distributed situation, it was felt that a co-located setting provided greater control in terms of experimental set-up and variables, while still allowing adequate evaluation of ICR Grid performance. The set-up, as shown in Figure 8.1, was almost identical for the two tasks (using 3-X-5 approach, using ICR approach). For the 3-X-5 task, each participant was issued with a briefing document and paper template to complete their concepts. During each round of the session, participants completed sketches in the allocated spaces of the paper template before passing it to the adjacent participant. The paper templates then continued to rotate around the team in this manner. For the ICR Grid task, each participant was issued with a briefing document and similar paper template for completing concepts and circulating around the team, but were additionally issued with a laptop to find and manage digital information during the session. Unlike the protocol studies in Chapter 4, which highlighted the role that information can play as stimulus in concept design, no transcription of the sessions took place as the focus of evaluation was on output.

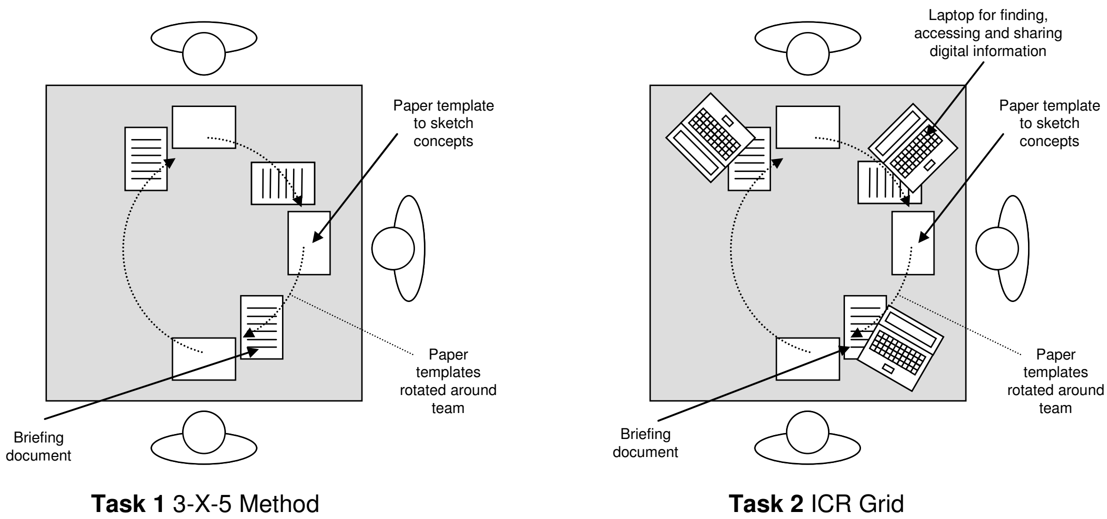

Figure 8.1: Physical set-up for sessions

8.2.2 Paper template

It is envisaged that the information-enhanced method would ultimately be incorporated into a digital environment. The programming and configuration of such a system was not, however, deemed integral to the research and was therefore not undertaken for the purposes of the study. Instead, it was decided to proceed with a paper-based format similar to that used in the previous developmental tests for documentation of design sketch work, integrated with digital support for information sharing. The paper templates issued to participants were in 'book' form – it consisted of a series of pages with spaces to identify the resources used and to sketch concepts, as shown in Figure 8.2. The books were then rotated around the team as the session progressed. Each participant was asked to use a particular colour of ink to help identify the creator of each concept. At the end of the session, the books could be opened out and placed in parallel to show the overall progression.

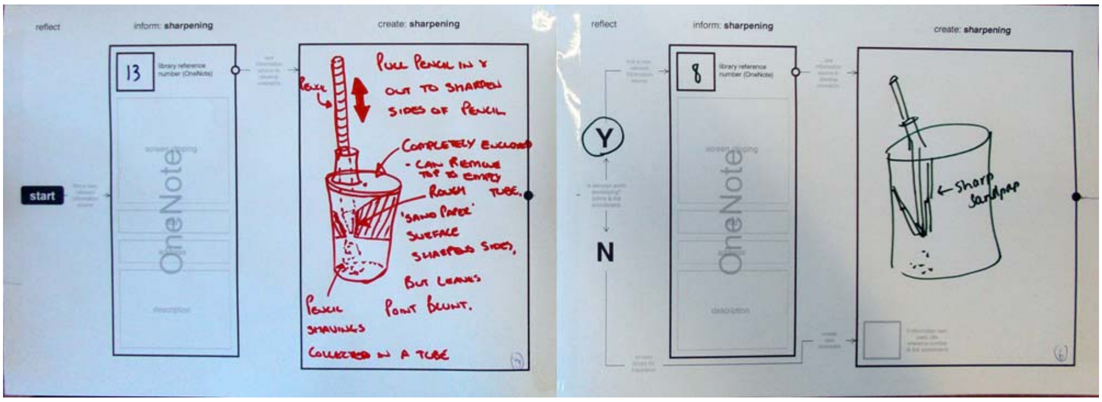

Figure 8.2: Paper template in book form, showing Session 3, Thread 1, Rounds 1-4

8.2.3 Software set-up

The software used on the laptops to manage the shared information resources was Microsoft OneNote[31], an integrating package that allows information from a range of sources, including notes, documents and screen clippings, to be captured and shared. The result is an information hub more akin to a designer's notebook than a traditional electronic document, with an informal mix of media. A crucial advantage of OneNote for use as an information management tool in the sessions was that it allows a group of people to open and edit a document simultaneously. Utilising the clipboard feature which allows areas of web pages to be selected, dragged and dropped into the shared document, was found to be a good way to create a reasonably dynamic and responsive shared digital library.

With the addition of some accompanying text, the thumbnails pulled from the most relevant aspects of web pages allowed a group to quickly share and assimilate the information found online by employing, like Cooliris[32] and Visual Thesaurus[33], a more visual way to browse the information sources when compared with the more traditional format of the LauLima Digital Library (as reviewed in Chapter 5). There, information is presented in list-based structures, and the addition of metadata is mandatory for all new items uploaded, whereas using the OneNote set-up allowed more informal storage and categorisation.

It was decided to specify Google[34] as the primary method of searching for new information. If participants were going to spend time searching in what is generally a very fast-moving phase of the design process, an extremely straightforward method of searching was necessary. Typing a word into Google and browsing the displayed results is familiar and easily accomplished. It was originally intended to supply participants with key textbooks and a digital camera so that if there was a physical resource they wished to add to the library, whether from a book, sketch, or model, they could do so. However, on consideration it was not felt that this option would be heavily used, primarily because of the time pressures associated with maintaining momentum in the session and it was therefore not offered. The migration of information from the web to the OneNote environment is illustrated in Figure 8.3.

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[31] http://office.microsoft.com/en-gb/onenote/default.aspx (Accessed: 8th January 2010)
[32] http://www.cooliris.com (Accessed: 8th January 2010)
[33] http://www.visualthesaurus.com (Accessed: 8th January 2010)
[34] http://www.google.com (Accessed: 8th January 2010)

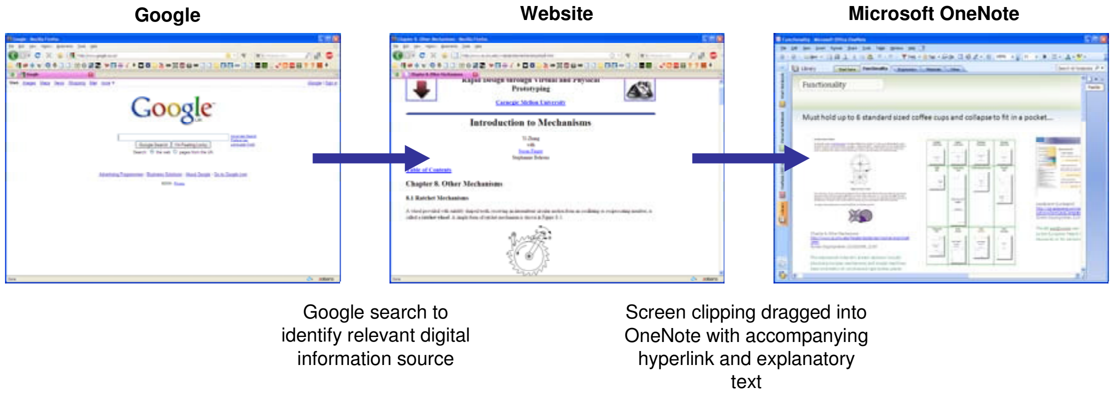

Figure 8.3: Acquiring and sharing digital resources

8.2.4 Experiment variables

The independent variable of the sessions was the mechanism used for the concept design task – the ICR Grid vs. 3-X-5. The aim was to keep all the other factors as near to identical as possible, and measure the effect of the method on the teams' output. It was therefore necessary to develop a set of appropriate criteria in order to monitor the effect of the information-enhanced approach on the concepts produced.

8.2.4.1 Dependent variables

The metrics used to evaluate the concepts produced included *quantity*, *detail*, *novelty*, *variety* and *quality*. *Quantity* was easily monitored by totalling the concepts created in each session. *Detail* was evaluated by comparing concept sketches for annotation, explanation and sketch complexity with a set of reference concepts adapted from Rogers' (2000) complexity scale as outlined in Chapter 1. Shah's (2003) metrics for concept design were identified as providing a robust and thorough review of concept output and utilised as a basis for further evaluation of concepts, with a number of small alterations and augmentations as described below. *Novelty* was rated for each idea by comparing the total number of ideas for a particular attribute to the number using a particular principle. *Variety* on the other hand was applied to the concepts as a group and was measured using a simple genealogy tree for each PDS function, highlighting different working principles used. Shah's measure of *quality* was adapted by including the level of sketch detail as a contributing factor in addition to his suggested rating of performance in relation to the identified functional criteria. Table 8.2 summarises these metrics, and the assessment of each is described in more detail below.

Measure	Metric	Description
Quantity	n	Total number of concepts produced for a session
Detail	$D = S_n$	Rating of detail compared to a set of reference concepts for each concept
Novelty	$N = \sum_{j=1}^{m} f_j S_j$, $where\ S_j = \frac{n - C_j}{T} \times 10$	Comparison of total number of concepts against number using working principles for each concept
Variety	$V = \sum_{j=1}^{m} f_j \cdot b_j / n$	Comparison of number of concepts against number of working principles per branch of genealogy tree for a session
Quality	$Q = \sum_{j=1}^{m} f_j S_j + \sum_{j=1}^{m} f_j D$	Rating of performance combining rating against criteria and rating of detail for one concept

Glossary of terms	
n = number of concepts	*f = weight of attribute*
S = score for concept	*C=number of concepts using same attribute*
j = attribute	*b= branch*
m = number of attributes	

Table 8.2: Summary of metrics and glossary of terms (after Shah et al.)

8.2.4.2 Controlled variables

A quasi-experimental design is ‘a research design in which an experimental procedure is applied but all extraneous variables are not controlled’ (Christensen, 1991). This can reasonably be applied in this instance as the nature of the work dictated that it was impossible to completely control variables such as the variations in design brief, items introduced into the digital library and the team make-up across all sessions. The key aspects which it was endeavoured to keep constant included:

- Brief – the complexity of the two design briefs was comparable.
- Duration – the time allocated for both tasks was the same.
- Team formation – participants had broadly the same level of experience, and although the experiments did not take account of personalities and team dynamics, the random formation led this to be considered constant.

- Order – the teams completed the 6-X-5 task first each time, familiarising them with the principles of rotating sketchwork before undertaking the ICR method and its additional use of information search tasks.

8.3 Questionnaires

In addition to the analysis of design output, a questionnaire was used to help reveal more qualitative and tacit aspects of the design process undertaken during the sessions. The design of a questionnaire can be split into several stages (Wilson, 1985):

1. Preliminary design work on the areas to be explored in the interview
2. Question wording and sequencing
3. Physical layout or design

The main areas of exploration identified for the questionnaire were the *use of digital information*, *team communication*, and *perceived value*. Through these topics, it was hoped to reveal the emotional reaction of the participants to the mechanics of interaction imposed on them during the sessions, as well as the tactics they used to accommodate this. The problems caused by questions that allow generalisations to be made are problematic when trying to obtain responses. However, it was desirable to include a number of open-ended questions which allowed participants the freedom to express deeper opinions and more subtle qualitative information relating to the sessions. Therefore, the questionnaire was split into two sections. A number of closed questions based on a Likert (Wilson, 1985) approach have been used for distinct issues that required a simple answer. The majority of these related to specific mechanics of the interaction. Open-ended questions have been included where a more interpretive approach was required, particularly regarding the emotional response of individuals where a linear scale is not necessarily appropriate.

It was decided to ask participants to complete the questionnaires themselves, rather than relying on interviews. Bradbum and Sudman (1979) describe the importance of managing the role of the interviewer in the process, in terms of expectations being communicated to an interviewee. There is a natural instinct to try and fulfil these expectations with the ‘correct’ response. Therefore, the participants were asked to complete the questionnaire with the interviewer in attendance in order to ensure that there was no conferring or discussion, but not in close proximity or obviously monitoring their responses. Appendix V shows the questionnaire and results in full.

8.4 Results

The results of the sessions can be divided into two categories. The output-related results consist of the analysis of the concept sketches produced during the sessions. The process-related results are based on interpretation of the questionnaire responses. These are addressed in turn.

8.4.1 Session output

When the results from all eight sessions were compiled, it was found that there was a reasonably strong correlation across them. This is illustrated by the bar graph icons in Figure 8.4, where the five metrics of quantity, detail, novelty, variety and quality were averaged and re-scaled from 0-10 for the concepts produced during the 3-X-5 and ICR tasks in each session. It can be noted, however, that Sessions 6 and 7 deviated significantly, with the performance of the ICR Grid in particular being poorer than in the others. The possible reasons for the variation in these sessions are explored below. It was found that the different project briefs had no obvious effect on the concepts produced during the sessions.

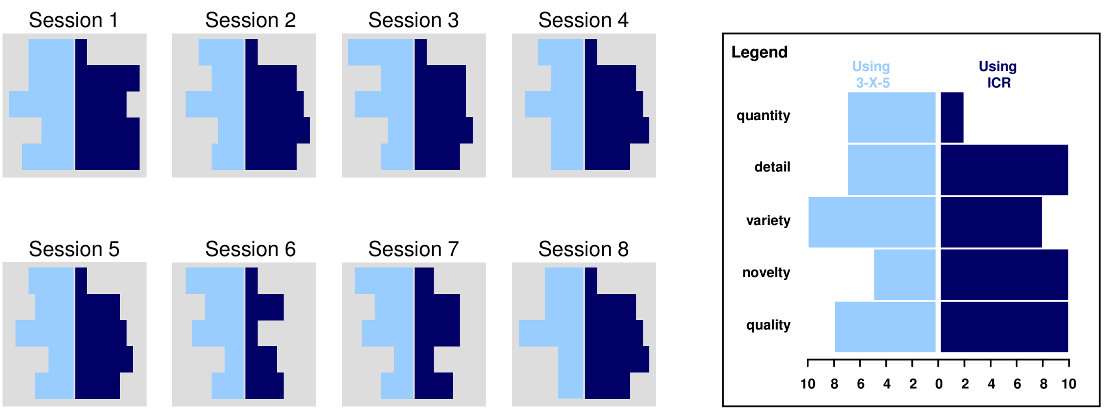

Figure 8.4: Summary of results

8.4.1.1 Quantity of concepts

The easiest output of the sessions to monitor, this was simply the total (*n*) number of concepts produced. It was found that the results followed a similar pattern across the sessions, with 3-X-5 producing significantly more concepts than the ICR Grid. This was anticipated beforehand, since the ICR Grid required participants to undertake search activities as well as sketching activities, and a more methodical approach was required in their construction. This is reflected in the average number of concepts produced in each (3-X-5 – 38, ICR Grid – 10). When using the 3-X-5 Method, participants were asked to sketch as many concepts as they comfortably could in five minutes, rather than demanding three no matter the quality. A properly completed 3-X-5 session would have produced 45 concepts. The results are summarised in Figure 8.5.

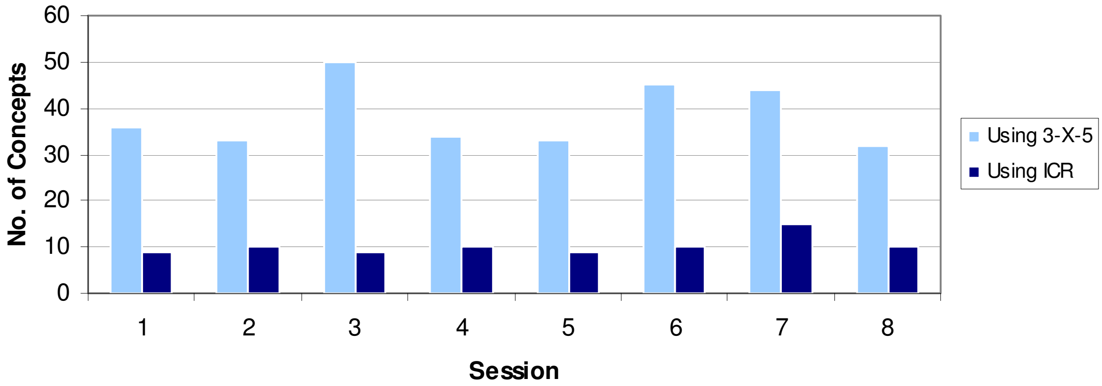

Figure 8.5: Quantity of concepts produced

8.4.1.2 Detail of concepts

The scale of complexity adapted from the work of Rogers et al. (2000), and set out in Table 1.1, p.12, was used in analysing the level of detail of sketches in each session. The ICR Grid tasks consistently produced concepts that were of a higher level of detail. This was expected: the access to information, time to complete concepts, and encouragement of clear developmental threads were strongly orientated to concepts with a greater depth of thinking. The results are summarised in Figure 8.6.

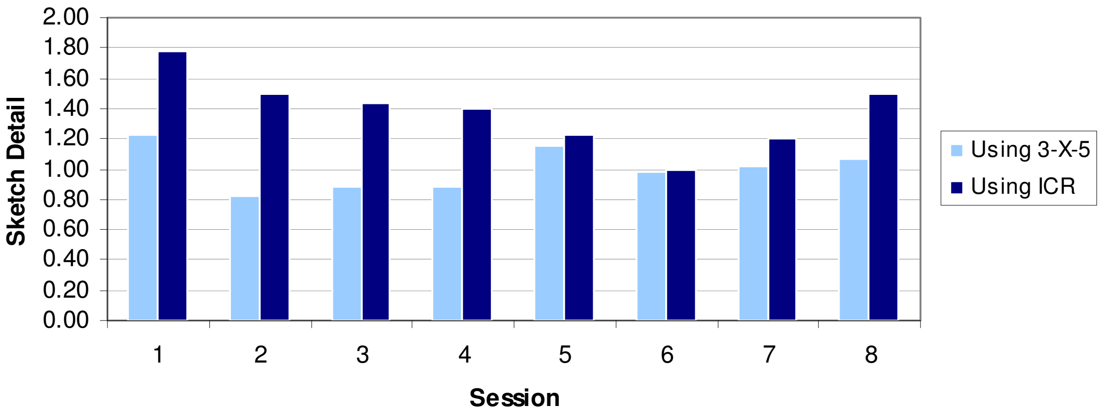

Figure 8.6: Detail of concepts produced

Session 5 and, in particular, Session 6 were found to be anomalous in that the level of sketch detail between the two tasks was very close. From closer inspection of the sketchwork from Session 6 (Figure 8.7) a number of possible reasons are apparent. The evaluative criteria for sketch detail was weighted towards visual embodiment rather than textual annotation, and while sketches for the ICR Grid generally employed more lengthy annotations than the 3-X-5 sketches, the quality of rendering remained low. This resulted in a lack of differentiation between concepts which may in fact have contained disparate amounts of detail. Additionally, the quality of sketchwork in Session 6 was particularly poor and although the author aimed to be as impartial as possible when evaluating across the sessions, disenchantment with the general quality of work may have affected objective judgement, leading to them being judged more harshly than necessary.

