"He's Different, He's Got "Star Trek" Vision": Supporting the Expertise of Conceptual Design Engineers

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This paper is based on a programme of research within the conceptual design department of a leading international aerospace company. An ethnographic approach was taken to study the creative behaviours and perceived barriers to creativity of engineers employed in this department. The research project comprised three phases incorporating four studies employing qualitative research methods. This paper draws upon the main studies which were the Tracking and Shadowing studies of Phase 2. A primary output of the research was the development of categories drawn from the data which exhibited barriers to creativity under micro (day-to-day experiences) and macro (larger organisational, strategic and global levels) conditions. Examples of engineers' experiences are presented to illustrate how the thirteen categories are derived from observations and interviews. Phase 3, the analytical phase, involved the development of a matrix to explain the complexity of interrelationships between the phenomena under investigation in relation to the conditions. The structure of this matrix is described in this paper. The paper concludes with a discussion of the implications of the findings for supporting expertise in design.

The aim of this research was to investigate the work of design engineers working in a conceptual design department of a leading aerospace company (Company X) and identify the perceived barriers that inhibit their creative activities. It sought to understand and describe what those barriers were primarily from the viewpoint of the design engineers and placed them in the context of the wider company environment. The work in this particular department is important to Company X as it involves long-term (15-20 years) strategic designing of aero-engines. Hence much of the conceptual design work, although operating within a number of constraints, sometimes allowed for futuristic and novel ideas to be explored to meet customer specifications. It is in the company's interest to ensure that creativity is encouraged and nurtured in order for it to continue to be internationally competitive.

1. Background literature

This research drew upon a wide spectrum of topics from different disciplines to present a rich representation of the perceived barriers to creativity as experienced by the conceptual design engineers. This reflects developments in design literature to build upon the technical aspects and cognitive processes of design activity by explaining the significance of social, psychological and cultural aspects involved in design.

1.1 Creativity
There are many interpretations and definitions of the concept of creativity, however, a review of the literature provides four basic definitions of creativity. The first relates to output where a product is judged to be creative by being original and having appropriate value and use (Gero 1996). The second relates to the process to generate creative thought and action through a number of phases and techniques (Poincaré 1952, Finke, Ward and Smith 1992). The third definition refers to characteristics and personality traits which are said to be exhibited by creative individuals (Sternberg 1988). The final definition is that of environment which includes both social and physical factors (Eder 1995).

These aspects or characteristics of creativity have been explored in a number of ways. This includes the study of the methods and models of design and supporting technologies described in sections 1.2 and 1.3.

1.2 Design methodology and models
Design is a most "complex and intellectual human activity" which still needs further explanation and understanding (Gero 1996). A number of formal structures and frameworks to better understand the design process have been suggested from many different disciplines. For example, engineering (Pahl and Beitz 1984), psychology (Thomas and Carroll 1979) and industrial design (Pugh 1996).

Theory and research has moved a long way from the 1960's postivist approaches where design was viewed as a logical search process to find a solution (Dorst and Dijkhuis 1995). This approach is reflected in various sequential linear models representing the design process (Pahl and Beitz 1984).

Schön's (1983) work provided an important step when describing design as a process of "reflection-in-action" where through evaluation and reflection design problems are restructured and improved. This particular paradigm compliments models which consider the importance of observing and doing in learning to design with the emphasis on the building of a rich experiential base (Coyne 1990). Current thinking has had to accommodate more complex design environments and researchers such as Pugh (1996) have recognised the collaborative and interdisciplinary nature of design. Most design takes place in a team/group environment within an organisational context and these factors need to be acknowledged and understood in describing models of design.

1.3 Mechanisms and artefacts for supporting design activities
Various external representations, cognitive artefacts, tools and technology provide a means for facilitating understanding and communication in design. Where once designers used drawing boards and drafting tools to produce designs, computer-aided-design (CAD) technology has been introduced. Whilst CAD automates some of the more tedious and repetitive tasks at the detailing stage several psychological disadvantages, for example, the tactile, visual and social limitations of IT, have been identified (Allwood and Kalen 1994). Technological developments in software such as Pro/ENGINEER™ and rapid prototyping have begun to

address some of these issues by providing 3D modelling and the capability to produce physical models.

