Knowledge Elicitation in Design :
A Case Study of Page Layout Design

by

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A doctoral thesis

submitted in partial fulfilment of the requirements

for the award of

Doctor of Philosophy of the Loughborough University of Technology

(1990)

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Abstract

Knowledge elicitation remains a fundamental feature of Knowledge Based Systems evolution. However, there is insufficient evidence to support the presumption that the knowledge elicitation philosophy is viable for design. Scant effort has been applied to research into techniques for design elicitation, and the nature of design is poorly considered. In particular, design tasks that involve visual design skills appear especially neglected.

The scarcity of proven knowledge elicitation methods for design has not dampened the enthusiasm for "Intelligent" Computer Aided Design Systems. However, it is argued that design knowledge acquired from ad hoc, unsubstantiated and untested procedures, and knowledge that is undocumented and untested cannot be considered reliable. Indeed, it is extensively observed that a deficiency of intelligent performance exists in current ICAD systems, and the exigency for laudable design elicitation methods is prevalent.

Here, knowledge elicitation in design is promoted through a review of design and knowledge elicitation research literature. Design must be considered dissimilar to scientific problem solving, and the holistic nature of the task is an important characteristic. Further, the spatial, diagrammatical and drawing forms of communication, that are manifest in design, must be tackled.

A method for the elicitation of design knowledge is proposed, and tested in the domain of page layout design. Computerised methods of knowledge acquisition currently lack the sophistication to expound the enigmas associated with design elicitation. It is concluded that the personal interview strategy is appropriate, in which the nature of the design task, and the visual and spatial components are equitably considered. The understanding of page layout design is demonstrated in a communicable report, and tested through an evaluation study.

It is concluded that methodological principles of knowledge elicitation are appropriate to design, and a suitable method is outlined. The domain of page layout design illustrates that the techniques are successful, useful and practical.

Dedication

To Mother and Father

Acknowledgements

The author wishes to thank Professor Ernest Edmonds for advice and direction throughout the project. The dedication of supervisor Stephen Scrivener is greatly appreciated, and the contributions, advice and friendship offered by Steve have never been underestimated. In addition, the author wishes to thank Tony Clarke for useful discussions, generally, and in particular for advice in the development of the evaluation procedures. Also, the author is grateful for the tremendous effort and endurance expended by John Williams of Derby College of Higher Education and a special thanks to Nancy Johnson of Brunel University, for discussions, advice, and encouragement. This work has been supported by the SERC.

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1 Introduction

1.1 Intelligent Computer Aided Design

Traditional Computer Aided Design systems can offer sophisticated modelling, viewing, planning, calculation, representation, and user interface facilities. Yet, Tomiyama and Yoshikawa (1985a) argue that they remain principally drafting, detailing and checking packages, and they do very little to aid the fundamental aspects of design, such as conceptual design. It might be argued that they allow the designer to work at higher levels of the design conception, by reducing the amount of time and thought otherwise necessary for straightforward and tedious design practice, like detailing and calculation, but Tomiyama and Yoshikawa (1985a) argue that "all these facts do not mean designers can get creative or intelligent support from computers. We think there is an additional task, ie, intellectualisation of CAD systems for increasing productivity and for decreasing errors...designers will need more computer supports for the full scope of the design process including the thinking process." Further, Tomiyama and Yoshikawa (1985b) identify that "Though the main aim of introducing CAD systems is to increase designer's creativities, it is doubtful whether designers are really supported by such CAD systems. We think that Knowledge Engineering is useful to improve such situations."

Landsdown and Roast (1987) maintain that "Although knowledge-based systems can be shown to be of assistance in a number of areas like diagnosis of faults, testing for conformity to regulations, selection of elements and components, and so on, there are problems in their more general design application," and Landsdown and Roast (1987) suggest that current Knowledge-Based CAD systems do not address the wider aspects of design activity. Further, Landsdown (1988) argues that designs are often deficient, or even fail, because designers do not take into account all the relevant design information, and fail to make use of proven techniques and procedures established through design principles and practice. Landsdown (1988) reviews recent reports of efficiency in the domains of aerospace, automobile and architectural design. For example, a report on housing defects (Mills, 1988) indicates that one third can be termed 'design failures.' Landsdown argues that these failures are to a greater extent avoidable, and that designing can be greatly enhanced by providing designers with simple, direct and convenient ways in which to augment computer based knowledge with their own. However, the above domains of design are also typical of those where applications of Intelligent Computer Aided Design systems are widespread, and this implies that either the technology is not being utilised, or it is inadequate.