3-X-5 Method
Thread 1, Round 6

ICR Grid
Thread 3, Round 2

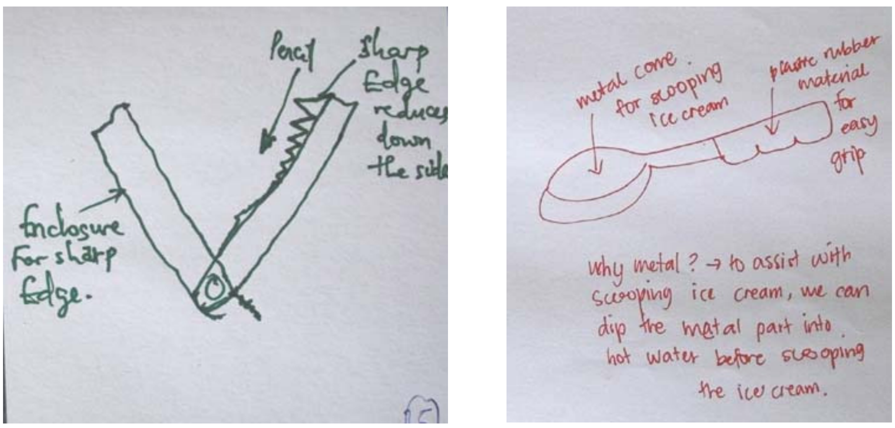

Figure 8.7: Session 6 sketches illustrating level of detail

8.4.1.3 Novelty of concepts

The measure of novelty was important to show that the ideas produced had a degree of originality. For the two briefs, three attributes were identified as relevant with weightings of 0.4, 0.4 and 0.2, as shown in Table 8.3. Each concept was assessed for the approach it had taken to each of the three attributes, and the range of principles used during the course of all eight sessions are also shown.

Ice cream scoop			**Pencil sharpener**		
Extracting (0.4)	Handling (0.4)	Cleaning (0.2)	Sharpening (0.4)	Handling (0.4)	Portability (0.2)
screw	manipulate	spoon	plane axial	rotate	tabletop
lever	crank	blade	plane axial, plane rotational	thrust	handheld
scrape	rotate	core	plane axial, sand axial	rotate, thrust	compact
scoop	squeeze	grater	plane axial, sand rotational	manipulate	folding
archimedes	hit	head	plane rotational	lever	modular
ratchet	thrust	shaft	plane rotational, sand axial	crank	wall mounted
hammer	lever	bag	plane rotational, sand axial	slider	
cut			sand axial	button	
bore			sand axial, sand rotational	ratchet	
heat			sand rotational		
pump			saw		
punch			scrape		
squash			carve		
vibrate					
vacuum					
claw					

Table 8.3: Range of functional principles used

The novelty of each concept was calculated by dividing the number of times the principle was used in the session by the number of concepts produced. The measure of novelty was pertinent given that the use of information has been hypothesised as having a positive impact on concept generation. One of the concerns associated with this was that access to previous ideas and concepts may result in derivative output, and that encouraging developmental threads may limit scope for blue sky thinking. However, it can be seen (Figure 8.8) that there was a marginal difference in novelty between the concepts produced during the 3-X-5 and the ICR Grid tasks, with the 3-X-5 concepts being only slightly higher.

In the ICR Grid, participants created concepts using a comparable number of different attributes, but lacked the occasional 'radical' and often light-hearted idea (for example, a hammer to smash out the ice cream) which emerged during the 3-X-5 tasks. This accounts for the marginally higher score for novelty across the 3-X-5 tasks. Although these ideas have limited value in that they are unlikely to be developed further, it can be argued that they are important in stimulating creative thinking. It may be that some form of loose idea generation is desirable to encourage diverse thinking and act as an information resource prior to the more focussed ICR Grid.

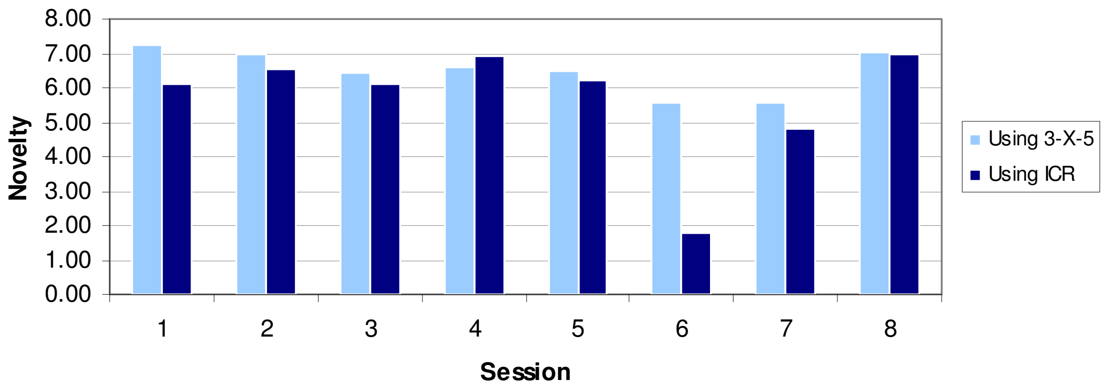

Figure 8.8: Novelty of concepts produced

Again, Session 6 proved to be a particularly inconsistent result, with the novelty score for the ICR Grid far lower than for the 3-X-5 Method. It was apparent that during this session that when using the ICR Grid that participants failed to find information to take the design in new directions. Instead, they repeated the same fundamental concept, continually saying 'yes' to its development and incorporating basic information which failed to meaningfully improve or innovate upon the previous design. Figure 8.9 illustrates the development of one of the Session 6 threads, with the failure of the design to evolve evident in the lack of variation in form or embodiment. It could be that participants had difficulty finding relevant information because of the subject of the design brief, although this is not strongly suggested by the results from the other sessions. It does, however, highlight the danger of 'going through the motions' in terms of finding basic information and failing to challenge the development of a concept thread.

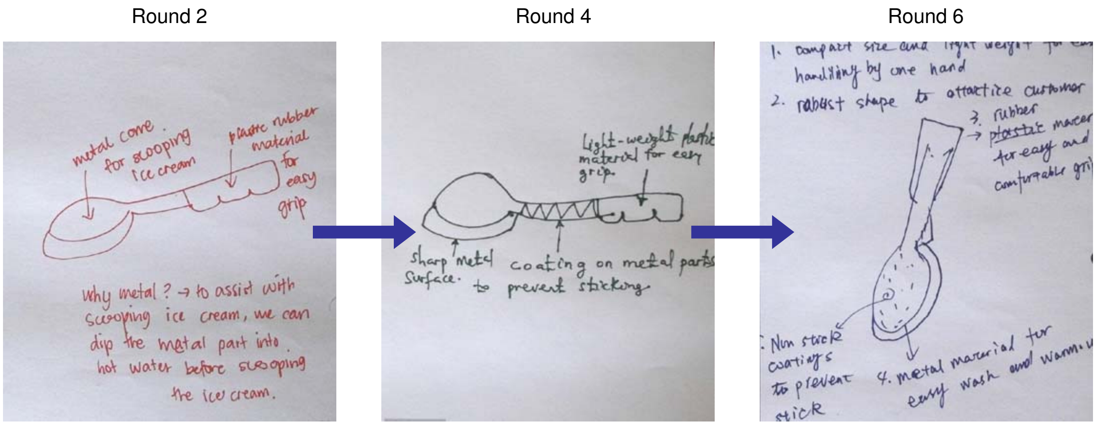

Figure 8.9: Session 6, Thread 3 illustrating poor novelty development

8.4.1.4 Variety of concepts

Variety differs from novelty in that it applies to a group of ideas rather than the characteristics of an individual idea, and is a measure of the breadth and differentiation between them. Variety was determined using genealogy trees to distinguish the different principles used for the different functional aspects of each concept, with the functions again weighted (0.4, 0.4 and 0.2) according to importance. The overall measure of variety for each function was calculated by dividing the number of working principles by the number of concepts for each branch and multiplying it by the weighting function. These were then added to give a total value.

Shah and Vargas-Hernandez (2003) identify four levels of detail for such trees – physical principles, working principles, embodiment and detail – but given the limited amount of detail in the concepts produced during the sessions, it was decided to use a simplified genealogy tree consisting of only working principles. Figure 8.10 illustrates the genealogy tree derived from Session 1, when participants were using the 3-X-5 Method to develop ice cream scoop concepts. For each of the design criteria (as specified in the brief) the various working principles used and the number of concepts employing them are illustrated.

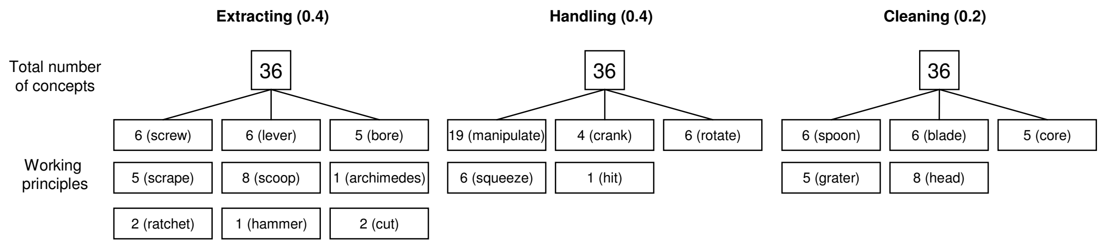

Figure 8.10: Variety genealogy tree for Session 1, 3-X-5 Method

It can be seen from Figure 8.11 that the concepts produced in the ICR Grid showed significantly higher levels of variety than using the 3-X-5 Method. This can be attributed to the fact that proportionately (although not necessarily as many absolutely) a greater range of principles were applied for the number of concepts produced. Fostering separate threads of development to help maintain diversity, and introducing new working principles through information stimuli for different working principles, meant that for a smaller pool of concepts a greater breadth was addressed. In the 3-X-5 sessions, however, it was found that the same principles were often repeated with small variations between them.

From the results, it was again obvious that Sessions 6 and 7 did not reach a comparable standard to the other sessions, particularly using the ICR Grid. Although the subject matter of the brief (the ice cream scoop was the subject for Sessions 4-8 when using the ICR Grid) can be identified as a possible factor, the reasonable performance in Sessions 5 and 8 make this seem less likely. On closer examination of the concepts, it seems that the problems described above for the poor novelty rating of Session 6 (simply saying ‘yes’ to concept developing concepts, failing to find imaginative information sources, lack of sketching skills) again affected the ICR scores for the two underperforming sessions. Although the variety scores for the 3-X-5 tasks in Sessions 6 and 7 are also lower than elsewhere, they have not been affected as badly as the ICR Grid scores: given the smaller number of concepts in the ICR tasks, the calculation procedure for variety particularly punished this failure to explore diversity.

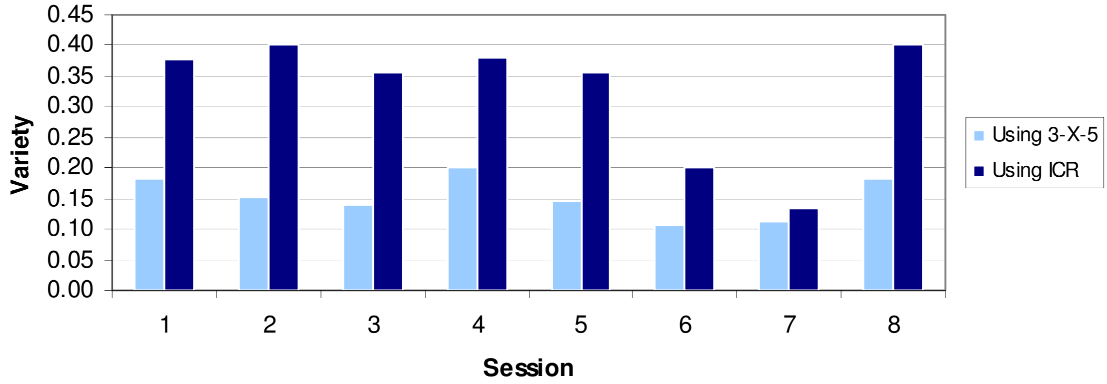

Figure 8.11: Variety of concepts

Regarding the improved variety performance of the ICR Grid with respect to the 3-X-5 tasks, we can question whether the proportion of principles to concepts would remain consistent if the ICR Grid task were continued until a comparable number of concepts (30 as opposed to 10) were explored. It may be that there were few principles beyond the ones explored during the sessions, which would result in the variety score falling to something more comparable with the 3-X-5 score. One of the aims of the ICR Grid, however, is to allow participants to continually introduce new information and encourage new technologies, principles or data to be introduced, providing participants with inspiration to take concepts in new directions. Figure 8.12 illustrates the advantage of being able to find information to introduce new principles for development in Session 8, which was addressing the seemingly more challenging ice cream scoop brief. Round 2 shows a cylindrical cutter being used. In Round 3, information relating to heating elements has been introduced, and this has been incorporated as a fundamental part of the concept with a similar product configuration. Finally in Round 6, an enhanced mechanical configuration combining cutting and heating actions is proposed. The relevant information sourced prior to each of these rounds (on cutters, heating elements, and mechanisms respectively) gives the designer more confidence to incorporate these tellingly into the design configuration.

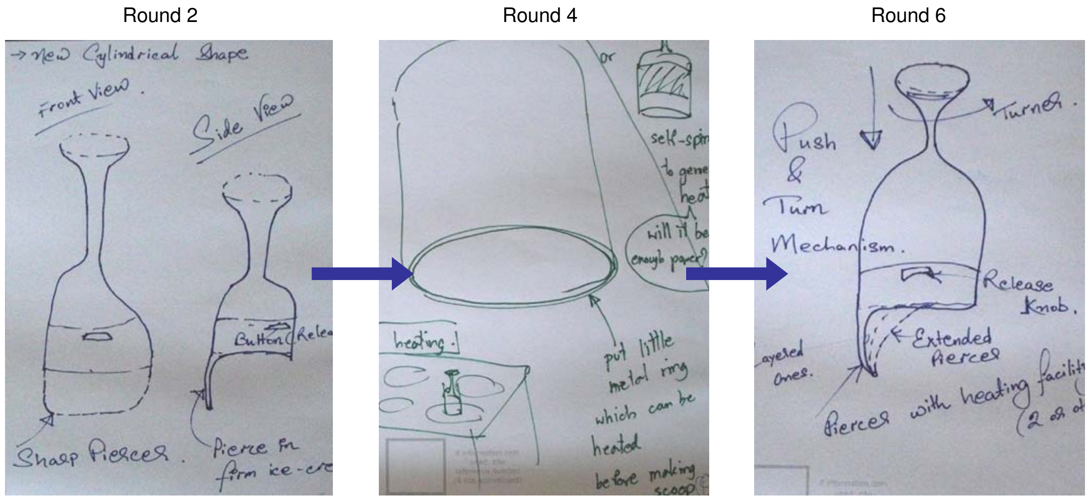

Figure 8.12: Session 8, Thread 2 illustrating variety of principles introduced

8.4.1.5 Quality of concepts

A key measure for the sessions was the quality of concepts produced. Given the main hypothesis of this research that *enhanced use of appropriate digital information will result in the improved performance of concept design teams*, this provides a strong indicator of how useful the output will be going forward in the development process. As described in Section 8.2.4.1 above, it was decided to make quality a composite of a subjective rating system and the level of concept detail. To determine the subjective rating, the functional categories were again weighted and rated individually (0 – not addressed, 1 – poor, 2 – okay, 3 – good) according to a combination of the perceived originality and feasibility of the concept embodiments. Given the relatively simple nature of the concepts, these ratings were based on the author's own experience and judgement and, having a complete overview of concepts produced during the sessions, every effort was made to be as consistent and objective as possible. The detail ratings, as described in 8.4.1.2 above, were used as an indicator for the depth of thinking associated with a concept. The subjective ratings and detail ratings were then combined give a quality score for each concept and averaged to give an overall score for each session. It was found that quality was consistently better in the ICR Grid tasks (Figure 8.13). This reflects that fact that participants were encouraged to implement information, reflect on validity, and develop promising threads during the task.

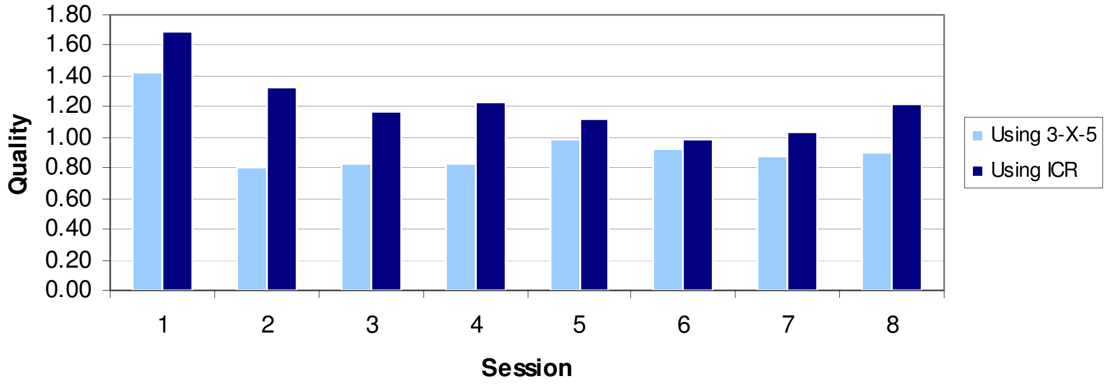

Figure 8.13: Quality of Concepts

8.4.2 Questionnaire feedback

The questionnaire was split into two sections: Section 1 was based on Likert Scale responses and are illustrated in Figure 8.14. Section 2 contained more open-ended questions, with the main points to emerge summarised below.

8.4.2.1 Section 1: Likert ratings

1. The time allocated for creating concepts was…

Participants felt somewhat pressurised in both sessions to produce ideas, with the 3-X-5 task deemed particularly onerous. The requirement of the 6-3-5 Method to deliver three concepts within the five minute rounds had been removed for the 3-X-5 sessions, although the paper template presented did have three assigned spaces. Given this flexibility, participants usually fell short of three concepts, suggesting that the pace of 6-3-5 demands that they move beyond their typical level of comfort. A degree of discomfort is not necessarily undesirable – the motivation provided by a time deadline can assist in focussing effort and help participants find 'flow'. Overly demanding pressures such as three concepts in five minutes can, however, be detrimental to performance. It was found that participants tended to put enough pressure on themselves with the empty boxes both sessions.

2. The sessions allowed for development of ideas…

The opinions regarding this were broadly similar, with an indication that the ICR Grid was perceived as providing slightly better scope for development. Given that the ICR Grid was explicitly structured to identify and develop strong concepts, it would have been disappointing if this was not the case. The more open-ended approach adopted by 3-X-5 meant that participants could develop concepts as they saw fit, but could also result in small variations which did not move the concepts forward significantly.