With companies having to work collaboratively in teams which may be separated by long distances, issues relating to communication, shared understanding, roles and relationships are important to consider (Cross and Cross 1996). Strong information networks between individuals and groups therefore play an important role in supporting and sustaining transactive memory systems (Wegner 1987).

1.4 Relationship of the literature to the research project

Exploration of organisational working climates and environments have identified certain characteristics which can enhance or inhibit creativity such as organisation structure, communication and volume of tasks (Majaro 1992, West 1997, De Alencar and Bruono-Faria 1997).

The literature provides many interpretations and explanations on the productive aspects of creativity and design. However less work has been done to understand the difficulties organisations have in balancing its complex array of business and operational aims and goals with the creative needs of conceptual designers to invest in future technological development and creative ideas.

Company X recognised that there was a limited understanding of what barriers and obstacles to creativity occurred within the conceptual design department. This led to a research project to look at the phenomenon and try and understand and explain what was happening.

2. Research setting

The conceptual design department is located within a large manufacturing site. It has about 30 employees including project managers, team leaders, experienced designers (operational, performance and technical), new designers and trainees working together in multidisciplinary teams. The department includes both specialists and generalists, as the projects require a broad spectrum of skills and knowledge that involve co-ordination and organisation as well as detailed expertise of specific areas in design.

The role of the department is to develop forward looking design projects ranging from short-term feasibility studies to long-term strategic innovation programmes. Project teams interface with many of the individual departments in Company X and various other external organisations such as customers, suppliers and collaborative project partners.

2.1 Aims of the research

The research had three main aims.

1. To broadly identify and describe the nature of the design process conducted by engineering designers in the conceptual design phase of aero-engines.

2. To identify what the perceived barriers to creative design may be and analyse users' experience for overcoming them.

3. To define design engineers' requirements for an environment to support the conceptual stage of design.

To achieve these aims the research comprised three phases as shown in figure 1 and described in section 2.2.

2.2 Methodological approach and phases of the research

The research took a pragmatic ethnographic approach due to time and access constraints that were imposed upon the research project [1]. The research is perhaps best described as being conducted in the context of *purposiveness* (Ball and Ormerod 2000).

The techniques used to collect the data were qualitative and naturalistic enabling a systematic, logical and integrated account of the phenomena under investigation from multiple viewpoints (i.e. project managers/team leaders, experienced designers and new designers and trainees). A rich picture of conceptual design activities was revealed using grounded theory analysis (Strauss and Corbin 1998). This approach helped to identify where barriers to creativity were experienced on a day-to-day level (under micro conditions) and where the phenomena occurred under organisational and strategic levels (macro conditions) and analysis of the interplay between them. The sequence and iterative nature of the research is shown in figure 1.