In summary, Intelligent Computer Aided Design systems are recognised by ICAD developers to provide important tools that are potentially capable of aiding designers (Gero et al, 1985; Gero and Maher 1987; Landsdown, 1987; Akman et al, 1988), but they are currently less than satisfactory, and they need considerable development before they can provide intellectual help to the designer.

1.2 The need for Knowledge Acquisition in design

Gero et al (1985), amongst many authors, indicate that advances in ICAD can be helped by advances in knowledge elicitation "Since knowledge-based systems require a knowledge base on which to operate, the feasibility of acquiring such knowledge is critical to any implemented system." And it is further argued (Gero, 1985) that "Design is one of the most intelligent activities of man, and requirements which emanate from CAD systems go beyond the level of the traditional computing technology. This is the main reason why up to date the whole design process has been only partially computerised. Knowledge Engineering has introduced a new technology into the the information processing arena and thus given us hope for an advanced CAD system."

Landsdown and Roast (1987) argue that "A better understanding of what designers know both implicitly and explicitly is therefore fundamental to further developments in creating design KBS, and considerable research into this subject still needs to be carried out. Current techniques of knowledge acquisition and elicitation also need further development."

Landsdown (1988) argues that "Anyone who has attempted to set up an advice-giving knowledge based system will have soon realised the difficulty of ascertaining the necessary knowledge on the one hand and the unsuitability of much published information on the other." This suggests that the observation of design activity may contribute more to design understanding than design theory, and justifies the need for, and value of, design elicitation.

Thus, knowledge elicitation is widely recognised, academically, to be an issue of great importance. However, there appears a notable absence in the research literature to information on appropriate methods of design elicitation in general, enlightenment on systematic procedures for design elicitation, or even reports of practical studies of knowledge elicitation used in the development of current Intelligent CAD systems. These points are discussed below.

1.3 Where is the Intelligence in ICAD ?

The principles evolving from the technologies of Artificial Intelligence, Expert Systems and Knowledge Based Systems are warmly embraced by Computer Aided Design researchers aiming to promote the Intelligence in their systems (Topping and Kumar, 1989; refer to Bibliography A). However, it is observed here that in practice the requisite attention to knowledge elicitation procedures is not evident, and the subject as a whole is marked with indifference and consternation. This point is illustrated through the examples of ICAD research literature, discussed below[1].

The role of knowledge engineering for CAD was first recognised in the Budapest conference "Knowledge Engineering in Computer Aided Design" (Gero, 1985). However, in only one paper (Gero et al, 1985) is the relevance of knowledge acquisition discussed, but even here the subject is poorly dealt with, covering only two printed pages (as design theory, design lore and induction), and amounts to a brief description of an inductive method of knowledge acquisition. Gero (1986) mentions Knowledge acquisition (in the apparently informative paper "An overview of knowledge engineering and its relevance to CAAD"), only once in passing, where "[Knowledge engineering]...is concerned with the acquisition, representation and manipulation of human knowledge in symbolic form" (Gero, 1986, p107). The remainder of the

[1] An important exception is Miles and Moore (1989) in the case study of conceptual design of bridges, where many techniques are used, including the personal interview.

paper discusses knowledge representation, but fails to address knowledge acquisition, as does the conference as a whole (Pipes, 1986).

In a subsequent conference (Gero, 1987), only a single paper refers to the application of a recognised knowledge acquisition procedure. Dietterich and Ullman (1987), without reporting the acquisition procedures or analysis methods, briefly mention the use of protocol analysis, in a mechanical engineering application. However, in the following discussion (pp18-24), Maher (and also Gero) express criticism at the inconsistency between the reported findings of the protocol analysis, and the implementation of that information in the ICAD system (as logic programming). For example, Maher (p18) argues that "Another contradiction is what you've observed is that drawings play a critical role in the design process but drawings and spatial reasoning or any kind of spatial representation is not listed as one of your requirements." The value of drawing in design is, incidentally, an important point that will be established later.

Boose and Bradshaw (1987b) propose their methodology "Acquiring Design and Analysis knowledge for Knowledge-Based Systems" in an Intelligent CAD workshop (ten Hagen and Tomiyama, 1987). However, no special considerations or adaptation are made for the task of design elicitation, for example, the same paper appears in Boose and Bradshaw, 1987a. The limitations are clear, and Boose and Bradshaw (1987b) acknowledge that "presently Aquinas works best on problems whose solutions can be comfortably enumerated (analytic or structured selection problems such as classification or diagnosis) as opposed to problems whose solutions are built up from components (synthetic or constructive problems such as configuration or planning)." It will be argued that the above restrictions are typical of design problems in general, and therefore, the methodology proposed by Boose and Bradshaw is clearly deficient.