3. The sessions allowed for adequate interchange of ideas…

Again the results are very similar with marginally more positive feedback for the ICR Grid. The rotation of work was integral to both tasks, and the number of times that work was rotated around participants was the same for both tasks so it is unsurprising that the results were so similar. The main difference was that using the ICR Grid, information sources as well as concepts were rotated around the team, and this extra dimension may have accounted for the slightly higher scoring. Using 3-X-5 there was at times the impression that the same ideas were simply being rotated around the team with little inspiration to develop new insights, rendering this interchange less significant.

4. Overall quality of concepts produced was…

The fact that participants clearly felt that the concepts produced using the ICR Grid were of higher quality (while eight participants indicated some degree of confidence in their concepts using 3-X-5, fifteen indicated confidence using the ICR Grid) was an important indicator. Many participants described feeling more confident having been able to look for relevant information on the design topics, and this could have contributed to their greater confidence in the concepts they produced. The competitive element and greater allocation of time for concept sketching were additionally intended to ensure participants had the motivation and opportunity to create better crafted concepts.

5. Scoring was a motivating factor…

There was an interesting split in opinion regarding the use of scoring to monitor how well participants performed during the ICR Grid. The majority felt that this was a positive thing and enjoyed the edge it lent to proceedings. However, eight participants indicated that they felt some degree of discomfort, whether it was regards to judging concepts or having their concepts judged. Given the fact that different personalities are generally more or less comfortable with such competition, it is not surprising that there was a mixed response. The scoring aspect of the ICR Grid was not intended to be overbearing in any sense, the intention being to give keep participants 'on their toes' without it being a cause for friction. These results highlighted the importance of setting this element of the ICR Grid at the correct level.

6. The requirement to find or browse information was…

There was a broadly positive response to the requirement for participants to find or use information in the ICR Grid. As an integral aspect of the mechanics of the approach, how participants responded was another key indicator. Prior to the sessions there was a concern that this requirement would be perceived as detracting from the act of creating design concepts, but the idea of breaking the session into discrete chunks where tasks alternated between design and research was generally well-received with participants at times effusive in describing how they enjoyed and felt they benefitted from finding and browsing for information.

7. The library content uploaded during the session was…

The rationale behind using OneNote to share and manage the digital resources was to provide a dynamic and responsive environment. There were concerns, however, that the limited hardware participants were asked to use – the laptops used during the sessions were a number of years old – would inhibit its effective use. Although not as quick as it could have been, the system performed adequately and the sessions produced some significant information resources given the short space of time. There were certain issues which arose regarding information literacy (see below) and a lack of diversity in search strategies, but the positive response to this question reflects the general enthusiasm for the 'find as you go' approach to concept generation.

8. Rate your enjoyment of the sessions…

There was a favourable response to both tasks, with the ICR Grid being slightly better received overall. Participants generally approached the sessions in good humour and gave of their best when undertaking them. The opportunity to find information and the increased focus in concept generation emerged as important factors in the greater enjoyment of the ICR Grid – feedback indicated that at times the 3-X-5 Method felt somewhat haphazard.

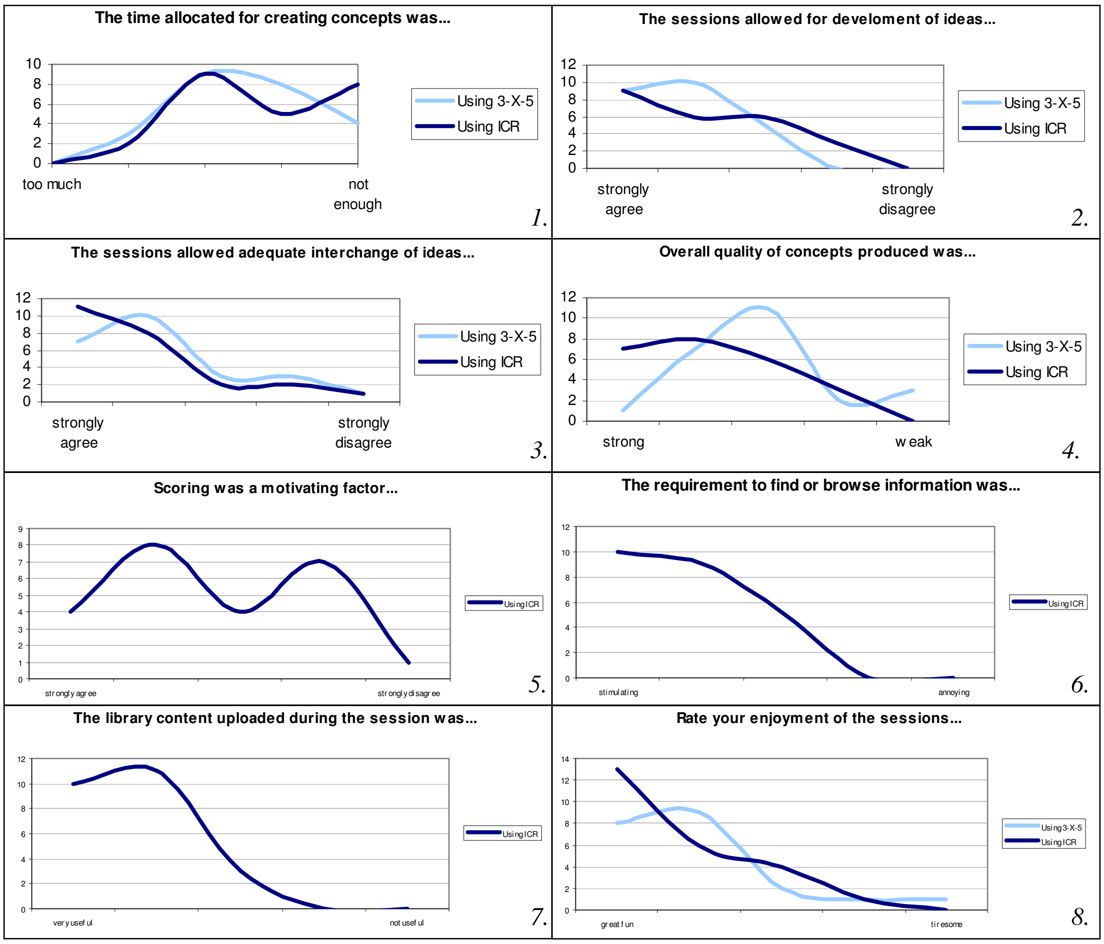

Figure 8.14: Questionnaire Section 1 results

8.4.2.2 Section 2: General feedback

1. How did you feel the ICR Grid compared to the 3-X-5 Method?

Almost all participants stated that the ICR Grid was more enjoyable and productive than the 3-X-5 task. The ability to ‘source information dynamically’ proved particularly popular, and there was a general consensus that being able to browse images triggered ideas. There was, however, a concern that searches done using a ‘typical keyword’ led to similar information sources and therefore similar concepts being produced.

2. What were the best and worst features of the 3-X-5 method?

The ability to quickly generate a large number of ideas was recognised as being a positive feature of the 3-X-5 Method. A repeated concern was that there was a danger of repetition, with the same concepts being recycled several times with no significant development. Additionally, many participants found it difficult to decipher other participants' ideas and without the option of communicating verbally it became difficult to make use of them. A minority, however, felt that the ambiguity this caused was a positive stimulus, leading to the creation of new ideas.

3. What were the best and worst features of the ICR Grid?

Generally, the sharing of resources proved very popular. Participants felt more confident that their ideas were grounded and better substantiated. There were concerns raised, however, that sourcing and using information could lead to thinking 'inside the box'. A number of participants indicated that they did not feel comfortable with the yes/no decision they were required to impart to or receive from other participants. Finally, the flow of the task was strained at times due to a combination of the interaction mechanics requiring the author to clarify next steps and the assigned hardware failing to perform to a satisfactory level.

4. How did the sessions compare to brainstorming?

There was a general feeling that the sessions allowed more robust development of concepts than brainstorming. There were a number of responses indicating that the 'arguments and discussion' of brainstorming were something that was lacking in the more structured approaches, but also a number of responses that highlighted the more focussed and equal contribution as a positive aspect.

5. Did the different project briefs affect the sessions?

There was no strong consensus that the different briefs affected the sessions.

6. How do you think moving through topics in the ICR Grid affected the concepts produced?

The feature of the ICR Grid requiring different elements of the requirements to be the primary focus at different stages did not work particularly effectively in the sessions. The complexity of the ICR Grid and the short duration meant there was insufficient time to pay close attention to each topic. As a result, most responses were lukewarm, although a number of participants did see the value in shifting emphasis: 'helps you explore other areas of design', 'beneficial in adding detailed aspects', 'enhanced looking for further opportunities of developing existing concepts'.

7. How do you think sketching ideas individually affected the concepts produced?

There was a general appreciation of the fact that sketching then sharing ideas 'allows individuality' and 'gave… independent thought flow'. However, considerable problems were highlighted regarding a lack of sketching ability of some participants meaning that 'people with less artistic skills were not able to express themselves'. This in turn led to issues for other participants trying to interpret sketches, at times leaving them hamstrung due to 'incomplete or un-understandable design[s]'. The issue of sketching skill, like information literacy, is a key factor for this type of idea generation and before such a session takes place there should be an understanding of general ability of participants to communicate ideas. In certain cases, it may be necessary to consider strategies to accommodate this, e.g. 'writing notes helps a lot in understanding sketches.'

8. How do you think searching and using information during the ICR Grid session affected the concepts produced?

Feedback was almost unanimously positive regarding the benefits of being able to find and share information, and then applying this to the concept work: 'searching produced new ideas', 'helps to effectively search for and look through existing information as a team', and 'made the whole process effective and efficient'. Participants generally felt that this process 'affected [the concepts] in a positive way, since triggers creative thinking' and helped 'significantly to shape our own ideas in productive and progressive way', although a few concerns were raised again regarding the possibility that focussing on existing sources could 'limit your ideas or inspir[ation]'. This relates to issues of information literacy and the importance of participants being familiar enough with search strategies to enable them to bring strong information sources to bear on the session.

9. What type of information would you like to see in a digital library?

There were a range of answers encompassing typical design information such as 'mechanisms', 'patents', 'material selection properties' and so on. Although a limited timeframe can make it difficult to access such specific material, it can be expected that organisations implementing such a technique would have various related technical materials – mechanical principles, industry catalogues, material data etc. – available in physical or digital forms for access. Another strong recurring theme was a desire for visual information: ‘visual: prefer pictures and visual representations’, ‘pictures, specifications, 3D pictures would be great to see, operation explanation, advantages and disadvantages’, ‘images, concepts’. The adoption of OneNote as a medium for sharing digital information was orientated to trying to achieve this. For future incarnations, an effective way of integrating this further with physical sources would be desirable.

10. How did you feel about being asked to judge other participants’ concepts in the ICR Grid?

As indicated by the responses in Section 1, Question 5, this received a mixed response: some participants were comfortable with it, but others were not. A slight majority were positive regarding the competitive element: ‘very useful; this helps to go in more depth to others’ concepts’, ‘I'm ok about it, considering they are my peers and it is part of the job’ but some people felt it caused problems: ‘felt it may be of negative effect rather than positive’, ‘to stop a concept from development would prefer more discussion on why’. Overall, it was felt that the yes/no decision succeeded in focussing participants on crafting their concepts as well as possible, but care should be taken to the level of emphasis that is placed on such a mechanism in what is a co-operative design task.

11. Were you more inclined to vote yes or no?

Sixteen people indicated they were more likely to vote yes, four people no, and four had no bias. This was anticipated, as there is a tendency (certainly in the early stages of a new group formation) for people to avoid ‘offending’ other participants (Osborn, 1953). Different cultural elements could have played an additional role in this aspect. The ICR Grid was designed to cope with this tendency, requiring participants who vote no to undertake a search task and it was perceived that the level of searching versus the level of sketching undertaken during the sessions was generally about right.

12. Were you motivated by the scoring system in the ICR Grid?

Although participants were made aware that scores were being kept based on the outcome of each round of the task, in practise it did not form an integral part of the sessions due to time and logistics – similar to the issue of different topics for different rounds. Even if they were not completely familiar with the calculation procedure, participants generally had definite feelings on whether it was important to them: the split was very even (11 – yes, 12 – no, 1 – no response). Responses varied from 'Definitely […] motivated in terms of finding quality ideas', to 'No, because […] score means nothing after the session is over.' Although it was expected that this would not be a universally popular feature, the feedback questions whether scoring was necessary at all. A significant competitive element was contained in the evaluation of each other's concepts, and it could be argued that the inclusion of a scoring system was excessive, detracting from the fundamentally co-operative spirit of the sessions.

13. Did you feel the personalities of the participants was an important factor?

The majority of participants responded no (7 – yes, 12 – no), which was expected since very little verbal communication took place in either of the sessions. However, some people interpreted personality as the manner in which undertook the tasks: 'Of course! People have different strengths, some may be more creative, others are better at researching.' Generally, however, participants felt that people were to an extent equalised and focus was on the concepts rather than the people. This was indeed one of the intentions of the approach.

14. Any other comments?

Overall, the sessions seemed to be a positive experience for the majority of participants: 'This was nice experience for me. Thank you!', 'Good experience for me', 'I felt motivated', 'Would like to participate again if given the opportunity'.

8.4.2.3 Summary of questionnaire results

The questionnaire results for the ICR Grid were generally favourable when compared to the 3-X-5 Method. Overall, it was rated the more enjoyable and participants perceived the concepts they were producing to be of better quality. There were, however, some key observations regarding the format of the task:

- Information use – Despite a concern prior to the sessions taking place that there may be a resistance to the requirement of the ICR Grid to undertake searching tasks at the expense of concept sketching, it was found that there was a preference for this among the participants. Generally, there seemed to be a confidence associated with the use of information that the concepts consequently generated would be better substantiated. Although it was accepted that the information sources did provide stimulus for concepts, there was a concern that difficulty in finding good quality and diverse sources could inhibit the associated conceptual work.
- Time constraints – Both the 3-X-5 Method and ICR Grid were run under fairly stringent time constraints. Participants felt particularly pressurised in the 3-X-5 task, but the ICR Grid also forced them to search and sketch faster than they normally would. Given the fact that participants are being asked to be fairly rigorous in the sourcing and crafting of concepts, it may be worthwhile to modify the interaction mechanics to allow more time to complete these elements. The motivation associated with a fixed time frame for task completion, however, proved valuable in focussing group effort and should be retained in some capacity.
- Sketching ability – Many participants felt uncomfortable and inhibited by their lack of sketching ability. While the 3-X-5 Method allowed no verbal communication, the ICR Grid did allow it in the window between information sourcing and concept development. This was still insufficient for participants who were trying to make yes/no decisions on concepts they had difficulty understanding. On the other hand, some participants felt the ambiguity caused by sketches which were hard to understand acted as a stimulus for further creative interpretation. Strategies for sketch communication (e.g. encouraging annotation, 2D drawing) and increased opportunity for verbal clarification could enhance this aspect of the approach.
- Competitive element – The competitive elements of the interaction consisted of the yes/no decision and the consequent scoring associated with these. There was a mixed response to the yes/no decision: a majority found it stimulating and encouraged them to do their best, but a sizable minority

found it inhibiting and contrary to the co-operative nature of the session. Although it had a similar split in terms of those for and against it (with a slight majority against), the scoring system was less effective in providing a true incentive to the participants. Overall, it was concluded that the competitive element must be managed carefully: the reflective decisions in themselves provide an adequate motivation for participants to do their best. An overall scoring tally may be best omitted where a spirit of co-operation must be fostered.

8.4.3 Use of information

The use of OneNote during the sessions was reasonably successful, with an annotated sample of the typical grid output shown in Figure 8.15. The laptops used were a number of years old and limited in computing power, but in the end a number of useful information resources were constructed despite the restricted speed of response. The average number of sources found was 11 for the 30-minute sessions, with all information sources coming through Google searches. It is anticipated that given a greater timeframe and better hardware, physical sources such as textbooks, models and sample material could be captured through the use of digital cameras or scanning and inputted to the grid in a similar manner.

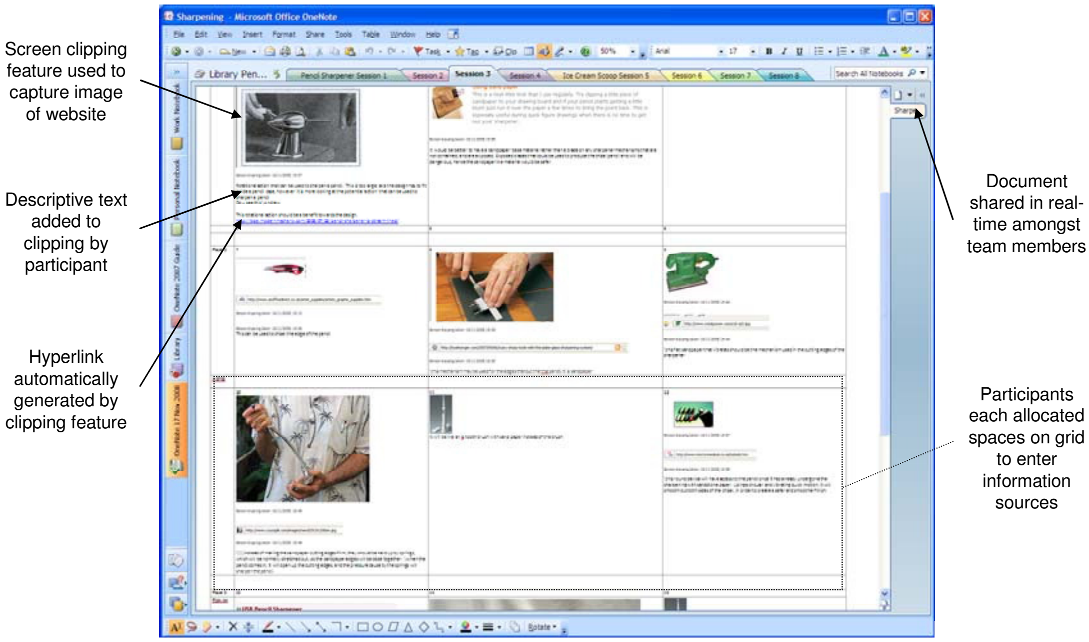

Figure 8.15: Screenshot of information grid output in OneNote for Session 3

8.5 Analysis and discussion

Although a number of consistent patterns emerged in the results, Figure 8.4 (p.160) identified Sessions 6 and 7 as deviating noticeably from the other sessions. On exploring their output in more detail, a number of issues have been acknowledged relating to the mechanics of the ICR task to explain why they were particularly poor. These included a propensity to simply say 'yes' to developing concepts without rigorous evaluation, failing to find adequate information sources to motivate and inform new threads of development, and a lack of sketching skills which led to limited communication through annotation.

While these issues were noted as significant for the performance and future development of the ICR Grid, the results for the 3-X-5 tasks in Sessions 6 and 7 were also poorer than in the other sessions, suggesting that on a broader level team composition may have been a factor. The teams were randomly assigned and it could simply be the case that those sessions had students who were weaker in specific skills assigned to them. The personalities in the team may not have gelled, leading to poor dynamics. Also, the language skills of some of the students in those teams were poorer than others, inhibiting the quality of communication between team members. These sessions were two of the three which indicated they enjoyed the 6-3-5 Method more than the ICR Grid – the other teams showed a preference for using the ICR Grid.