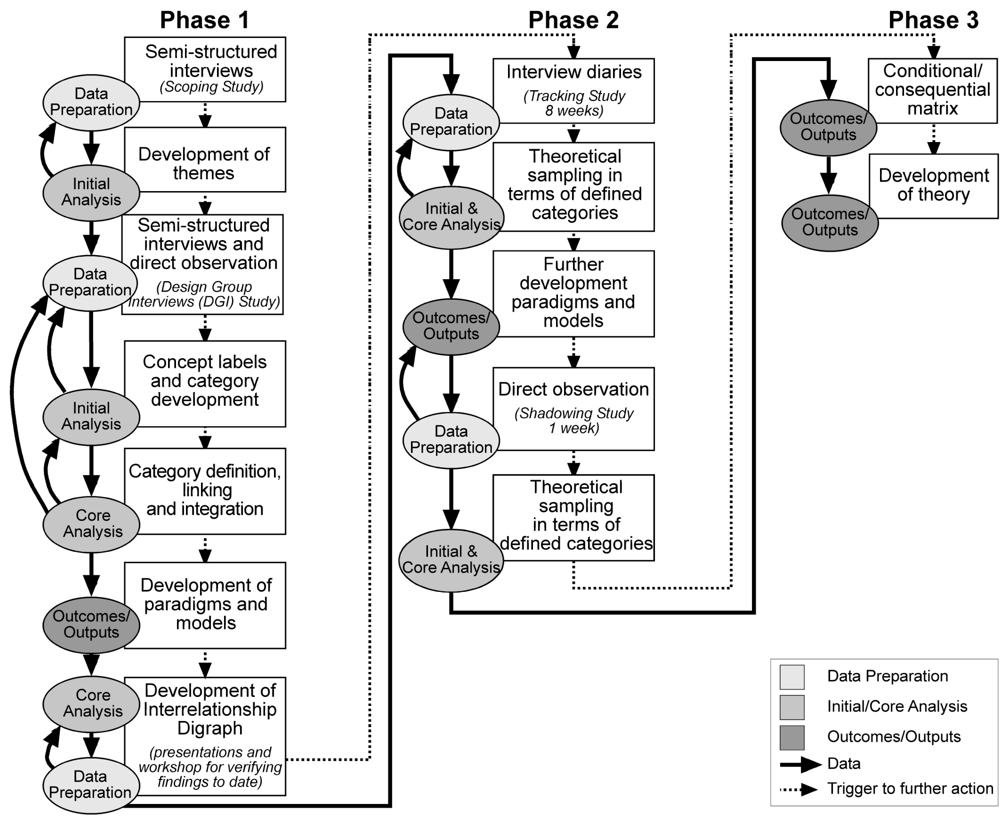

Figure 1. Schematic diagram of the three phases of the research.

The Scoping study of Phase 1 comprised semi-structured interviews to elicit designer's views and perceptions resulting in the identification of six major themes of the main issues and perceived barriers to creative design activities (Carkett 2002). The purpose of the second study (Design Group Interviews, DGI) study was to synthesise a more comprehensive view of the environment in which conceptual engineering design took place, the designers' perceived barriers to creative activities and how they were circumvented. This resulted in the identification of 16 categories drawn from the data.

In Phase 2 the Tracking study tracked 13 people over an eight-week period using the interview diary technique which identified the scope, saliency and frequency of instances of perceived issues and barriers to creativity. Analysis of the data drew out thirteen categories with the majority confirming those from phase 1. To validate their retrospective accounts, a one-week Shadowing study followed. Observations and conversations were noted in this study from two of the main design engineers who had been involved in the other studies. The output from these studies is concentrated upon in this paper.

Phase 3, the analytical phase, led to the development of a matrix explanation based on the findings of the research to illustrate the complex interplay between the macro and micro conditions where perceived barriers to creativity were found to occur.

3. Discussion of major findings

Each study and phase of the research inter-linked with the next phase. Themes and categories drawn from the data were revisited and reviewed as the analysis progressed (see figure 1). At the end of the second phase, 13 categories had been identified as perceived barriers to creativity:

- organisational processes
- weltanschauung (world view and culture)
- timescales of project
- integration with other companies
- working practices (changes in)
- project management
- management style
- experience of designers
- design process
- communication (social)
- technology
- creativity
- workload and time pressure

Carkett (2002) presents a full description and definition of the categories and examples of the phenomena under micro and macro conditions. She also pulls together the categories into 5 major themes, but for the purposes of this paper they have been grouped into four themes as two of the themes, knowledge sharing and social mechanisms, refer to similar issues and concerns from different perspectives and are very closely related. These themes (described in sections 3.1 to 3.4) provide the main areas of concern for understanding the contexts and environments that the categories exist in.

3.1 Knowledge sharing and social mechanisms

This theme covers the category communication (social) and was found to be pivotal in understanding the engineers' design practice. It related to communication and also to knowledge sharing practices and social mechanisms involved in creating a professional community.

What was clearly evident in all the studies was the importance of the establishment of networks of people who could be drawn upon for their knowledge, expertise and specialist advice when needed by the designers. They provided informal support and communication, access to wider internal and external networks than would otherwise be available, experience of similar problems in the same domain or analogous areas of work, expertise in engineering solutions and organisational issues. As found by Baird, Moore and Jagodzinski (2000), these networks of social connectivity were developed over time as an individual's expertise grew and others trusted that knowledge. Examples of this knowledge sharing between experts was reported in the Phase 2 studies and provided clear evidence of a transactive memory system (Wegner 1987) being in place in Company X. For example,

> I had to modify an engine to fit an air frame so I decided to fit a yoke device. I knew [a colleague] had worked on this before so I looked up the archive and had a chat with him to see what could be done.
>
> B(2)8/bk1/pg40/ln2-9 [2]

All of those interviewed highlighted the need for knowledge, information and advice from others although many experienced barriers to accessing it. They identified communication to be of major significance and influence on many of their activities.