Akman et al (1988), in their paper "Knowledge Engineering in Design", fail to make any reference to knowledge acquisition. However, they acknowledge that ICAD systems are poor, and argue that "The need to make CAD more sophisticated is real and being felt today...The weakness of the existing CAD systems is basically due to the fact that they have no task-domain knowledge to reflect the thinking processes, terminology, and intentions of designers, and the system software is written in an unstructured, ad hoc and hard to maintain/upgrade way, with no sound basis of a formal design theory." Therefore, Akman et al (1988) argue that the development of Intelligent CAD rests on three issues; a theory of knowledge, a theory of design processes, and a theory of design entities. However, as stated above, they make no reference to the procedures by which ('task-domain') design knowledge can, or should be, elicited.

In a more recent ICAD conference (Gero, 1989), knowledge elicitation appears to be more generally recognised. Kloster, Gjerlow and Ohren (1989) use protocol analysis, but fail to report the acquisition procedures, analysis methods, or evaluation techniques that they used. Maher (1989, p10) states that "The experienced designer defines a knowledge base that includes decomposition, planning, constraint and evaluation knowledge." However, the procedures or precautions by which the designer should provide such knowledge is not documented. Cameron and Grierson (1989), in a system for structural steel design, convert an existing Fortran based expert system, to a rule based system. Cameron and Grierson (1989, p18) claim that "The knowledge base contains rules based on expert knowledge that control the design process, including rules that reflect good design practice and designer preferences." However, without reference to original methods of acquisition, or substantiating the proficiency or extent of the embedded knowledge, the reliability of the original knowledge is suspect. Three of the conference papers report classical methods of induction (Guena and Zreik, 1989; Kamal et al, 1989; Fruchter and Gluck, 1989), but they are applied without modification to non-scientific applications. In the design of Aerospace structures, Kamil et al (1989) propose a system to provide a relevant knowledge base, carefully noting the need for a knowledge representation language, an optimisation theory and a blackboard architecture, but fail to indicate how the knowledge should be acquired. The remaining conference contributions fail to report methods of knowledge elicitation, fail to indicate what methods should be used, and decline to establish that such methods are in fact necessary (or desirable).

The promises of Intelligent Computer Aided Design are not evident (Bijl, 1985; Bijl, 1987; Landsdown and Roast, 1987; Akman et al, 1988). Mutki (1986) argues that the predicament can be directly attributed to deficiencies in depth, and inconsistencies within the embedded design Knowledge Bases, and Oshuga (1985) perceives a lack of generality and diversity in domains of (Intelligent) Computer Aided Design application. Landsdown and Roast (1987) argue that "Current design KBS are not 'expert' in any real sense of the word. Although they are able to simulate the performance of human experts in very limited domains...they hardly begin to model the broader aspects of knowledge that good designers possess."

Therefore, it appears that the most elementary aspect of Knowledge Based Systems research, the significance of thorough Knowledge Acquisition procedures (Gaines, 1987a, 1987b), are only starting to be addressed by ICAD constructors, despite the principle being widely accepted and the availability of knowledge elicitation literature (Bibliography C). Current 'Intelligent' Computer Aided Design systems apparently designate scant provision, thought, or value to the consideration and application of thorough knowledge elicitation procedures. Therefore, in such systems, the propriety of the terms 'Knowledge-Based' and 'Intelligent' are contended to be unqualified.

It is important to note that although a few attempts at knowledge elicitation in design have been made, and methods are starting to emerge, in the light of the paucity of attention to the subject, there is insufficient evidence to substantiate the view that knowledge elicitation is a viable proposition in design applications. Therefore, it has yet to be shown that design knowledge, as a counterpart to scientific classification and diagnosis types of knowledge, can be communicated, analysed, checked and interpreted.

However, Jerrard (1986) argues that "Some phenomena associated with design appear fundamentally subjective although it was found that identifiable and individual criteria are used by designers," indicating that design information, albeit subjective and individual, can be acquired from designers. Bradshaw and Boose (1990) argue that personal preferences constitute a significant repository of expert knowledge, and the identification and elicitation of preferences is an important consideration for knowledge engineers.

In summary, ICAD researchers observe that their systems are not as intelligent as they aught to be. It is asserted here that the design knowledge embedded in such systems is deficient, resulting from the failure to adopt sound knowledge elicitation methods. Thorough knowledge elicitation procedures for design still need development. Current approaches to knowledge elicitation cannot be assumed to be appropriate, without scrutiny, and the nature of design needs to be reviewed first, in order to establish a likely approach for the elicitation of design knowledge.