Considering the overall profile of the concepts produced (averaged for all eight sessions) is illustrated in Figure 8.16. The *quantity* of concepts produced by the 3-X-5 Method is clearly greater, despite consistently falling short of the target of three concepts for every five minute round of the task. During the 3-X-5 task, at times participants seemed to be drawing ideas for the sake of it, with similar themes noticeably repeated towards the end. If the purpose of a concept design session is to produce a large number of ideas, then it is important that there is sufficient focus and scope to sustain the team's effort throughout. If the combination of personalities is not right and the quality of concepts begins to wane, there is little scope in the 3-X-5 Method for re-invigorating proceedings. The ICR Grid's emphasis on providing stimuli through the task helped to give fresh impetus at times but the downside of this was that it did not have scope for the rapid iteration of the 3-X-5 Method. This was accepted as a consequence of allocating a portion of the task time to search activities in the hope that the range of activities would ensure that the output would be more robust overall.

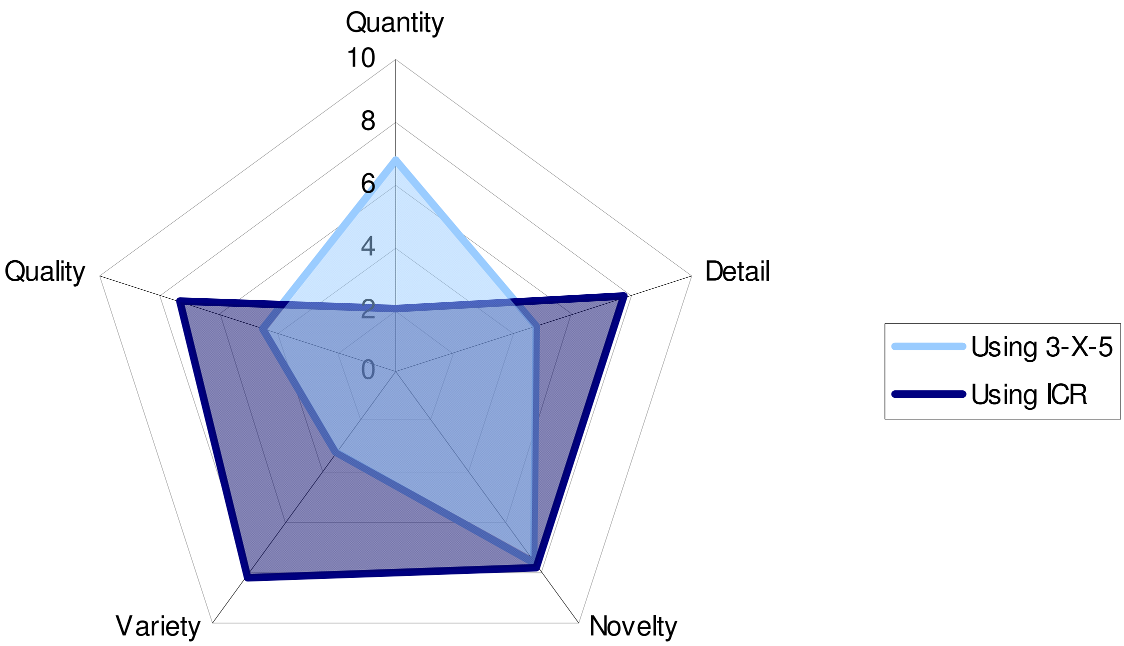

Figure 8.16: Overall profile of concepts

Participants in both tasks were asked to sketch at a speed that felt comfortable to them, so even if they did not produce the projected three concepts per five minutes for the 3-X-5 task, they should have completed sketches with a comparable level of *detail* to those in the ICR Grid. In actuality, the concepts produced in the ICR Grid generally showed better attention to detail. An attributable factor is participants having the opportunity to examine and utilise reference mechanisms, details and forms from existing competitor and pertinent designs.

The 3-X-5 concepts scored marginally higher in terms of *novelty*, and as a measure of how different each concept was from another this reflects its more open-ended approach compared to the ICR Grid. The previous ideas to which participants had access as the task progressed could be freely used or discarded as new concepts were produced. In the ICR Grid, participants were at times required to build directly on a concept if it had been identified as promising, thereby limiting the scope for a high novelty score with the resulting concept sketch. As the 3-X-5 tasks progressed, it was obvious that the concepts created were heavily referred to during the sessions and as a result the novelty score for 3-X-5 is only marginally higher than that for the ICR Grid. This shows a tendency for participants to be influenced by the thinking of others.

The score for *variety* is considerably better for the ICR Grid. As a measurement applied to the group of concepts, this indicates that despite a smaller pool of concepts, a proportionately higher number of different principles were used. In the ICR Grid, a good range of different principles of operation were identified and then variations of these subsequently created. Again, this can be attributed to participants having the opportunity to explore relevant information and suggest appropriate solutions. The 3-X-5 tasks tended to be more haphazard in that new configurations would occasionally be introduced, but then small variations would be applied continually without necessarily taking the concept anywhere new.

The overall rating for *quality* was a combination of an evaluation against requirements and detail of the concepts. The evaluative scoring took into account both originality and feasibility, but the quality score can best be viewed as an overview of concept viability. It can be argued that as a measure of quality this does not sufficiently reward the level of creative thinking in the concepts, but novelty and variety scores have been used to provide more insight into these specific aspects. Again, the ICR Grid scored noticeably higher. This can be linked to the higher detail documented for the concepts of the ICR Grid. Additionally, the ICR Grid was more explicit in asking participants to address the requirements in the brief, so the concepts produced were more likely to satisfy these. The order of task completion was one further factor in quality of output. Teams completed the 3-X-5 Method first, allowing participants to become familiar with the principles of passing concepts around the team. While not particularly noticeable in the author's observations of the sessions, it may have affected the performance in the ICR sessions. Towards the end of this task participants had been concentrating for a significant period of time and fatigue may have affected their quality of their output.

Overall, it was found that the ICR Grid produced better rounded concepts than the 3-X-5 Method, scoring more consistently across the measures and resulting in a more circular profile in Figure 8.16. However, the 3-X-5 Method did produce more concepts with a slightly better novelty value. This suggests that it lends itself better to an earlier phase in the design process where the team wish to simply explore a range of high level ideas unconstrained by design requirements and without emphasis on trying to develop robust concepts. The best of the ideas produced in such a session could easily be compiled to form one of the inputs to the ICR Grid.

8.5.1 Quantity of ideas

Prior to the sessions, it was assumed there would be an inverse relationship between quantity and quality, given the extra time taken to complete concepts. In reviewing the results, however, the relationship proved to be less straightforward, as shown by Figure 8.17. The grouping for the 6-3-5 Method and ICR Grid tasks are markedly different, with the ICR Grid results being of lower quantity with a significant range of variation in quality, while the 3-X-5 results show a higher quantity with significant variation, and consistent but lower quality.

Techniques that aim to produce high volumes of concepts rely on the precept that the more there are, the higher the likelihood that at least one will be of value for development. The 3-X-5 Method is not as focussed on quantity as intense, verbal methods such as brainstorming, but still relies on a rapid turnover of ideas. Each session, therefore, consisted of a significant range of concepts: there were moments of genuine insight when participants developed provocative approaches to the design challenge, but at other times it was noticeable that participants lacked inspiration and drew half-hearted concepts just because they were expected to do so. Given that the scores for quality have been averaged, it may be that a given session had one or more concepts of extremely high quality reduced by poorer concepts within it. As such, the overall quality results for the 3-X-5 tasks are consistent in quality despite large variations in the quantity of concepts produced.

The ICR Grid on the other hand, has a larger variation in quality with a more consistent quantity of concepts produced across the sessions. Although each session of the ICR Grid had scope to change considerably depending on the yes/ no decisions of participants, the fact that there was a reasonably consistent volume of ideas produced indicates that it will yield a predictable number of concepts for a given timeframe. Reasons for the variability in quality are explored further in relation to patterns of information searching in Section 8.5.2, below.

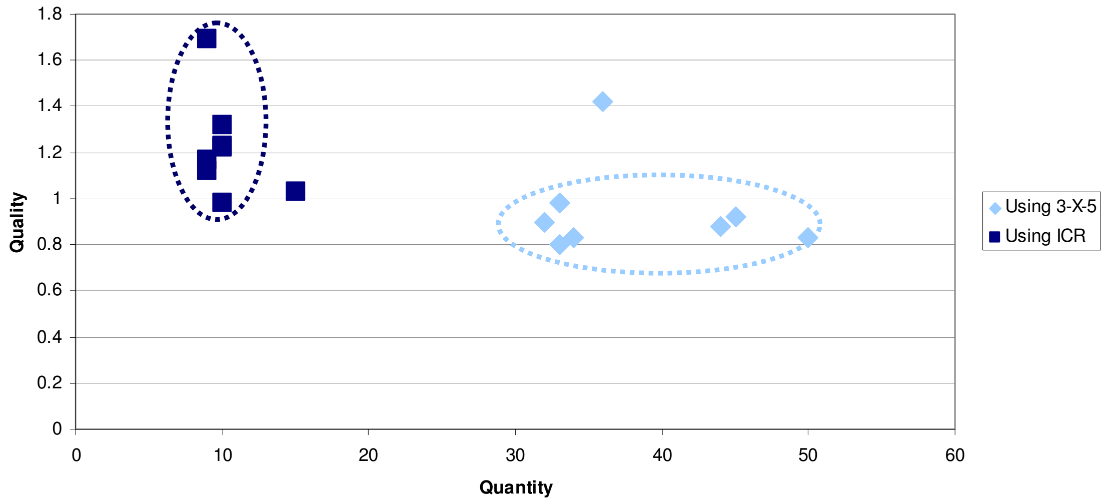

Figure 8.17: Quantity vs. Quality

8.5.2 Information retrieval

The major difference between 3-X-5 and the ICR Grid in the creation of design concepts was the systematic utilisation of information required by the ICR Grid. It was therefore instructive to examine the information retrieval and use within the ICR Grid task to better understand the reasons for the variability in concept quality. The number of items found is principally the result of the decisions made during the task: if a concept was good it generally received a yes vote, resulting in an information item search task in the next round. This is a virtuous circle, with more information continually being added to better concepts. In sessions where the concepts produced were poor and received no votes, this resulted in new concepts being created and less information searching. This too could result in a cycle whereby poor concepts are continually created with no new information being added to the information library for inspiration. This is, however, unlikely as participants were noted to favour yes votes wherever possible. As can be seen from Figure 8.18, the results indicate that the teams that found and used more information over a full session produced better quality concepts.

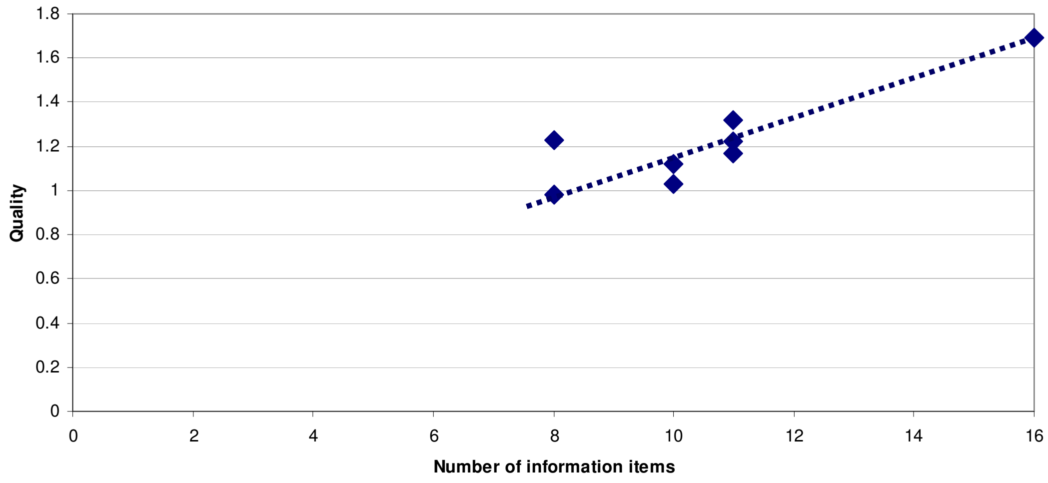

Figure 8.18: Information items created versus quality

The types of information sourced by the teams were reviewed (Figure 8.19). From Vincenti's (1990) taxonomy of design knowledge (described in Section 4.3.1, p.56) the most relevant category was *fundamental design concepts,* consisting of representations of existing principles, configurations or structures. *Quantitative data* (relevant constants, properties or processes respectively), *criteria and specifications* (universal constants, properties of substances, physical processes, operational conditions, tolerances, factors of safety,), and *practical considerations* (information learned from experience) were the other categories of information identified by the author in the course of the analysis, but in significantly smaller quantities. Given the range of items that fundamental design concepts could encompass, they were additionally identified as *direct* or *indirect,* after Howard's (2008) internal/external delineation, in order to better distinguish items directly related to the design application and those brought to bear from different contexts. In all cases, these were what Howard considers *guided* stimuli, in that they have been purposely chosen by the participants for a specific application.

In reviewing the information found in the fundamental design concepts category, the bulk related to images of products, either direct competitors or devices using mechanisms which may be applicable. In terms of information literacy, finding competitor products (direct stimuli) can be rated the easiest type of information to source: simply using the product name is enough to return results on related products. Finding different, but potentially relevant, products or technologies (indirect stimuli) requires the participant to think about possible features or major specifications relating to the design, with search results typically providing more tangential information. More sophisticated behaviour is shown when participants identify the underlying characteristics and principles that could be adopted, and interpret how these could be applied. Although this did happen sporadically, most searches seemed to be relatively shallow. These degrees of sophistication are reflected in the overall numbers across the sessions: in total 70 of the 82 sources found were fundamental design concepts, and 45 of the 70 were direct sources.

The strongest sessions in terms of quality (1, 2 and 8) tended to have a mix of different information types. There was an inclination, however, for some sessions to fall into a pattern whereby participants consistently found similar information types and it was noticeable that those with the lowest quality (6, 7 and 5) had these one-dimensional resource sets. Therefore, while it was not possible to identify detailed correlations between types of information sourced and concepts subsequently produced, it is suggested that any information library would ideally be made up of a mix of different information types to provide a variety of stimuli for the concept generation task. Despite the desirability of diversity, in the context of focused concept development (as was the case in this instance) fundamental design concepts directly related to the domain of application are likely to be the main constituent of stimuli.

Although no prior coaching was given to participants on information searching, it did emerge as an important factor in ensuring the ICR Grid is as effective as possible. It may be that participants are required to undergo some initial training to better understand how search strategies such as concept mapping (Tergan, 2005) can assist in developing appropriate search terms, and more sophisticated search features such as AND, NOT and OR can be used in the execution of information searches. Additionally, targets could be set or particular information types required during the course of the ICR Grid to ensure that the overall resource available to the team has an appropriate balance for effective concept generation.

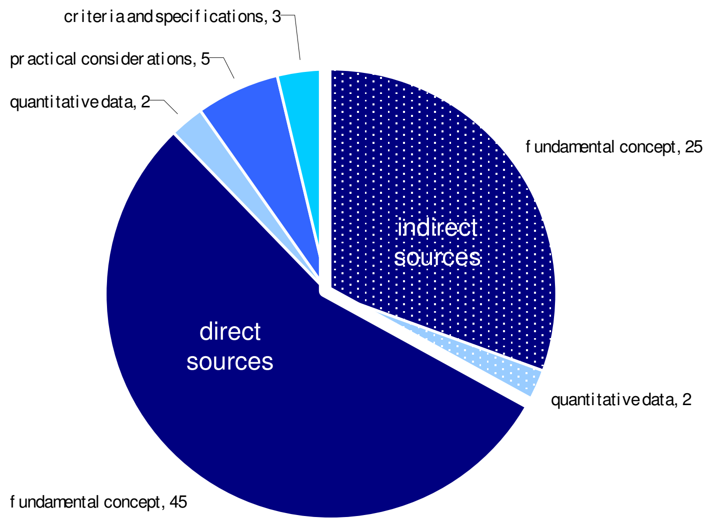

Figure 8.19: Information sourced across eight sessions

8.5.3 Creativity

Although the use of information resources have been shown to have had a positive effect on the overall quality of the concepts, the question of the scope or 'creativity' of the design session being constrained by their use persists. To monitor this, the originality and diversity of thinking in the concepts was specifically measured through the novelty and variety metrics. Figure 8.20 reveals these to have a direct relationship, with higher variety associated with higher novelty in both the 3-X-5 and ICR Grid tasks. This is to be expected given that both metrics relate to the diversity in concept features. The difference between the two, as outlined above, is that novelty is a measure of how different a concept is from any other in the group based on its features, variety is a more fundamental analysis of variation in concept characteristics across the group.

This is an important distinction. ICR Grid concepts have a generally (discounting the Session 6 and 7 anomalies) higher level of variety. This means that for the number of concepts a greater range of different principles were adopted, i.e. the 'threads' were quite distinct. This can be attributed to the different information sources which were used to generate the ideas, and the yes/no reflection step raising overall awareness of the developmental threads. Participants would select the concepts they thought had scope for development, the poor ones were simply eliminated.

3-X-5 on the other hand had a marginally higher novelty score but a lower variety score. Novelty being a measure of how different one concept is from another, a slight variation on an existing concept is enough for this to happen. 3-X-5 had a higher number of concepts but they tended to include smaller, less fundamental differences than in the ICR Grid session – they would be 'variations on a theme'. Although the ICR Grid encourages linear development of strong concepts, the fact that new information sources were introduced as the session progressed meant that more significant changes were being suggested for concepts than were for 3-X-5. In essence, the results suggest that in terms of diversity within the group of concepts (novelty) the methods are comparable, but that in exploring different principles (variety) the ICR Grid performs more strongly for a given number of concepts.

Of course, the measure of variety is a factor of the number of concepts produced. The fact that the 3-X-5 sessions produced a greater number of concepts meant that because it did not have a comparably greater number of different operational principles utilised in the concepts that it scored lower. Perhaps if the product brief had been more complex, or offered more configuration possibilities, the scores would have been closer. However, the fact remains that the ICR Grid provided a better ratio of alternative approaches and, as other measures indicate, produced better overall concepts.

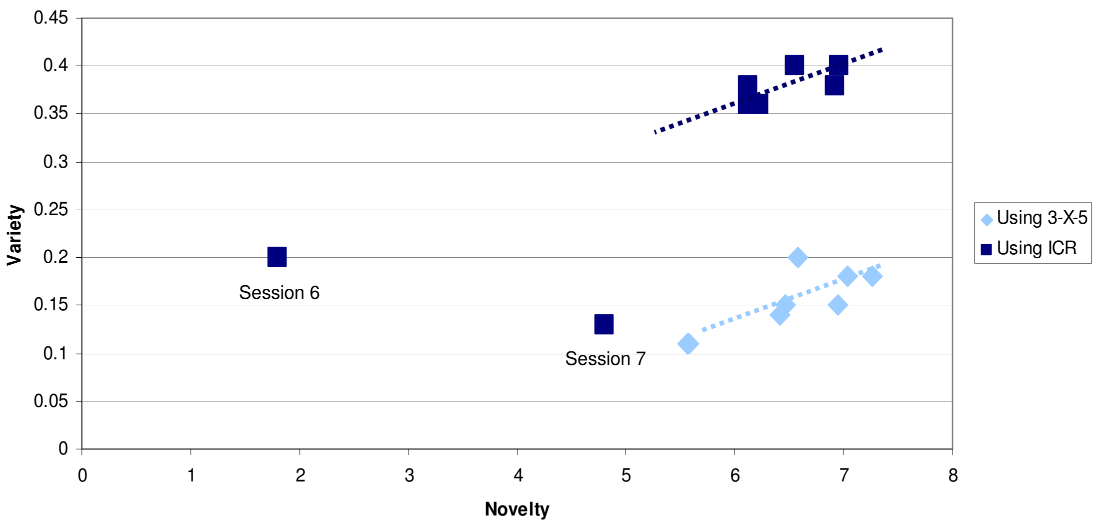

Figure 8.20: Novelty vs. Variety

8.5.4 Participation

Communication during the sessions was defined by the fact that the primary medium was the sketches produced. The ICR Grid allowed scope for verbal clarification during the phase of the task between information retrieval and use, but remained like 3-X-5 very much orientated around the information contained in the concept sketches. This was certainly an issue for some participants who were inhibited by their inability to sketch fluently and may be a factor in the variability of contribution during the sessions (Figure 8.21).