Knowledge was seen as power and there was a perceived reluctance by some to share it as they felt their job was threatened. One of Company X's messages was the value of "shared information". However designers felt that the company paid "lip service" to this statement as access to information from other departments was often blocked which could be an indicator of "hidden agendas" (Majaro 1992). The designers perceived it to be due to demarcation and "internal politics and power" and provided evidence of the "walls of silence" that can be developed through a competitive "divide and rule" policy adopted in a company (Majaro 1992).

Another problem regarding the communication between people was the location of the working groups. Although some designers were involved in collaborative projects, often other members of the project team were based on different sites. Demarcation and the streamlining of Company X had meant it was difficult to establish a line of contact outside their own department and was a major concern to those interviewed.

The social aspects of design (both individual and collaborative) were highlighted throughout the studies as an important element of the design process which supports the findings of Bucciarelli (1988) and Cross and Cross (1996). However the interviewees lamented about the demise of the drawing boards and how that social interaction and opportunistic discussions, which had taken place around them, were lost to the much more solitary activity of design using a computer.

> Big design teams used drawing boards and you could see the design develop. As a young designer you could saturate yourself and see what was happening. Workstations are much more difficult. It's more difficult to see the screen, what the problem is.
>
> X(2)5/wk1/bk2/pg26-27/ln23-28

This also had a detrimental impact on the project managers and team leaders who reported they felt much less involved with the designs.

The easy visibility afforded by a drawing board provided a social focus to enable discussion and this was observed when two old boards in the department were used for display purposes.

3.2 Management structures and organisational constraints

This theme covers the categories of organisational processes, weltanschauung (world view and cultures), timescales, integration with other companies, working practices, project management and management style.

In recent years Company X had been reorganised and decentralised resulting in the fragmentation and demarcation of departments. Functional departments previously home to specialists of a common discipline had been replaced by project groups comprised of multi-skilled and multi-disciplinary teams. This arrangement had had an impact on the social networks tending to weaken the maintenance of the specialist's knowledge base and undermine informal contacts needed to sustain and nurture some of the management activities and co-ordination on expertise between teams.

> Company reorganisation tends to work against creativity. There are self-contained functions and project groups which are very efficient in producing a product, but militates against creativity and innovation. It's [Company X] fragmented now. People can't feed off each other's ideas. We can't communicate now. The barriers to creativity is a general feeling and people are leaving.
>
> X(2)5/wk1/bk2/pg26/ln9-13;19-22

Another recent change affecting the organisational processes and IT systems was the introduction of the System Application Product (SAP) system that automated much of the project management process.

The SAP required all tasks and time on a project to be booked in advance with the relevant specialists. The system was perceived to undermine the personal networks established over years as it was too formal and discouraged designers in seeking ad hoc advice. To circumvent this issue, "dummy codes" were used to try and make the system more flexible.

Many interviewed perceived the SAP system as militating against creativity by placing increased demands of administration and project management on the designer. Such administrative influences can inhibit creativity (De Alencar and Bruono-Faria 1997).

Other organisational processes such as the need to present a business case for new software were perceived to be a constraint and a barrier to creativity. For example, where relevant software was not made available, it had to be accessed from other departments or 'add-ons' were developed. It was perceived that this approach was unnecessary and resulted in short-term gains with no real appreciation of the impact such decisions had on design activities.

> The cost of the licence is probably between £400-£500. I'm paid good wages and I waste a lot of my time trying to get access to the software whereby if I had the licence it would be much more cost effective.
>
> U(2)6/wk2/bk1/pg32/ln47-50

Such evidence of lack of equipment and other material resources are further characteristics identified by De Alencar and Bruono-Faria (1997) as inhibitors of creativity.

In the competitive aero-engine industry working to timescales was essential. Concerns had been expressed throughout the studies of the impact this had had on the outcome of many of the projects undertaken in this department. For example the designers reported they were unable to follow alternative solutions, studies were shallower and "workarounds" had to be incorporated into software developments in order to meet the required deadlines.