Overall, it was found that the participants contributed more evenly in the ICR Grid than in the 3-X-5 tasks. It was expected that there would be variation in the number of concepts produced by individuals using 3-X-5, since the initial instructions were to draw as many concepts as was comfortable in the five minute round. In the ICR Grid, however, one concept was explicitly required for each sketching task but the allocation of tasks depended on the decisions made by individuals during the session. Despite this, the number of ideas produced per participant gave some indication that those who were more productive in 3-X-5 were also more productive during the ICR Grid, which may have been due to less productive participants failing to complete the tasks allocated to them. Nevertheless, the exchange of ideas and information through the sessions was relatively efficient, and allowed more equal contribution than using more open-ended techniques such as brainstorming where one individual can easily dominate proceedings.

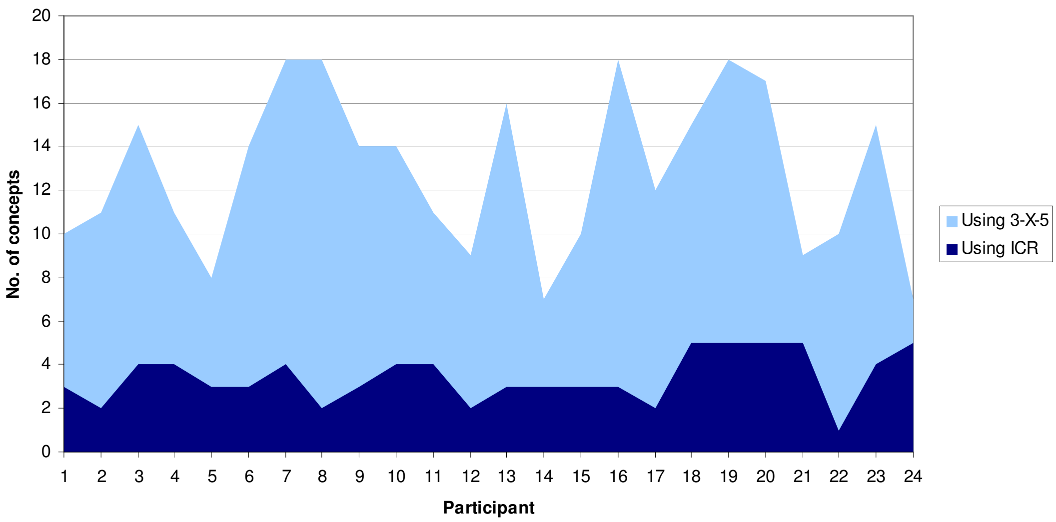

Figure 8.21: Contribution per participant

8.6 Conclusions

In questionnaire feedback on the design sessions, the ICR Grid was rated as the more enjoyable method and participants perceived the concepts they were producing to be of better quality. This is consistent with the analysis of design output from the sessions. In conclusion, some key observations can be made regarding the format of the ICR Grid:

- Information use – Despite a concern prior to the sessions taking place that there may be a resistance to the requirement in the ICR Grid to undertake searching tasks at the expense of concept sketching, it was found that there was a preference for this among the participants. Generally, there seemed to be a confidence associated with the use of information that the concepts generated consequently would be better substantiated. Fundamental design concepts directly related to the problem domain were found to be the most popular category of information. Although the information sources did provide stimulus for concepts, there was a concern that difficulty in finding good quality and diverse sources could inhibit the associated conceptual work.
- Time constraints – Both the 3-X-5 Method and ICR Grid were run under fairly stringent time constraints: they required participants to search and sketch faster than they normally would. Given the fact they were asked to be fairly rigorous in the sourcing and crafting of concepts, it may be worthwhile to modify the ICR Grid mechanics to allow more time to complete these elements. The motivation associated with a fixed time frame for task completion, however, proved valuable in focussing group effort and should be retained in some capacity.
- Sketching ability – Many participants felt uncomfortable and inhibited by their lack of sketching ability. While the 3-X-5 Method allowed no verbal communication, the ICR Grid did allow it in the window between information sourcing and concept development. This was still insufficient for participants who were trying to make yes/no decisions on concepts they had difficulty understanding. On the other hand, the ambiguity caused by sketches that were hard to understand acted as a stimulus for further creative

interpretation. Strategies for sketch communication (e.g. encouraging annotation, 2D drawing) and increased opportunity for verbal clarification could enhance this aspect of the approach.

- Competitive element – The competitive elements of the ICR Grid consisted of the yes/no decision and the associated scoring system. Although a majority found the yes/no decisions stimulating and encouraged them to do their best, some found it inhibiting and contrary to the co-operative nature of the session. The scoring system was found to be less effective in providing a true incentive to the participants and was not representative of the contribution made by participants. Overall, it was felt that the competitive element must be managed carefully: the reflective decisions in themselves provide an adequate motivation for participants. An overall scoring tally may be best omitted where a spirit of co-operation must be fostered.

8.7 Summary

As the first part of research Phase d (*application & reflection*) this chapter has documented the formal evaluation of the ICR Grid in a comparative study with a derivative of the 6-3-5 Method. Overall, the ICR Grid was well-received by participants in the evaluation and performed better in terms of producing concepts of superior quality, variety and detail. The integrated 'research, create, evaluate' approach was found to be effective in bringing information to bear on concept design and positively affected the quality of concept work. Its approach to generating and linking information resources as part of the conceptual design work suggests a new model to improve the effectiveness of digital libraries and information resources in the design process as well as compressing previously discrete stages in the concept design phase. There remain, however, a number of areas for improvement in both system presentation and mechanics of interaction to ensure that it runs more efficiently. The following chapter therefore describes final modifications to the method prior to implementation in a number of industrial contexts.

Chapter 9 Industrial case studies

This chapter reviews the application of the ICR Grid in a number of industrial settings. The comparative studies of Chapter 8 provided sufficient evidence that a robust approach to the utilisation of information in conceptual design had been realised. However, it was desirable to examine the use of the method in a number of different, practical contexts. Therefore, three different companies (LAT 56°, Scottoiler and Calcarb) were invited to utilise the method to address their current design issues. This allowed the evaluation of the ICR Grid's effectiveness in different types of problem, sizes of team and diversity of disciplines. A range of data sources, including the grid output, observation and semi-structured interviews were used to identify the benefits of adopting the ICR Grid method when compared to the normal practice of each organisation. While the organisations found the method refreshing, they all utilised it in different ways. The reasons for this are explored, and are used to draw new insights on its potential uses and applications.

9.1 Modifications to the method

After the formal evaluation of the ICR Grid method in the previous chapter, a number of continuing issues were highlighted regarding information use, time constraints, sketching ability and competition. Since the research was not static, it was deemed appropriate to make further tweaks to the mechanics to address these and optimise the method prior to the industrial sessions. These alterations were categorised in a way similar to the iterative development of Chapter 7, and are summarised in Table 9.1.

Feature	Revision
Game motivation	Scoring system omitted
Reflection	Verbal communication permitted as required
Pace	Time allocated for each round less rigorously enforced, but maintained informally as motivating element
Digital library	IL support prior to session to assist with finding good quality resources
Sketching & annotation	Introduction of digital sketching to provide integrated environment

Task distribution	Decision/task structure altered (simplified) to yes or no decision and search or create task

Table 9.1: Revisions to ICR Grid for industrial sessions

9.2 Structure

The setup for the sessions (Figure 9.1) was similar to the previous experiments in that OneNote was used to share digital information. This was enhanced, however, with the introduction of digital sketching using tablet interfaces to allow the session to take place entirely in the OneNote environment, rather than relying on paper to capture sketch work. Although in theory all users should have had an identical board displayed on their laptop, the network update lags meant that small discrepancies could arise. The author was therefore present in the room and active in the digital environment to ensure that the format of the board was consistent and to deal with any technical issues caused by the number of people accessing the shared file. To help clarify the status of the shared board, the author's laptop was connected to a projector, providing a reference point and allowing participants to monitor any discrepancy between their board and the latest shared update. It also provided an easily legible version of the board and a shared visual focus for the session.

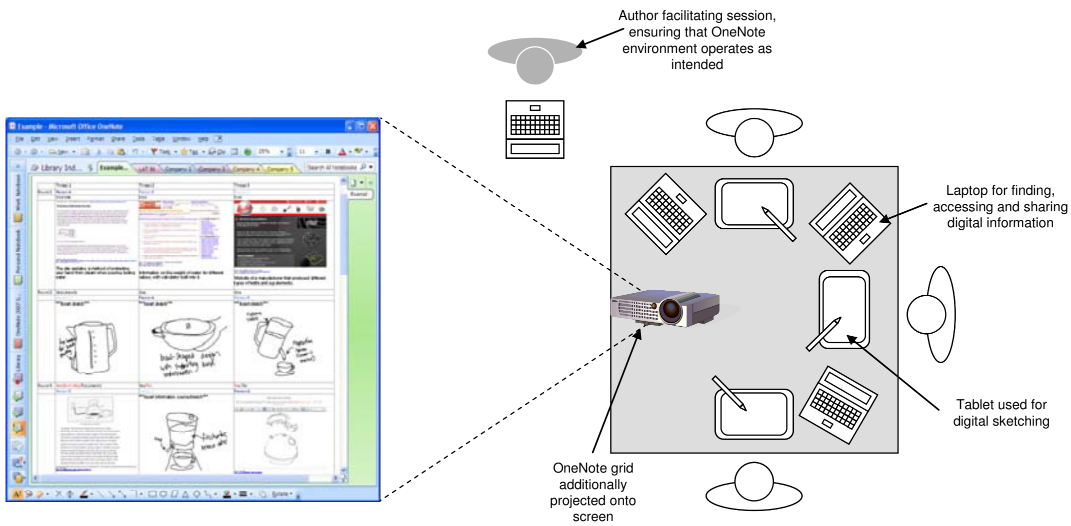

Figure 9.1: Setup used in the industrial tests

Prior to the sessions beginning, the participants were given a short overview of the ICR Grid, the theory behind it and how it would operate in practice. The design problem to be addressed had been agreed previously with each organisation. A flowchart with an overview of the tasks allocated based on the team interaction, as shown in Figure 9.2(a), was provided to ensure all participants were clear on procedure. At the beginning of each round, participants review the square above in the grid. If it contains an information item, this should be used as inspiration or stimulus in the development of a concept. If it contains a concept, this must be reviewed and a decision made on whether to develop it further. If yes is selected, a new, relevant information item must sourced and inserted into the grid, along with a suggested application. If no is selected, a new, alternative concept is created.

The output of the session is a linked grid of ideas, information and rationale that provides a comprehensive record of the work completed. The format of the grid output is illustrated in Figure 9.2(b). The number of columns correlates to the number of participants involved, with each column forming a thread. Participants complete squares of the grid according to the flowchart, and each time a round is completed move diagonally across the grid. This means participants are exposed to all the information and ideas produced by others in the team. Each thread has a different problem focus derived from the design problem to encourage diversity, and if consistent yes decisions are made then a concept can evolve with the continual addition of relevant information. A step-by-step illustrated guide to using the method is provided in Chapter 10 (Figure 10.1, p.214).

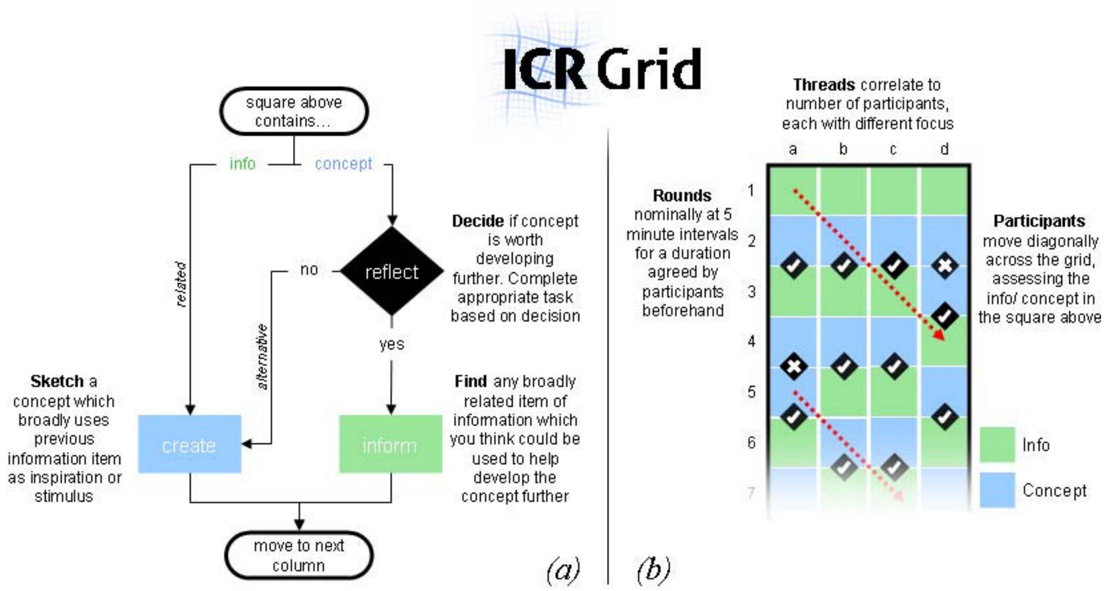

Figure 9.2: Task flowchart and overview of grid composition

The sessions themselves took place over a half day, including an introduction to the method, tutorial on the technology used, and debrief, with the actual design work roughly an hour in duration. While the formal experiments of Chapter 8 focussed on analysing the conceptual output, these studies reviewed the output grid in more general terms, reviewing the number of rounds completed, concepts created and information sources found. These are summarised in Table 9.2 and explored in more detail below. In addition, qualitative data from the semi-structured interviews and observation were used to develop an understanding of the process of using the method and its practicality in the industrial setting. The format of the semi-structured interview covered the topics of context, engagement, information use, communication, and output. Extracts have been included and reviewed in tabular form in the body of the thesis, while complete grid outputs and interview transcripts from each session can be found in Appendix VI.

Company	Problem	Team composition		Rounds	Concepts	Info. sources
LAT56°	Hanging suit carrier over a door or rail	2	(2 Designers)	8	9	7
Scottoiler	Improved delivery of oil to motorcycle chains	4	(3 Design Engineers, 1 R&D manager)	7	15	17
	Dual injector, slipperblock, front sprocket feed, oil fling catch guard/ sprocket hugger	4	(3 Design Engineers, 1 R&D Manager)	7	14	15
Calcarb	Product for identification throughout manufacturing process	4	(1 Training Officer, 1 Manufacturing Supervisor, 1 Materials Manager, 1 Process Improvement Manager)	6	10*	12

*5 of which were text-based

Table 9.2: Summary of industrial sessions

9.3 Case 1: Latitude 56 Degrees Ltd.

Latitude 56 Degrees (LAT56°)[35] is a design and development company based in Glasgow. It consists of two designers, Lawrence Broadley and Kevin Fox, who graduated in Product Design and Innovation prior to starting the business in 2007. Their stated aim is to design 'pioneering products for an adventure lifestyle'. They design and manufacture products for travel and outdoor use, working as design consultants while also developing in-house products. Their main product is the Rat-Pak™, a compact suit-carrier to allow easy transportation in demanding situations such as cycling.

9.3.1 Approach to concept generation

Given the background of the partners in the company, it is unsurprising that LAT56° have a high awareness of the product development process and the place of structured techniques in supporting it. They use a systematic brainstorming approach to tackle design challenges, with sessions often lasting over several days and progressing from words to ideas to concepts.

9.3.2 Design problem

The design problem LAT56° chose to address was a current issue they had with their Rat-Pak product. It was necessary to develop an integrated device which would allow the unfolded suit carrier to be hung over a rail or door. This would have to fit within the current space envelope of the product, be flexible enough to fit over several types of rail or door, and be as cheap to manufacture as possible.

9.3.3 Results

Eight rounds were completed in the session, which lasted just over an hour. The first two took almost ten minutes each – significantly longer than expected – but it did speed up significantly thereafter. The format of only two participants was one not previously envisaged for the method, although the mechanics were still workable. It was found that the two resulting threads developed broadly similar concepts – a concept using a loop of Velcro or similar fastening material. This convergence can be attributed to the small number of participants: with only two initial information sources, and lack of other participants bringing diverse information sources and ideas

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[35] http://www.lat56.com (Accessed: 9th January 2010)

as the session progressed, there was limited scope for a range of information and ideas to be introduced and developed.

Additionally, the participants seemed to have fairly strong shared, pre-conceived notions of how the design should develop. This is evidenced by the speed with which the material loop principle was settled upon and embodied, despite there being two ‘no’ decisions in concept evaluation. The strengths of the ICR Grid with regards to integrating information and concept development became particularly apparent in Rounds 5-8: a number of manufacturers and suppliers of components to allow different configurations of the basic design principle were established and explored, providing a level of output appropriate for a product and problem approaching the manufacturing stage.

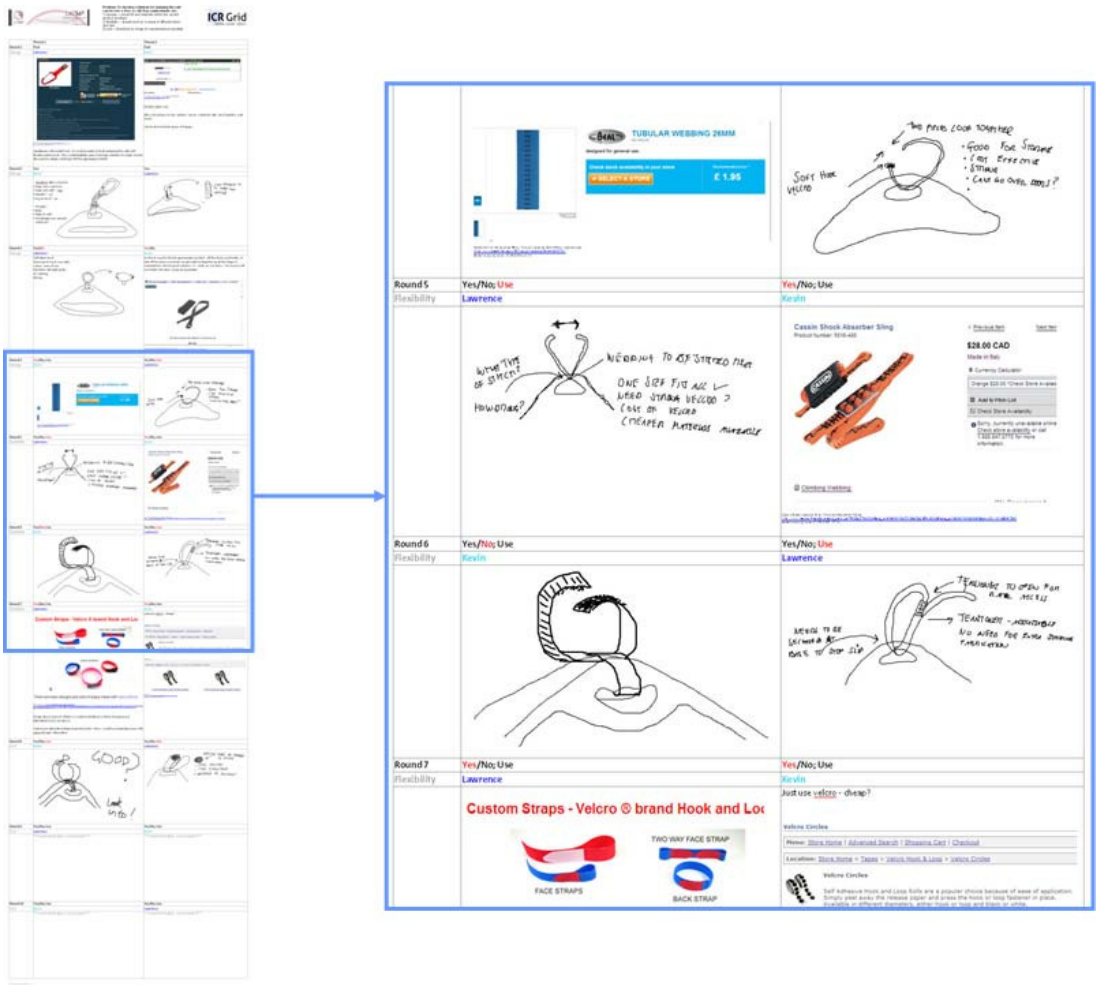

Figure 9.3: OneNote ICR Grid with sample from LAT56° design session

9.3.4 Feedback

Feedback from the participants in the LAT 56° session is summarised in Table 9.3. The full transcript of the semi-structured interview can be found in Appendix VI.

Topic	Feedback
Context	The integrated environment appealed to the participants. They indicated that it was like 'logging into something and updating it', providing a more robust record of their design work. The fact that user requirements were not addressed in depth was highlighted as a potential weakness in the method. It was, however, acknowledged that the design problem could have had more detailed criteria and that data from prior research could have formed information items as part of the grid.
Engagement	They felt the concurrent ('all in the same pot') approach made the concept design process feel 'fresher', and helped to focus their design ideas. In terms of evaluating concepts during the session, they felt that 'usually a maybe' was a more appropriate than a definite yes or no, allowing aspects of concepts to be developed as they saw fit.
Information use	Given the nature of the problem they were addressing, they highlighted how their background knowledge affected their information searching approach. The fact that information sources were captured as the session progressed was something which appealed strongly, as they cited previous cases where they would 'forget about it [the information source] whereas this is recorded and it's there and saved'. An interesting point was made on the importance of information selected for use in Round 1 of the session. This dictated the direction of the threads and hence required careful consideration. Another observation was that the grid was quite 'organic' in that it was not dictated how much or what type of information was required at a particular point.
Communication	Although fluent sketchers, they found verbal communication useful for clarification purposes. They preferred to do this rather than re-interpret unclear sketches, instead using any ambiguity as a discussion point to augment the development process.
Output	The participants were generally positive in their feedback, describing the grid as 'a good base to work from' and at least one idea was produced which had 'potential… to look into'. Although generally positive about the integrated nature of the development environment, they did observe that the method would benefit from a less complicated interface.

Table 9.3: Summary of feedback from LAT 56° session

9.4 Case 2: Scottoiler Ltd.

Scottoiler[36] manufacture chain lubrication systems for motorcycles. In normal use, a coating of oil or grease protects the chain from wear and corrosion but road dirt adheres to this and the combination of dirt and oil forms a grinding paste that accelerates wear. To prevent this happening, the chain is required to be removed and

[36] http://www.scottoiler.com (Accessed: 9th January 2010)

cleaned – a tedious and messy chore. Scottoiler's vacuum-operated chain lubrication system instead enables the chain to be cleaned and lubricated continuously while the engine is on by using a reservoir system mounted on the bike which slowly releases the oil. Their kits gives a range of approximately 400-800 miles between refills of the RMV (Reservoir Metering Valve), depending on the flow setting, with the supplied bottle of Scottoil sufficient for 2500 miles of lubrication.

The company was founded in 1986 by Fraser Scott, a biking enthusiast whose problems with his bike chain in high-mileage use led him to develop his own solution to the problem. Since then, continual improvements and innovations have been made, with the company now employing 23 people. Scottoiler's R&D department consists of four people: Rory Ingram, Barry Stewart, Rachel Tramschek (all Design Engineers) and Stephen Hood (R&D Project Manager).

9.4.1 Approach to concept generation

Scottoiler have a range of established products, meaning much of their work is on incremental improvement and problem solving. Additionally, the on-site manufacturing issues can result in a lot of time and effort being absorbed by production and customer-related issues. In terms of their design and development process, concerted innovation generally takes place in the form of informal brainstorming sessions as part of their periodic R&D team meetings. These utilise whiteboards and discussion to produce ideas, with natural consensus generally being used to dictate direction. Occasionally, R&D team members will take different concepts resulting from these sessions to work up individually and bring them back to the team for evaluation.

9.4.2 Design problem

The design problem addressed in the session was a generic one: how to improve delivery of oil to motorcycle chains. It was viewed by the R&D team as an opportunity to encourage team working and develop new lines of thinking. Fitting, delivery and reliability were identified as the main criteria for any new design. Given the problems with a limited initial information base inhibiting the previous session with LAT56, the first row of the ICR Grid was filled by the author with a diverse (and random) range of sources prior to Scottoiler's session. This was intended to ensure that the four threads would lead to a diverse set of concepts.

9.4.3 Results

To avoid a slow start, as experienced with the LAT56° session, the first row of the Scottoiler grid was completed by the author beforehand, providing the participants with an indication of how they were expected to complete it and giving a diverse range to the threads. Additionally, the instructions for participants outlining the session mechanics were refined, with a flowchart for reference given to everyone. Although this helped ensure the session started and continued at a reasonable pace (in all, eight rows of the grid were completed in the hour), it was became apparent that the team were uncomfortable with some of the directions the initial information items forced them into. Nevertheless, as the participants developed an understanding of the grid method, a diverse range of information items and concepts began to emerge in Rounds 2-5. The team size of four was found to be more effective than the two in the previous session, with the threads providing a variety of topics for individuals to address. This seemed to help with levels of engagement and information exchange.

The team had generally good levels of IT and sketching ability (though one participant did struggle more than the others), meaning that they were able to cope with the OneNote interface and tablet equipment necessary for the integrated environment. In terms of information items, catalogue parts and images of components from other manufacturers featured highly, accompanied by suggestions or ideas on how these could be applied in the chain lubrication context. The decisions made during the session were mostly positive, though there were a couple of no's. Again, the decision seemed to matter less that moving the idea or thought forward in some way. Towards the end of the session, the participants seemed to find the general direction of Thread 4 the most exciting in terms of its development, though there were elements of cross-fertilisation across the columns of the grid.

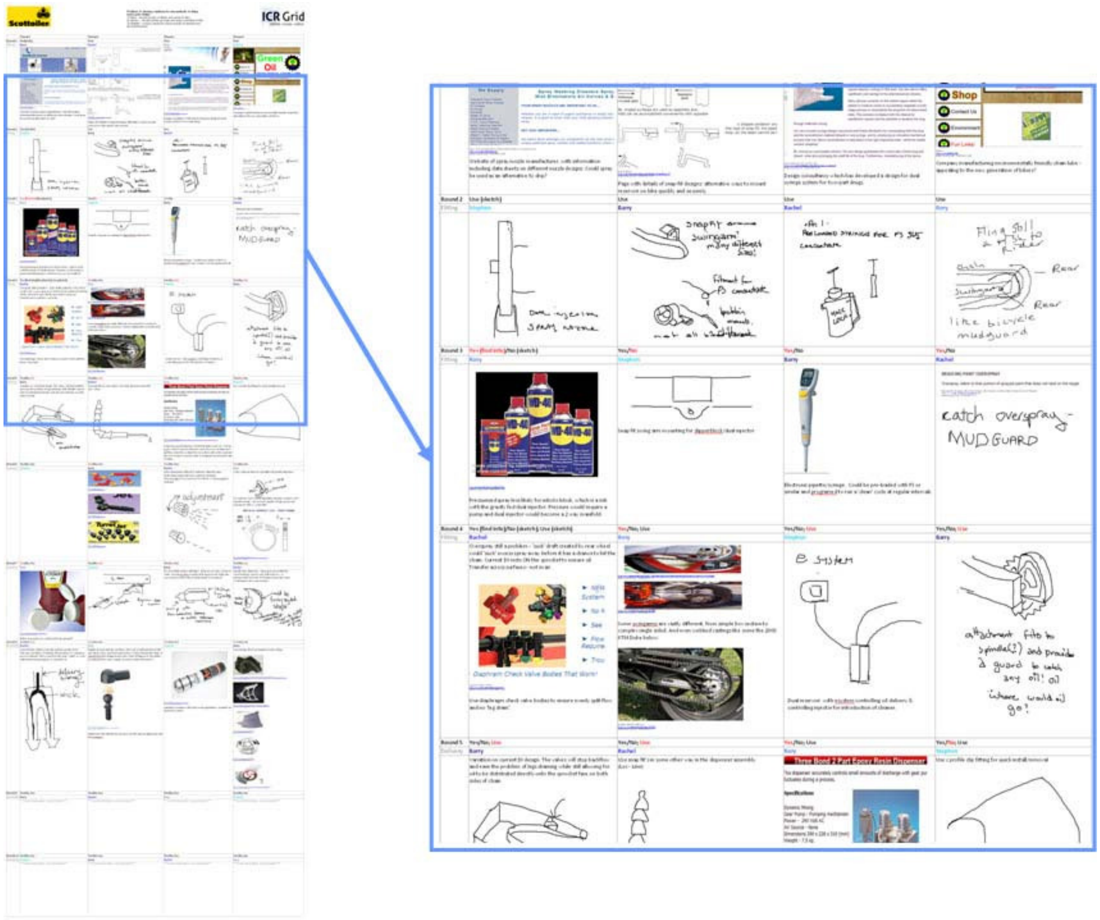

Figure 9.4: OneNote ICR Grid with sample from Scottoiler design session

9.4.4 Feedback

Feedback from the participants in the Scottoiler session is summarised in Table 9.4. The full transcript of the semi-structured interview can be found in Appendix VI.

Topic	Feedback
Context	The team appreciated how the grid captured information as the session progressed, since the company currently struggles to document rigorously and to ‘get the information that’s been discussed on a whiteboard concisely into a minuted note and for that to actually make any sense’, suggesting that the records formed by the Grid would be more meaningful to anybody revisiting them. Additionally, they enjoyed the variety provided by working on multiple ideas, finding it ‘quite easy to deviate to another idea without getting caught up in the one thing’.
Engagement	The team found the exchange of information between team members stimulating as it ‘helped lead them [threads of development] in different directions because you were getting new information, things you’d never seen before.’ IT ability was also identified as important: with one participant markedly less confident in this area, his input was at times curtailed not by a lack of ideas but by a lack of expertise in finding information or inputting them into the grid. Concerns were also voiced for other company employees (‘the

	girls in production') who may not have equivalent IT skills if they wanted to participate. The R&D team, however, were extremely confident in their searching ability with good prior knowledge of where they would find relevant sources to the extent that 'the information I was looking for, I knew what I was looking for. It wasn't like I was researching, I just went straight to something I knew most of the time.' The majority of the team were also very comfortable with searching for new items when required, being 'accustomed to being able to Google anything… it's like second nature, if you don't know or if you're looking for something the first thing you do is jump on the 'Net.' Searching activity was, however, rushed at times due to the timescales of the method and it was felt that this compromised the quality of items sourced.
Information use	As described above, in light of the previous session with LAT56° the first row of information was entered by the author to provide the teams with a strong start and to ensure there was a diversity of sources. The participants felt this actually detracted from the session as they would have chosen different paths for each: 'Say we started with a single sided rear sprocket feed, a dual injector sprocket feed, a front sprocket feed and a slipper block, then it could have taken a completely different path and been really focussed on how you apply the oil to the chain, which is what we were thinking about really.'
Communication	As the session progressed, the team felt that they tended to build on or change ideas rather than just eliminate them, suggesting that if there is an aspect of a concept that does not seem feasible then they were liable to simply highlight or alter this aspect in order to 'let the next person have their input in as well.' The problem criteria listed in the design problem and suggested for focus in each round was not particularly effective: 'You focus on the box above rather than if it's function or if it's robustness or whatever.'
Output	Overall, the integrated environment was popular in its functionality: 'I thought it was quite good you could drop a link in just like that... Whatever aspect of it it was you wanted rather than printing out a web page and circling it. It was much more concise.' The results were felt to have been reasonably useful, with Thread 4 identified as having evolved particularly well. It was suggested that with more careful identification of the starting point for the four threads, the results could have been better and that another attempt would be worthwhile.

Table 9.4: Summary of feedback from Scottoiler session

9.5 Case 3: Calcarb Ltd.

Calcarb[37] is a manufacturer of Carbon Bonded Carbon Fibre (CBCF) insulation material used in furnaces. Employing approximately 100 people, from their production plant in central Scotland they produce a range of low and medium density carbon based products. All materials are manufactured from a Rayon fibre and produced under a quality management system, offering full traceability. Calcarb work closely with their customer base, and have developed technical partnerships with major clients in a number of sectors including aerospace, semiconductor, automotive, and crystal growing amongst others. The participants in the session

[37] http://www.calcarb.com (Accessed: 9th January 2010)

were: Paul Latta (Training Officer), Jimmy Macaulay (Manufacturing Supervisor), David Hendrie (Materials Manager) and David Haddow (Process Improvement Manager)

9.5.1 Approach to concept generation

Calcarb is a manufacturing company and focussed very much on the engineering and manufacturing issues associated with the production of their insulation materials. They tend to take an informal approach to problem solving. Production issues are often solved on the shop floor or by individuals, although for more significant issues the management team would gather for whiteboard sessions. Although conversant with tools such as Fishbone Diagrams, these sessions are not generally structured but instead used as a forum for individuals to share ideas.

9.5.2 Design problem

The design problem addressed in the sessions was the marking of products for identification purposes through the manufacturing process. Calcarb have moulds that are shaped as boards, cylinders or discs of various sizes that go through several drying and temperature processes before being machined to customer drawings. These machined parts can then be further processed. Previous attempts to identify the parts by etching, marking, painting etc. have proved ineffective, and so the design challenge in this instance was to try and develop alternative means to permanently identify them. The main design constraints were: durability (had to last through entire process, including before and after machining), legibility (easy to read, ideally machine readable code), temperature resistance (able to survive temperatures up to 2200°C), and contamination (able to resist contamination through the process).

9.5.3 Results

After the slow start to LAT56°'s session and the subsequent problems caused by providing initial information items in Scottoiler's, in the Calcarb session the participants were again given the freedom to choose the first row of information resources. They were, however, asked to find something relating to one of the design criteria as stated in the problem definition to ensure that there would be good diversity in the four threads. During the hour-long session, six rounds were completed. Despite the enhanced instructions, the session was again slow to start, with the manufacturing background of participants perhaps an initial barrier to what was an unfamiliar method. IT was also an issue, with the participants struggling to use OneNote and the tablet interfaces to various degrees. It was found that despite a range of job titles, all participants were similarly familiar with the manufacturing process and its associated issues, and therefore cross-disciplinary factors were not significant.

Despite the slow start, the session picked up after around 20 minutes, when a number of information items were identified that provided new ways of approaching the identification problem, including one on a temperature resistant paint previously unknown to the team, and engendered greater enthusiasm for what might emerge from the session. It was at this point that participants also overcame a lack of fluency in sketching (again perhaps due to the background of the participants as manufacturing engineers) by focussing on text and annotation, meaning that the grid began to take the form of a shared information resource. Participants found items, suggested how they would be used, and passed them on to others who would repeat this process. This can be seen in the grid output, which consists mostly of linked information items. As an approach, this worked reasonably well and suited the participants in this case, providing an output which was of use, despite it not being conducted in the expected manner.

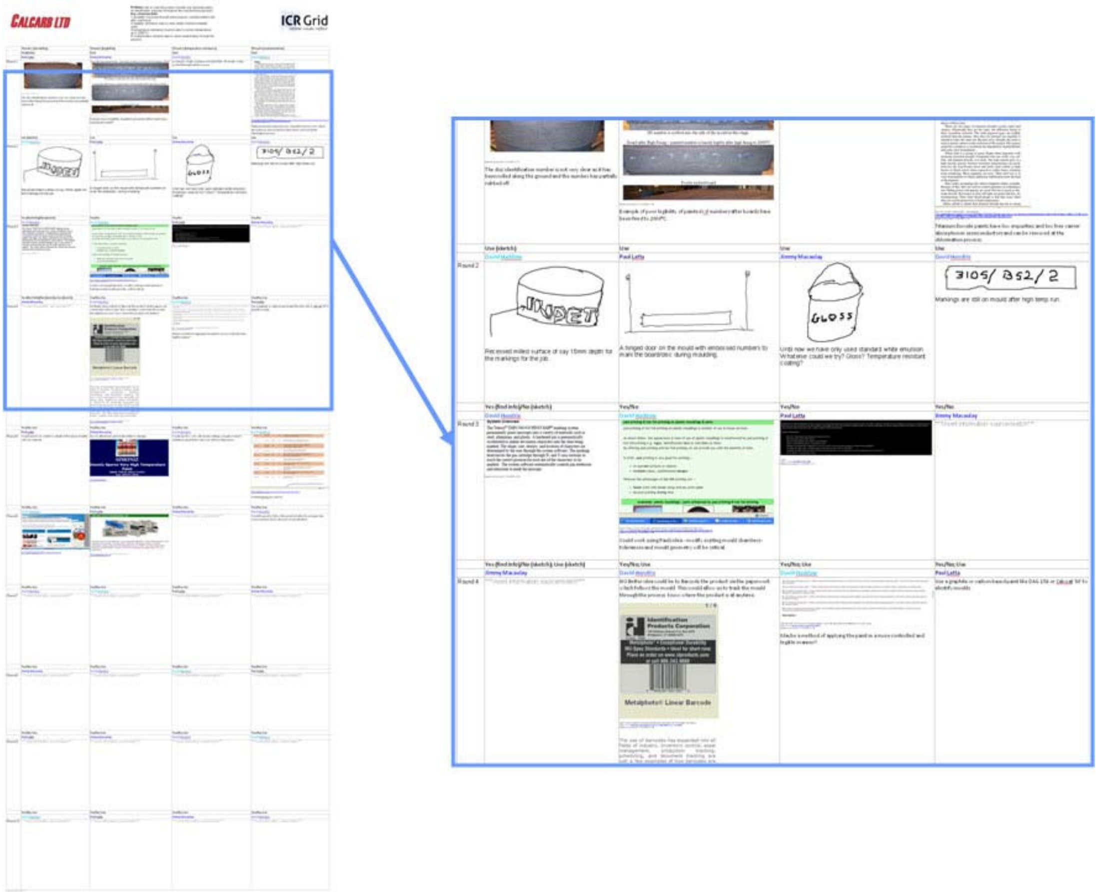

Figure 9.5: OneNote ICR Grid with sample from Calcarb design session

9.5.4 Feedback

Feedback from the participants in the Calcarb session is summarised in Table 9.5. The full transcript of the semi-structured interview can be found in Appendix VI.