> These days we have less time to do design work. Thinking time is dramatically reduced and therefore the quality of the end product is reduced too.
>
> B(2)9/wk2/bk2/pg55/ln208-210

The interviews conducted throughout the phases of the research highlighted many changes in working practices for the designers. For example, the engineers used to work in design halls and now they operated in project based design teams. Accounts led processes aimed to formalise design activities by introducing the SAP system. Drawing boards had been replaced by CAD and other new technology and software which offered new capabilities. However, they were not always used to the best advantage.

The nature of work in this department meant that not only were the designers involved in long-term projects, but that many smaller tasks and projects that demanded attention almost immediately came their way. Such situations caused problems for the designers as they were removed from longer-term projects with no forethought to the impact that would have on their thought and creativity processes and the timescales. The SAP system was designed to alleviate this scenario, but the unplanned projects were just not built into the system and yet had to be completed. This situation is akin to what Majaro (1992) refers to as a "lack of slack" which can be a barrier to creativity where too lean a company can impact on their creative output.

3.3 Individual/personal resource and design processes

This theme covers the categories of experience of designers, design process, creativity and workload and pressure.

A number of the designers commented on the reduction in manpower due in part to the automation of design and management processes. This situation was thought to have major implications for knowledge sharing in the company as the experience and wisdom relating to the success and failure of engines was held in the heads of designers and not documented anywhere on paper. Without access to this knowledge base, time could be needlessly spent 'reinventing the wheel' or considering possible solutions to problems that had previously been encountered and resolved in the past.

It was felt that the training regime for the new designers and trainees did not give them the opportunity to build a broad knowledge base, as had been the case in the past with apprenticeship schemes. This was felt to be partly due to the departments in the company being more specialised and process/project orientated.

A number of perceived qualities for design engineers had been mentioned by several of the participants involved in the studies. The title for this paper came out of an informal conversation and exemplified the characteristics of an expert designer who was able to work within the system and transcend the barriers to creativity experienced by other designers.

> You need lots of imagination, creative imagination, to make revisions 'fit' the problem space. Most [designers] have technical imagination, but innovative designers [B(2)] have 'Star Trek' vision.
>
> I(1)10/bk1/p51/ln113-116

One of the designers (coded B(2)) had been involved in all of the studies of the research. He clearly demonstrated many of the behaviours and characteristics said to be attributes of a creative person such as self-confidence, intrinsic motivation, and a commitment to work through problems and obstacles (Sternberg 1988, West 1997). Observing B(2) engaged in design activities was illuminating in how he overcome problems and barriers to take the design forward and achieve the outcome required. For example, problems were not solved instantly, they were arrived at by a series of approximations usually with a conversational dialogue with himself. This was evidence of a "reflective conversation with the situation" as suggested by Schön and Wiggins (1992). He displayed an internal desire to be creative, to develop innovative ideas into the design and deliver the best design he could given the constraints.

Another designer who was shadowed (X(2)) was not directly involved in the conceptual design of a component or engine although he provided a sounding board for ideas and suggestions for (B(2)). This was evidence for the "social permissions" Baird et al (2000) refer to which acknowledge the working relationship that has been developed over time where knowledge shared is known to be valuable and pertinent. X(2)'s contributions were based on intuition and a sound knowledge base of experience developed from his apprenticeship, experiential and situated learning (Lave and Wenger 1995).

Evidence of externalising thoughts and ideas on paper and a number of creative techniques were observed, for example, synectics, combinations, checklists and lateral thinking. However if time constraints intervened, information was blocked, or they were interrupted then it inhibited these processes.

> I would like more time. You need time for lateral and creative thought. It's not a production process. Human thought processes need an infinite amount of time. There are too many problems to think about and the total process suffers.
>
> X(2)39/wk8/bk2/pg172/ln111-112;117

Many of the interviewees experienced an erratic and unpredictable pattern of work as they juggled several jobs. The interviewees constantly referred to a lack of time and increase in workloads as more was demanded and expected of them. For example, less time meant compromises in the quality of the end product which was reluctantly accepted as a consequence.

Many alluded to the past when they could "wander about thinking and having incidental discussions with colleagues", but the SAP system did not accommodate this activity. A busy and noisy office environment and the need to support the new designers and trainees exacerbated this issue.