Topic	Feedback
Context	Given that the team at Calcarb did not meet to discuss problems as regularly as they would have liked, they returned some positive comments on the way the grid forced interaction with others' ideas. One highlighted the effectiveness of 'picking up somebody else's idea and researching it… getting feedback from the different people on ideas and … pick[ing] out the best one' as a means of engagement during the session. The evolution of concepts through evaluation, (information and reworking was identified as a useful approach.
Engagement	One participant particularly struggled with the IT associated with the Grid, stating that 'it certainly slowed me down a bit because probably I've got less proficiency… than the rest of these guys here.' Rather than just a problem with one individual, it was apparent that for those unfamiliar with software and concept design techniques, the set-up and rules were still fairly complex, requiring a period of acclimatisation. Additionally, pace was again mentioned as an issue, with one participant stating it was 'sometimes too fast', suggesting that a longer-term approach over a period such as a half-day may be more effective, 'instead of moving on every five minutes you move on every half hour or

	something so that you get a chance to discuss everything.'
Information use	In terms of searching for information, there was some frustration at being able to find appropriate items, with the suggestion that sometimes you can spend 'too much time… you can research, and research, and research'. The team did, however, find a number of items relating to paint manufacturers they were not previously aware of, and this was recognised as being particularly valuable knowledge for them moving forward.
Communication	Similar to the other sessions, there was a reluctance to vote against ideas. Participants reported putting forward alternative ideas when voting yes rather than voting no: '…I found myself looking at the ideas and then trying to find a way that it could work... rather than not working. You know, to see if you could actually expand the thing to its fullest.' There was significant debate and discussion during the session, on both the ideas and how the mechanics of the Grid operated. The participant who struggled with the IT in particular felt more comfortable in verbal communication: 'I didn't feel there was enough of that, I felt we could maybe have accomplished more if we had discussed the problems more.'
Output	Overall, there was a sense that the session showed a level of progression from start to finish: 'it takes you to that level where you can come out with maybe two ideas that are really good and two ideas, or four or five ideas that aren't good and maybe points you in a direction.' The participants felt that the Grid captured information sources they were not aware of and during the session they had managed to form 'an idea that we can take a step forward on.'

Table 9.5: Summary of feedback from Calcarb session

9.6 Scottoiler on-site follow up session

The R&D team at Scottoiler felt that the ICR Grid was helpful in allowing them to work together and generate design ideas. The previous session, while allowing them to see the potential of the method, had been limited by the information items presented at the start and difficulties using the OneNote environment. It was therefore decided to run another session on the Scottoiler premises (Figure 9.6) using a paper-based format similar to that used in the evaluation in Chapter 8. The problem addressed was again applying oil to the chain, but the four threads were to address specific approaches (dual injector, slipperblock, front sprocket feed, oil fling catch guard/ sprocket hugger) to ensure that the work was in line with the R&D team's current priorities.

Conducting the session on Scottoiler's premises meant that the team were in a familiar environment with access to their own computers and information sources. The position of desks at the company, while not ideal, was sufficient for verbal communication and for the paper templates to be passed around the team. The author was present while the team started the session, but after a period of time (roughly an hour) left the team to finish the session as they saw fit. As a result, the majority (Rounds 1-6) were completed synchronously, with the remaining cells completed on an ad-hoc basis over a few weeks.

Figure 9.6: ICR session at Scottoiler

9.6.1 Results

The session progressed noticeably slower than the previous ones, with the first four rounds taking around 20 minutes each, and Round 4 particularly time consuming due to the fact that there was a thread with three new information items to assimilate. The output from the second session was found to be more thorough than the previous session both in terms of the information found and concepts produced. The output (Figure 9.7) took on the quality of a collage, with printouts augmented with hand-written annotation and sketches to create the threads of concept development. Access to the participants' own computers, a local printer and all the company's on-site information meant that it was easier to include in-depth information where appropriate. It was found, however, that the Internet remained the most heavily used resource, though participants did occasionally hunt their desks or books for information they obviously remembered seeing previously.

The fact that the grid was completed part synchronously and part asynchronously had no discernable affect on the results. The yes/no evaluation again was not a big influence – participants were more flexible in looking to develop threads and find appropriate information as necessary. There was not a great deal of verbal communication. With participants putting more effort into the written narratives, it was not so necessary to get clarification. The atmosphere when undertaken in the synchronous mode was of an intense and focussed session. In the asynchronous mode, this was inevitably a lot less so. In all, it was found that the output was more comprehensive than the previous session, despite the paper format lacking the advantages of the OneNote integrated environment, specifically the inherent recording of digital links and images.

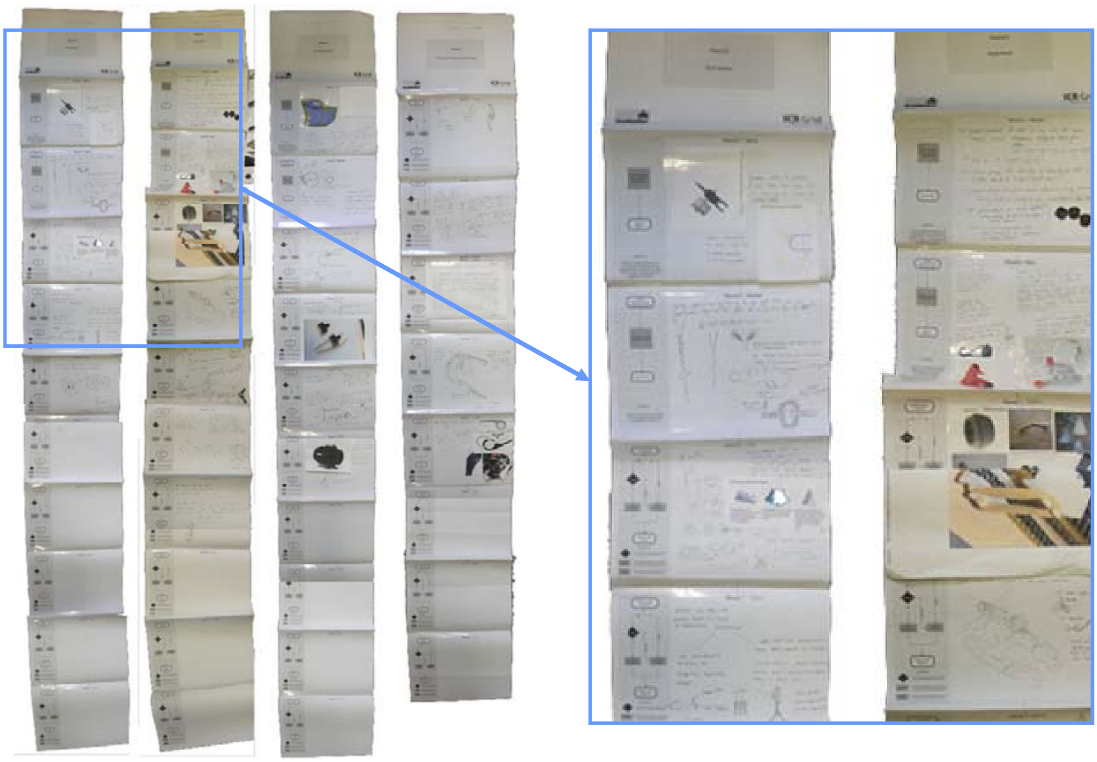

Figure 9.7: Paper ICR Grid with sample from Scottoiler follow-up design session

9.6.2 Feedback

The participants of the second session were again given the opportunity to give feedback on the ICR Grid, through an on-site follow-up visit and at an R&D team meeting when the results of the grid were discussed. This feedback is summarised in Table 9.6.

Topic	Feedback
Context	The team acknowledged that they did not strictly follow the guidance: negative concept decisions tended not to stop threads altogether, with participants instead illustrating pros and cons, and preferring to add sketches, text and information as they felt was necessary.
Engagement	There were mixed feelings on whether the process would work better asynchronously over the course of a number of days or working intensely in a synchronous manner. While the previous session conducted at the University was considered more 'slick', the information sourced and incorporated into the grid was felt to be more limited due to the time pressures. In the follow up session on company premises, the team felt more at ease and less rushed. One participant in particular was more comfortable given the lesser dependency on technology in the development of the grid. When pushed for time, participants reported only reviewing the previous concept rather than the full thread before creating their own additions.
Information use	When finding information, it was reported that a lot of sources were supporting personal insights and knowledge. The fact this was shared with the rest of the design team, however, was useful and something which did not otherwise necessarily happen. It was further suggested that the process of reviewing all material – by summarising and looking for key decisions – would be useful.
Communication	The participants reported at times getting confused with the different threads, leading to some quite significant crossover across the four threads. This was particularly apparent between the dual injector and the slipperblock threads. A contributing factor may have been that ideas were continued while still engaging with other threads – participants reported a desire to continue building on their own last contribution rather than what colleagues had added. After investing a certain amount of time and energy, individuals understandably have a certain bias. It was suggested that it would be interesting to try using just one booklet and compare results for continuity.
Output	On considering whether they would have achieved comparable results with their usual approach (brainstorming, agreeing on parameters, and working on ideas individually before presenting them at the next team meeting) the ICR Grid would result in more concepts but that the personal attachment to ideas may see them advanced more fully using their own approach.

Table 9.6: Summary of feedback from Scottoiler follow-up session

9.7 Conclusions

Despite problems regarding the usability of the OneNote interface, it was found the ICR Grid performed well in the three different contexts. Participants acknowledged the potential benefits in conducting all their concept design work in an integrated environment, particularly the recording of pertinent information sources and the contextualisation of them by linking them to sketches. All organisations were agreed that this was a unique form of documentation for this stage of the design process which would be of tangible use in further concept development. Regarding the mechanics of the grid method, the response to finding information in parallel to concept generation was generally positive, though concerns were raised regarding the depth of information searching possible during the session timescales and how this fits with the overall development process. Additionally, for corporate cultures where sketching of ideas is not prevalent, it is necessary to consider how the ICR method can be modified to accommodate this. It was found that in the instance where participants were less comfortable sketching that the grid formed a matrix of information sources and suggested uses, which in itself was a valuable resource for further development. Although the studies provide some clear conclusions on the performance of the method in a short, managed session, the follow-up, paper-based session revealed the potential benefits of conducting work over a longer period of time and in environments where appropriate information is close at hand.

While the paper version of the ICR Grid had a number of benefits in accessibility for the team, it did lose some of the mechanical elements prescribed by the computerised version that are important to the workings of the method. The overall output may have been more substantial, but it did run over a longer period of time and the team was more familiar with the process and what was expected. The optimal solution would have been to have had a computer-based version operating on the company premises to allow them flexibility in fitting it to their working practices, increased comfort, and access to on-site resources, while ensuring that the correct procedures were followed in its execution.

9.8 Summary

This chapter has outlined the application of the ICR Grid in a number of industrial settings. The three different companies (LAT 56°, Scottoiler and Calcarb) invited to use the method provided varied feedback on its effectiveness. As highly aware designers, LAT 56° quickly adapted to the rationale of the method and were able to apply it to a very specific design problem, although its diversity was inhibited by the fact there were only two participants. Scottoiler found the interactive benefits important, allowing them to improve communication across their R&D team. The Calcarb session illustrated how the method could be recalibrated for team-based research exercises. There was recognition across the organisations that the ICR Grid output was a unique record of the design sessions, with the capture of linked concept generation and information items providing a vivid document of the activity undertaken and a valuable resource for on-going concept development work. Additionally, Scottoiler chose to conduct a follow-up session on company premises, which suggested that the method could be applied effectively in the asynchronous mode. The fact that the different companies were able to adapt the method to best suit their needs has allowed a number of insights to be drawn on future development and further application, and these are outlined in the following chapter.

Chapter 10 Discussion and future work

This, the final chapter in the thesis, is the end of research Phase d (*application and reflection*). The output from this phase is the evaluation of the ICR Grid as a new method for use in concept design. While the previous two chapters in this phase have seen its formal evaluation in a controlled environment and application in a number of industrial settings, this chapter reviews achievements against the initial research aims and reflects on the ICR Grid's place in the realm of product development. The thesis ends by identifying avenues for future work.

10.1 Introduction

Using digital information as part of the concept development process was identified as a critical issue at the outset of this work. In investigating this further, the research has revealed that the informal nature of concept design and the ill-defined nature of creativity are central to the problem of applying logical methods to the utilisation of information in this activity. Thus, the development of an approach which allows participants a significant measure of freedom both in information retrieval and concept generation has been deemed appropriate. The resulting method, the ICR Grid, focuses teams on solution-based activity, and, uniquely, facilitates the retrieval and application of appropriate information sources in parallel to creative design work. The output of the method is a linked grid that vividly captures ideas, rational and development, providing a valuable resource for future development work.

In reviewing the overall success of the ICR Grid, it is appropriate to recall the elements suggested for enhancing interaction with digital information at the end of Chapter 6. *Motivation*, *interaction*, and *structure* (augmented by *implementation* and *innovation* to take account of the research context) were used to both in the evaluation of gaming genres and in the identification of the sim genre as the most applicable to the concept design task. In the subsequent developmental process, the embodiment of the ICR Grid has not resulted in a game in the conventional sense. However, the intention was to derive cues and characteristics that would aid in making the concept design interaction more engaging for participants, and in particular to encourage information use. Table 6.2 summarises the distinguishing principles of the ICR Grid against each of these criteria.

Criteria	ICR Grid characteristics
Motivation	Encourages a solution-focussed approach to concept design
	Brings information into the design activity as required to the point of need
	Creates tension of competition and collaboration
Interaction	Incorporates both individual and team working
	Communicates primarily through sketches and text, with verbal clarification where appropriate
	Stores information and sketchwork in homogenous digital environment
Structure	Builds information resource in parallel with the act of designing
	Supports shift between different modes of design thinking

Table 10.1: Assessment of ICR Grid against development criteria

10.2 Reflection on achievements

The initial hypothesis for the research was that *enhanced use of appropriate digital information will result in the improved performance of concept design teams*. This has been demonstrated through the development and evaluation of the ICR Grid. This method was shown to result in concepts of higher quality (though fewer) than using a comparable design method where information was not acquired during the process. In addition, when applied in various industrial contexts the grid received a generally positive response from participants. In order to achieve this main research output, a number of objectives were outlined in Chapter 2, and these have been reviewed as shown in Table 10.2.

	Objective	Outcome
i.	Establish the context of information use in product development	Problems managing large volumes of information at critical early stages highlighted. Industrial, team and design problem contexts identified.
ii.	Review current concept design approaches, creativity and the role of information	Processes outlined and range of methods reviewed. Solution-focussed approach, allowing for shifting modes of thinking, identified as desirable.
iii.	Review the nature of design information – how it is shared and used by teams	Taxonomies of design information reviewed. Direct, fundamental concept information identified as most relevant

		for concept design. Protocol analyses showed information to be important in stimulating exploratory interaction.
iv.	Investigate how digital technologies can provide information support for concept design teams	Gap between CSCW (groupware) and KM (digital libraries) illustrated. Implications for digital information use concept design explored, with class study illustrating lack of engagement with DL. Games evaluated by genre and relevant characteristics relating to motivation, interaction and structure reviewed. Scenarios for concept design based on game genres developed. Sim genre and aspects of game theory used to inform structured team interaction.
v.	Develop a new method to enhance digital information use by the concept design team	Iterative development and testing used to refine structured team interaction – identified as the ICR Grid.
vi.	Evaluate the effectiveness of the new method in a series of controlled test	ICR Grid performed better than the 6-3-5 Method in terms of concept quality, variety, and detail.
vii.	Evaluate the effectiveness of the new method through application to a number of industrial context	ICR Grid found to be flexible enough to be used in a number of industrial settings, with feedback generally positive feedback.

Table 10.2: Outcomes against objectives

10.3 Overview of method

An illustrated guide to using ICR Grid has been included in Figure 10.1. This consists of three stages: *prepare*, *conduct* and *review*. The interface for co-ordinating the work is not specified: both digital (using OneNote) and paper implementations have been detailed and reviewed in the course of this research. While it is easier for an organisation to set up and run a paper-based session, constructing and using a digital environment (whether OneNote or a similar system) provides the benefits of integrated and active concept and information links in the grid output that set the ICR Grid apart from other concept design methods. It also provides a powerful legacy in that any work undertaken can be revisited and reused in throughout the product development process.

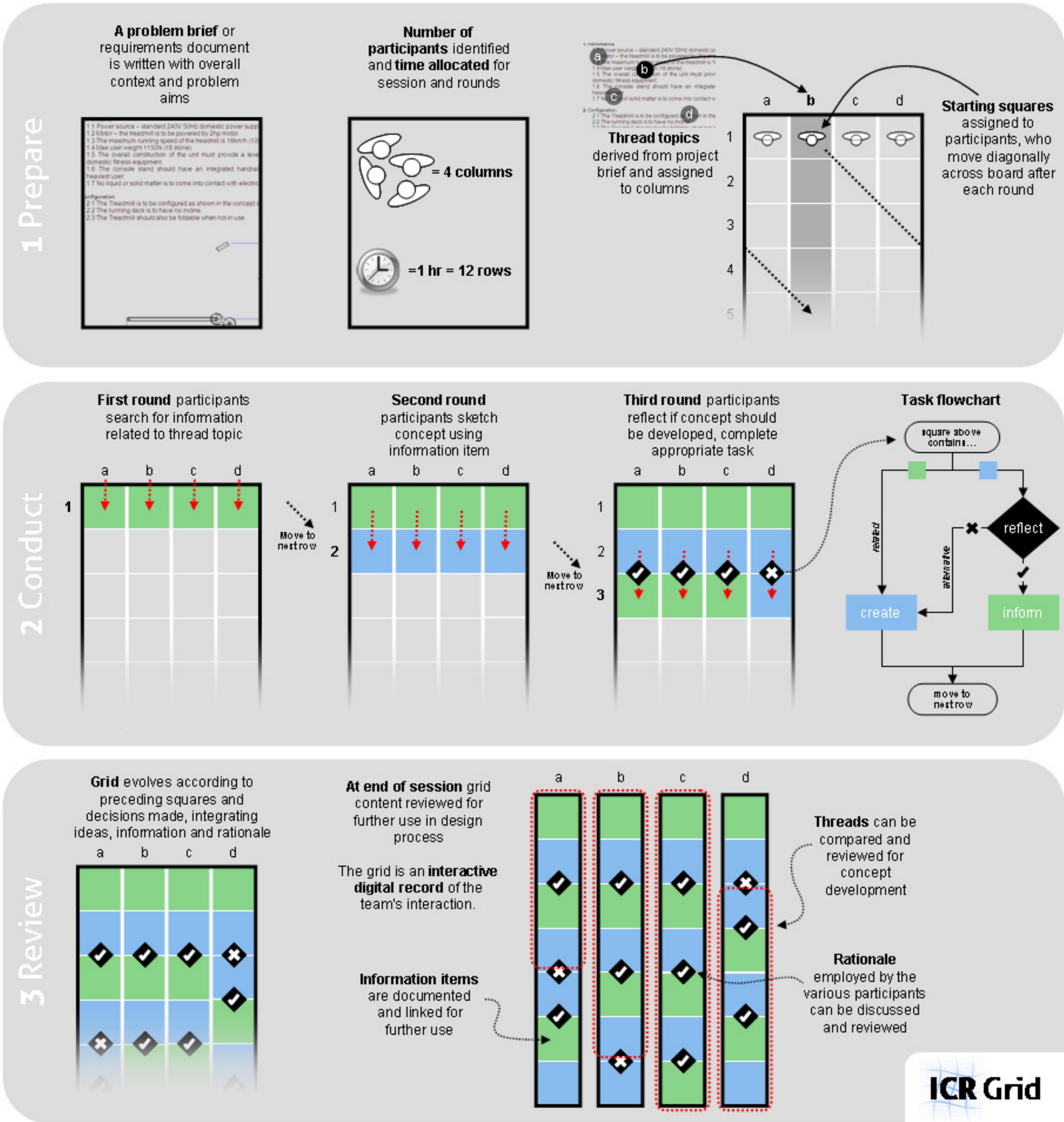

Figure 10.1: Illustrated guide to using the ICR Grid

10.4 Position in product development process

The ICR Grid takes its place in the product development process and alongside the various other available methods and tools. In considering the particular qualities it offers, Figure 10.2 shows the ICR Grid in relation to the categories of concept design method outlined by Shah et al. (2000). As described in Section 3.2 (p.37), intuitive methods tend to rely on information contained within the team, while systematic methods make more use of external information. The ICR Grid can be considered a blend of the two in that it gives the participants the freedom to pursue ideas and information as they see fit. The most comparable concept design tools are therefore progressive ones such as 6-3-5, C-Sketch and the Gallery Method which provide a similar framework for teams to undertake open-ended design work. The ICR Grid's prescriptive structure, however, differs in the systematic utilisation of both internal and external information. This means it incorporates search activities that other methods would not normally encompass, and furthermore the output is a combination of information and conceptual work, linked and categorised according to the design context.