> A local and transient problem is the number of new graduates in the department which are a great source of interruption. I accept that we need to pass on our expertise but all these interruptions are not scheduled in the SAP system. You can't very well tell them you can't answer unless they raise a booking code.
>
> N(2)28/wk5/bk2/pg127/ln35-41

The new designers and trainees working in the department called upon the more experienced designers' time and expertise quite considerably. This was felt by the designers to be detrimental, in the main, to their own creative thought processes. However some welcomed the opportunity allowing their thoughts to ponder on the problem (incubation) and reach the final stage of creativity, illumination, as described by Poincaré (1952).

3.4 Technical issues

This theme covers the categories of technology and technological communications.

Issues relating to the provision of adequate technology in terms of hardware and software were evident in all studies. Other technological issues related to the reliability of the hardware which was prone to crashing on a regular basis. The designers coped with this in various ways, but reliability issues became most important in times of pressure or creative flow.

> Tuesday I had a panic job. I needed information for the meeting. I was doing the last few lines of entry and the system locked. I hadn't saved as I was in a hurry. Therefore I went to the meeting with scribbled notes and needed to go back to the beginning and start again.
>
> N(2)28/wk5/bk2/pg126/ln2-6

General housekeeping skills on the computer drives were ad hoc and there was no common practice and as a result joint work on shared drives was not organised coherently.

Several issues relating to access of computers and other resources were reported. For example, access to the networked databases required passwords and well honed navigation skills to find their way through the non-friendly user systems. At times this appeared to be inhibitory to the design engineer's creative activities, as they tended to end up being preoccupied with the administration of their work rather than the development of it.

With drawing boards no longer in use for mainstream design activities, new software such as Pro/ENGINEER™ and CAD technology was used. Using CAD was problematic in terms of the mental power it required to operate it and its inappropriateness for the conceptual stage of design. This had been observed in the study where B(2) stated he was too tired to continue due to the cognitive demands imposed by using it. This was perceived to be a barrier to creativity as simple modifications to a drawing took several keyboard commands/mouse clicks and not only found to be laborious and time consuming, but interfered with the flow of thought. It was quicker and easier for the designer to revert to pen and paper to sketch and externalise his thoughts in a visual format regarding the design change. This assisted his internal cognitive processes, minimised the cognitive load of the technology and maximised the capacity for creativity.

The introduction of new software, Pro/ENGINEER™, to the department had provided a software system closer to the conceptual design software desired by the engineers. At the time of the research, further advances in this particular software were imminent and it was hoped that Company X would purchase them. However as with all requests in Company X, a business-case would need to be compiled and presented before any decisions could be made which often hindered progress.

3.5 Summary

These four themes have outlined many of the perceived barriers to creativity that the conceptual design engineers in Company X were experiencing. Many of the perceived barriers occurred under micro conditions, but seemingly distant and irrelevant influences relating to macro conditions ultimately affected the individual or teams as well. The outcome was a very complex interplay between the macro and micro conditions and the development of the matrix (figure 2) is an important step in understanding these relationships.

<table>
<tr><td>CATEGORIES</td><td colspan="8">MICRO CONDITIONS ◄──► MACRO CONDITIONS</td></tr>
<tr><td></td><td>Individual</td><td>Project team</td><td>Customer</td><td>Dept.</td><td>Other depts</td><td>Company</td><td>Other companies</td><td>Global</td></tr>
<tr><td>Organisational processes</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td rowspan="13">Globalisation
Market-led forces
Economics
Politics
International problems/crises
Advancements in technology
Regulatory standards</td></tr>
<tr><td>Weltanschauung (world view and cultures)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Timescales of project</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Integration with other companies</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Working practices</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Project management</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td>Experience of designers</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Design process</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Communication (social)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Technology</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Workload and time pressure</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Creativity</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Figure 2. Framework of the matrix used to illustrate the interplay of the phenomenon under micro and macro conditions.

Figure 2 presents the structure of the matrix where the grey cells denote the area beyond the scope of the research. Space in this paper prevents a detailed explanation and complete matrix. However in Carkett (2002), instances of barriers to creativity drawn from the data populate the relevant cells to complete the matrix and highlight the complex interrelationships.

Having identified these major perceived barriers it is perhaps easier to establish how expertise in design, and creativity in particular, can best be supported.