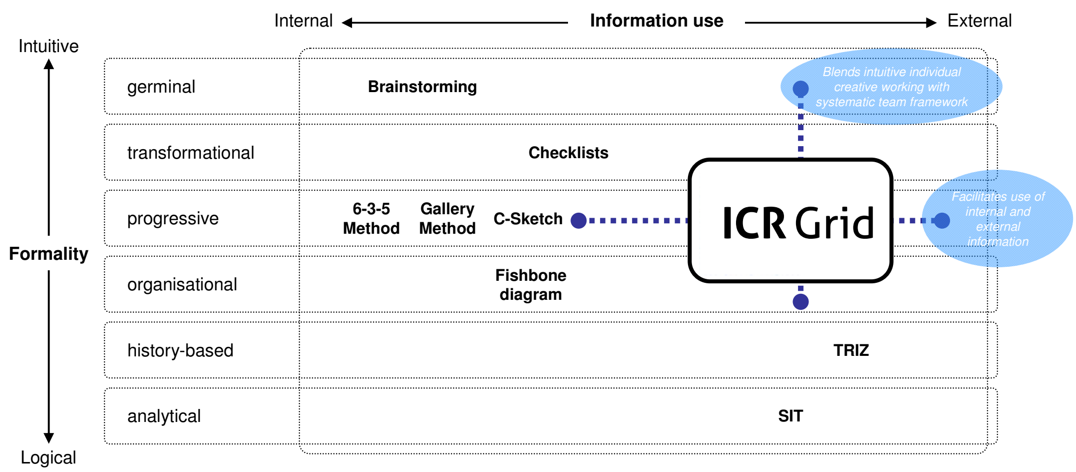

Figure 10.2: Placement of ICR Grid in development process

10.4.1 Information reuse

A key differentiating factor in the ICR Grid is its use of information: as well as creating concepts, the team also builds an information resource. This information resource is used in the development of concepts as the ICR session progresses, but it also provides a legacy which can be used in future projects, and in turn becoming a potential input for future ICR Grids. As an input, the grid could be searched and cited like any other resource. As a digital entity, it is likely that the relevant information source or concept square would be captured and the associated description and application added. If it was desired, the entire grid could then be opened when exploring the resource. This two stage process (Figure 10.3) applies to any item added to the grid.

The granularity (the resource size) of items sourced and used in the grid can vary significantly – from an image of a product to a textbook. The grid operates on the basis that the most relevant part of the resource is sampled through an image and the remainder can be accessed if deemed appropriate. For example, if a report has a relevant paragraph or diagram, this is captured through a photograph or screenshot and included in the grid with the appropriate description of use, but the entire resource can be freely accessed if a participant wishes to explore it further. This provides maximum flexibility in the range and types of item included.

It may be that the ICR Grid is employed to help organise or apply information that has already been gathered by the project team. For example, user studies, theoretical data or market analyses may have been completed. The ICR Grid in this instance becomes a facility to identify the most relevant aspects and apply them to concept solutions, while allowing the possibility of introducing new and alternative information sources as appropriate.

Regarding the categorisation of information, broad taxonomies were used rather than referring to complex thesauri. While the results of the formal evaluation in Chapter 8 (Section 8.5.2, p.183) indicated that a range of resources are useful for concept design, fundamental design concepts directly related to the domain of application have been identified as the likely main constituents of stimuli. The combination of Vincenti's (1990) and Howard's (2008) taxonomies could be explored in greater depth, encompassing the effect on concept output, appropriate categories for different stages of the design process, and the multiple modes of cognitive process used.

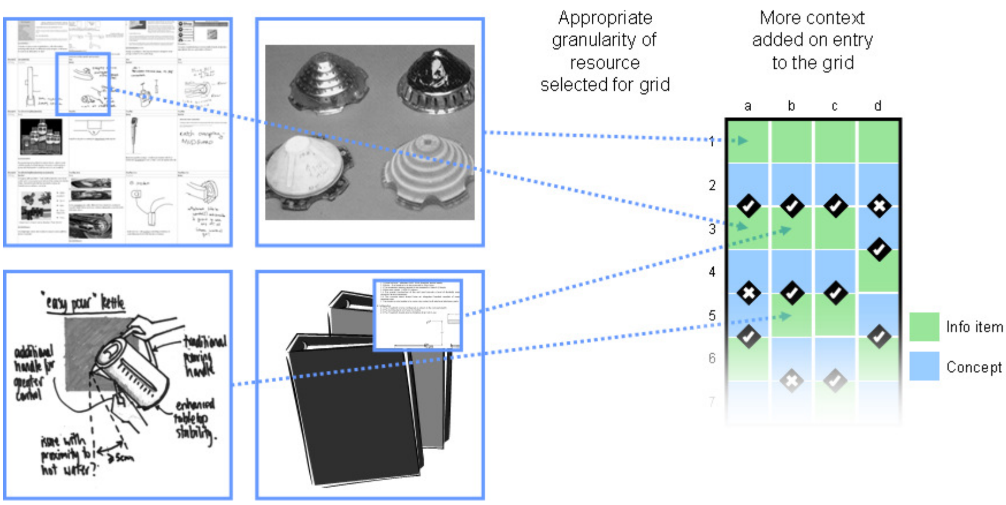

Figure 10.3: Reuse of information

10.4.2 Concept detail

The working definition of a concept used in the research was ‘an approximate description of the technology, working principles, and form’ (Ulrich & Eppinger, 1995, p. 108). The synthesis of this description can, however, be at different levels of product detail (whole system, sub-system, component) ‘depending on the level of detail at which you are working or being called upon to work’ Pugh (1991, p. 68). For example, a design team may be working on the re-design of the handle of a kettle rather than the entire product. The ICR Grid can, then, be applied to any topic at any level of detail, but when undertaking the session synthesis of realised concepts takes place.

The scale of concept complexity developed after Rodgers et al. (2000) was used to help define the typical context of concept design in Chapter 1 1.5.1, p.10) and to analyse the detail of concepts produced in Chapter 8 (Section 8.5.2, p.183). The nature of the proposed ICR Grid is to engage in vertical transformations by continuing to embody highly rated concepts as the session progresses, while incorporating lateral shifts in focus through the various threads derived from the brief or requirements. While many other concept tools such as brainstorming and 6-3-5 have been shown to produce higher numbers of concepts in the lateral mode with a relatively low (Level 1) level of detail, the opportunity for promising threads to be explored in the course of the session means that key revelations can be driven out and these concepts worked to a higher level of detail (Level 2 to 3) at one sitting rather than through a serial process. An illustration of increasing concept detail as a result of consistent thread development is shown in Figure 10.4. While the grid provides ample opportunity for participants to freely develop concepts, if the diversity afforded by high-quantity, generative process is felt to be critical by an organisation, such a session can be undertaken beforehand and used as one of the information sources to be fed into the grid.

The level of embodiment that can therefore be expected in well-developed threads at the end of an ICR session are beyond the *ideas* (Pugh), *solution principles* (Pahl and Beitz), or *sub-solutions* (Cross), that typically exist at the earliest stages of the conceptual design phase, but similarly not as developed as the *complete concepts* (Pugh), *concept variants* (Pahl and Beitz), or *solutions* (Cross) that would form inputs to an evaluation matrix. It lies somewhere in between, and will vary depending on the problem context, the participants and the extent to which ideas are developed. Over the course of any session, it can be summarised that *concept fragments* are being developed towards *solution concepts* (Ulrich and Eppinger). At the end of a given ICR Grid session strong concepts and project directions may have been identified, but further exploration and detailing would be required prior to undertaking formal evaluation and selection.

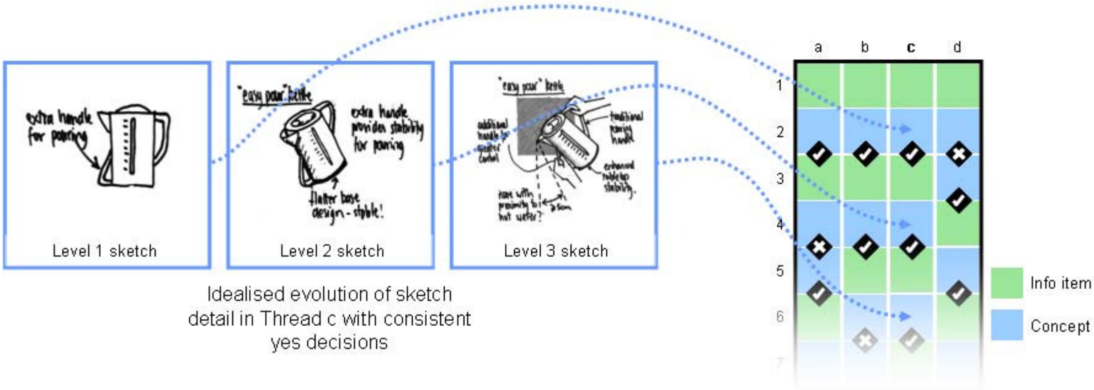

Figure 10.4: Development of concept detail

10.5 Future development

There are a number of ways the ICR Grid could potentially be developed. It offers a number of new approaches to the management of teams and use of information, both in and beyond the context of product design, and these are discussed in detail in the following sections.

10.5.1 Design process documentation

The ICR Grid provides a unique documentation of the concept design process that allows complete traceability. The real-time capture of information, ideas and their relationship means that an organisation can revisit and interrogate the grid at any point in further concept development. This could be for any number of purposes, such as to confirm the rationale behind a particular concept, to follow up on a promising information source, or to revisit alternatives in the case of a 'dead end' in design development. If the virtual interactive environment (see Section 10.5.7, below) used for the ICR Grid is in place and sufficiently robust, then the construction of this record consists of minimal extra input from participants – it simply ‘happens’ through the use of the method. The ICR Gird’s principles of linking ideas and information in digital form could, then, be adapted and used to document design team meetings that may not even be concerned with concept generation. As text-based records that require significant attention from at least one person in the design team, traditional meeting minutes are not well suited to the visual and fast-moving nature of much design work. The ICR Grid, then, suggests an alternative way to document meetings that is more vivid and meaningful that text-based records.

10.5.2 New structures for digital libraries

Instead of relying on the addition of metadata in the traditional form of descriptions and categorisations, the ICR Grid links information resources to the design context by suggesting applications. This process creates metadata in the form of connections, descriptions and narrative that are typically hard to capture and often tacit in nature. Extrapolated to larger library sizes, the principles employed by the ICR Grid could potentially inform new ways to capture, organise and interrogate the information in digital libraries.

Browsing has been shown to be attractive in concept design because of its visual nature, and the ICR Grid is suited to this mode of interrogation. Each item uploaded to the ICR Grid has a number of directly linked concepts and information sources that can be explored as appropriate. Searching, however, is more effective for interrogating larger resources where browsing is no longer feasible. The two types of resource uploaded to the grid have associated text: information items have suggested applications while sketches have annotation to help communicate features and functions. These could be used to provide additional metadata for searching and organising the library, with optical character recognition (OCR) software ideally being used to capture them automatically. Combined with information on the overall design problem and particular aspect (thread title) being addressed by an item, these provide the opportunity to retrieve groups of relevant items. When retrieved, the links to other information sources and concept sketches can then be explored in the browsing mode. A limited implementation, possibly in conjunction with the

LauLima digital library described in Chapter 5, would help reveal the practicality and potential of such an approach.

10.5.3 Team Internet searching

The greatest differentiator of the ICR Grid from other concept design methods is the requirement for participants to continue finding and integrating new information items as the session progresses. This aims to make the process of retrieving information more relevant, integrated, and tolerable. There is still, of course, a necessary place for specialised information gathering tools and techniques such as first-hand observation, market analysis and so on. In light of the industrial studies in Chapter 9, the ICR Grid is considered to have good potential for development as an enabler for teams to work together in finding and applying relevant information. The Calcarb session in particular illustrated that the method could be adapted and tailored as a shared searching method. As this session evolved, people identified relevant information and suggested applications, with mainly textual descriptions rather than sketches used. Others then rated these suggestions and found other applicable information. This came about primarily because the engineers involved were not comfortable with sketching, but the session nevertheless had value, as it quickly emerged that a useful database of information sources was being created, and a number of clear directions for future work identified. These findings suggest that the ICR Method could be recalibrated for team-based information searching, bringing the benefits of group working to what is normally a solitary task.

10.5.4 Types of information use

The types of information sourced and used by designers have been discussed, particularly in Chapter 4 (the initial study of information use in concept design) and Chapter 8 (evaluation of the resources found by teams using the ICR Grid). The type of information most applicable to the concept design situation was found to be *fundamental design concepts* of a *direct* nature. While this is in line with previous studies on design information and stimuli (Howard, 2008; Vincenti, 1990), the effectiveness of different types and formats is still far from clear.

The characteristic of the ICR Grid that allows designers to search and incorporate the information they feel is most appropriate makes it a potentially powerful tool for the examination of information use in engineering design. It would be instructive to run sessions in a number of contexts and to monitor the types of information being found, with a view to understanding better their effects on the resulting concepts and to perhaps develop a more sophisticated taxonomy of design information and stimuli. This would encompass the use of books, catalogues and other resources it was not possible to incorporate into the studies reported here. One particularly intriguing facet of this is the tension between physical models and imagery – as computing technologies evolve, will it be possible to replicate or mimic the vividness of 3D resources in a virtual way?

10.5.5 Use of gaming techniques

While gaming techniques have been identified as an area with significant potential for use in the design setting (Chapter 6), the development of the ICR Grid embodied only one thread of thinking, and during its evolution shifted focus to the interaction of the participants rather than developing a realistic gaming environment. This remains, however, an area with significant potential. The explosion of game-based learning and game-based productivity literature and software points to further implementation of these ideas in the future. The review of genres shows characteristics which can potentially be applied to the design context, but more resources and expertise from the gaming field are required to develop something akin to an actual 'game'. This is, however, an interesting potential avenue of investigation.

10.5.6 Application to distributed/asynchronous environment

The possible application of the ICR Grid to the distributed scenario was identified as early as Chapter 4 (in reviewing information use by design teams) as an area of interest. The structure provided by the interaction with both information and other participants alleviates a number of the logistical issues presented by teams undertaking conceptual design in distributed and/or asynchronous modes.

Distributed teams have to do without the more subtle aspects of communication, such as body language and intonation, that are intrinsic parts of discussion in a normal concept generation session. The ICR Grid provides a means for a team to undertake clearly defined steps in finding and using information while preserving the freedom of individuals to develop creative ideas. It shifts focus firmly onto the concepts themselves, with annotation and description providing the primary means of communication. This could be augmented using combinations of video and text channels through a program like Skype[38].

The effectiveness of the grid in the asynchronous mode was hinted at by the use in the Scottoiler follow-up session. The team completed approximately half of this synchronously and the other half asynchronously, informally passing booklets to prompt each other to complete tasks. This gave participants more flexibility in when they completed tasks, but was too informal in terms of deadlines for completion. Using a stage-gate approach to ensure equal and prompt contribution in the asynchronous mode could be an effective way to implement the ICR Grid – longitudinal tests in a variety of settings would help to evaluate this.

10.5.7 Integrated virtual design environment

One of the major restrictions in the testing and evaluation of the ICR Grid was the hardware and software set-up used in its delivery. Despite the fact that the OneNote software in conjunction with basic tablet sketchpads was operable and provided the required functionality, it remained clumsy and difficult to use, particularly for those not comfortable with IT. A fully programmed software interface would have allowed the mechanics of the grid to have been more easily controlled and would have resulted in a simpler experience for those involved. Instead, it was necessary to use OneNote in a way in which it was not intended to function, with participants supplied with flowcharts and the author acting as a facilitator to ensure sessions ran smoothly.

Regarding the hardware set-up, the use of laptops of limited power was problematic in terms of speed of response. In the industrial sessions, the tablet interfaces utilised to begin integrating the environment worked to an extent, but this

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[38] http://www.skype.com (Accessed: 11th January 2010)

type of technology currently only works well with high-end products running specialist software. Therefore, to fully realise the vision of an integrated information/ concept design environment, it would be necessary to develop a specific software solution and to invest in appropriate hardware. As computing technologies continue to evolve, the potential for development of such integrated systems becomes more realistic, and new possibilities, such as the use of iPhone-type mobile computing and 3D visualisation systems, continue to emerge.

10.6 Summary

This chapter is the culmination of Phase d (*application and reflection*), the final phase of the research. The work has encompassed a number of areas including concept design, knowledge management, CSCW and computer gaming. It has resulted in the development of a new method for conceptual design that suggests it is possible for teams to find and apply information resources as they design, and in the process enhance conceptual output through its effective utilisation. The method additionally provides the output of a linked resource of concepts and information that captures ideas, development and rational, and can be referred to in ongoing development work. The exploration of the various associated topics in the development of the method has resulted in a number of contributions to knowledge. These are outlined in order of importance:

1. Developed a new method for concept design that draws information into the concept generation activity
2. Demonstrated that the method enhances the quality, variety and detail of concept output
3. Demonstrated the viability of the method in a number of different industrial contexts
4. Identified aspects of computer games by genre that are applicable to design contexts
5. Illustrated the discrepancy between CSCW and KM in terms of their support for design activity

6. Demonstrated the problems with lack of engagement using current digital libraries in concept design

It is hoped that these findings can be used in a number of different ways. Given that the research set out initially to develop something of practical use, the delivery of a robust and evidently useful method was critical. The ICR Grid is novel in its approach and has been evaluated to a level that indicates the methodology can be confidently applied by design teams wishing to enhance their levels of information use. For its full realisation in the digital environment the method would benefit from a bespoke IT implementation: the use of OneNote in the evaluation was sufficient for these purposes but not appropriate for daily use in industry.

As digital technologies and organisational strategies continue to rapidly evolve, this work is timely in bringing new thoughts on how information is used and managed in the development of ideas. Issues regarding team structures and interaction, modes of creative thinking, the physical/digital relationship and technological barriers have, amongst others, been addressed in the context of the research. It is hoped that the ideas contained within it are of use to organisations and individuals considering how to best undertake conceptual design in a digital age where a world of information is at our fingertips.

Relevant papers by the author

Wodehouse, A., & Bradley, D. (2003, August 19-21). *Computer tools in product development.* Paper presented at the International Conference on Engineering Design, Stockholm, Sweden.

Wodehouse, A., Grierson, H., Ion, W., & Juster, N. (2006, September 6-8). *Student search behaviour in a digital library.* Paper presented at the Engineering and Product Design Education Conference, Salzburg, Austria.

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