4. Supporting and nurturing "Star Trek" vision in conceptual design engineers

Throughout the research it has been evident that design does not take place in a vacuum, but that it is a social skill developed through experiential and situated learning. A transactive memory system where "who you know" is just as important as "what you know" is a valuable and irreplaceable resource which needs to be cultivated, sustained and developed. By introducing a skills/expertise/experience register, personal development plans and exploration of informal and formal communication systems such as discussion groups and brainstorming workshops such a system could be enhanced.

Communication channels were not thought to be as open and flexible as they should be and were found to inhibit creativity although this was fundamental to the designers to allow the cross-fertilisation of ideas and the progression of the design activities. West (1997) suggests that communication can be enhanced by producing newsletters, team briefings and the use of integrated team meetings or cross team memberships and liaison personnel. Such ideas can generate the sharing of information and encourage a mutual understanding of objectives, strategies and processes between groups and teams.

For the new designers and trainees coming into the department, there needs to be adequate support and training to ensure they participant fully in this community of professional practitioners. They lacked the apprenticeship training most of the experienced designers had therefore need opportunities to involve themselves in the kinds of work experience that engenders deep and complex learning of design and the technical social and organisational issues which are essential to the process. Whilst the interruptions by these new trainees were perceived to be disruptive to the experienced designers, it could be seen as the continuation of the development of the new trainees' transactive memory system. Also it provided a type of apprenticeship model which could be expanded upon to provide an opportunity for learning in the social context of their environment (Lave and Wenger 1995).

Experts in design need access to the appropriate technology to facilitate their particular approach. Investment in technology both in terms of hardware and software is needed to sustain and enhance the design engineers working environment by providing support for both sketching and modelling activities. Software systems which provide databases of previous design histories (Porter, Counsell and Shao 1998) and support for thought processes and creativity in the design process are examples (Lambell, Ball and Ormerod 2000). However to ensure the operation of these is seamless, careful consideration of the human computer interaction issues need to be addressed.

Technology can support and facilitate collaborative work in design teams who are co-located or working at a distance. Developments such as large interactive whiteboards could aid discussion and interaction between groups helping to alleviate some of the misunderstanding regarding different cultures and working practices.

One of the main issues which came out of the studies at Company X was the lack of time to think and explore new ideas. Acknowledging the time needed to incubate thoughts and formulate ideas is important and could be built into the project timescales. Although there may be cost implications, these could perhaps be balanced against improved design and better market performance. Majaro (1992) argues that companies such as the 3M (Minnesota Mining and Manufacturing Corporation) have benefited from allowing their employees to devote 15% of their time to the generation of ideas and management of innovation.

Creativity cannot be separated from social relationships, culture and business need. It might help to identify a new skill set to enable creative activities and to deal with the barriers by adapting to new business, social and cultural conditions. Various measures and inventories which seek to measure a company's creative climate (Majaro 1992, West 1997) could facilitate this process.

	LOW BARRIERS	HIGH BARRIERS
HIGH CREATIVITY	More user friendly technology Increasing access to information Keyword access to experts Wider social networks	*Reliability and security issues*
LOW CREATIVITY	Voice messaging Alternative forms for logging into systems Greater flexibility in using the SAP system	*Reliability and security issues*

Figure 3. Representation of perceived barriers and their relationship to high and low creativity issues/activities after issues and barriers have been reduced.

Figure 3 represents the interaction between some aspects of a designer's work and suggests the need to reduce the barriers to creativity by in effect squeezing the right hand area of the grid. As illustrated in this figure populated by some examples, the high creativity area of the grid can be maximised enabling increased productivity of the project teams in new ideas. This would be in close association with the professional development and need for creative satisfaction of designers in exploring ways to support expertise. Such ideals are bound up with complex interrelationships exhibited in the matrix and which require further research into the relationship between the viewpoint of the design engineers and the wider needs of the organisation in the global market place.

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Notes

1 Company X operates in the highly competitive Aerospace industry market, therefore although access to the secure areas was arranged, there were limitations as to what could be recorded and noted and subsequently published.

2 Quotes and the corresponding reference originate from the PhD thesis and are coded to maintain anonymity of the participants and yet are fully traceable to the field notes taken. This piece of code refers to the interview reference denoting, who, when, where the recorded data can be traced.

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