1.4 Current approaches to design elicitation

The rule-based representation of expertise has been useful in classification applications (Clancey, 1985a) and the methodology has also been applied in ICAD, typically as rule-based planning (eg. Gero and Coyne, 1985; Goel and Pang 1987; Wong and Tsang, 1989). However, choosing the structure and form of representation (rule, frame etc) before the knowledge elicitation phase, is suspect. For example, Gero et al (1985) argue that "much architectural knowledge (particularly in the design) is not codified in any easily recognisable form." Further, the rule-based interpretation of expertise has received criticism (Collins et al, 1985; Dreyfus and Dreyfus, 1986; Partridge 1987) that suggests the traditional scientific metaphors (Symbolic Search Space Paradigm; Partridge, 1987) which presupposes the nature and structure of the domain cannot be applied to design. It is surely desirable to address the problem of modelling, representing and computerising design knowledge after the knowledge elicitation phase, and not before.

The current batch of methods for the elicitation of design knowledge, offered by elicitation researchers (Boose and Bradshaw, 1987; Chandrasekaran, 1988; Marcus, 1988), propose traditional reductionist approaches of hierarchical decomposition, and component level construction that are (arguably) successful in domains of scientific or classification problem solving. It is argued here that the reductionist view is less appropriate to design. For example, Bijl (1985) discusses the differences between design and problem solving, such as 'wholeness' and the inappropriateness of decomposition in design. Carroll and Rosson (1985) argue that the design process is non-hierarchical, and is neither strictly bottom-up nor strictly top-down. Bijl (1985) argues that "If we recognise the existence of parts, we do not know how to define them as discrete parts. It is not practical to work with discrete parts where changes to one part are likely to propagate unforeseen changes to many other parts."

The relevance of established problem solving techniques, that are predominant in CAD, are also scrutinised by Bijl (1985), who argues that "design is not problem solving" and "our thinking is too much conditioned by established concepts associated with successful problem oriented systems." In support of Holt (1985), Landsdown and Roast (1987) argue that reducing all designing to problem solving is too narrow a view, and conclude that "the whole of designing cannot be equated with problem solving."

Yet, despite abundant literature on design method and theory (Bibliography D), knowledge elicitation research continues to promote problem solving strategies for elicitation of design activity (eg. Boose and Bradshaw, 1987b). In many cases, issues of design can not be *comfortably enumerated* (eg Archer, 1979) and can not be adequately described by analysis, classification or diagnosis (Bijl, 1985; 1987; Landsdown and Roast, 1987).

In summary, reductionist views of scientific problem-solving, and hence knowledge elicitation, are prevalently endorsed in design applications, and there is a failure to observe alternative strategies proffered by design research and design practice, and scant consideration of the broader issues of design. Therefore, it is argued here that in order to expound the problems, issues and methods of design elicitation the nature of designing must be considered (eg Magee, 1986; Landsdown and Roast, 1987).

1.5 Design problems in design elicitation

A paucity in the quality of acquired design knowledge, it has been argued, results from the lack of attention to thorough knowledge elicitation procedures, perhaps explaining, to some extent, the observed lack of intelligence in current ICAD systems. Three interrelated factors are postulated, below, to be responsible for this situation.

Firstly, design is very difficult to study and a yawning gap remains between what is known about the mental process of design and observable results of design behaviour (eg Gero, 1985; cited in section 1.2). Brown and Chandrasekaran (1983) argue that design, in general, is difficult to study and that the highly intellectual nature of the activity itself is responsible for the difficulties experienced in its computerisation. Landsdown (1988) argues that "There is little agreement either among practitioners or academics on the exact processes that have to be gone through when we design" and Landsdown and Roast (1987) argue that "It is not yet clear, however, what parts of designers' knowledge can be made sufficiently explicit to incorporate into KBS." In an attempt to measure the relationship between design practice and aspects of theoretical design behaviour, Jerrard (1986) concludes that "A lack of understanding of the design process was perceived." Gero et al (1985) argue that "Architecture has an apprentice tradition where the transfer of expertise takes place under the direction of a recognised master, rather than through the learning and application of a body of theory and principles. Thus, the knowledge acquisition process in architecture is likely to be particularly difficult and time consuming."

Smithers et al (1989, p295) argue that "Design as intelligent behaviour is not well understood, and in some respects it is hardly understood at all. This lack of understanding presents severe difficulties when trying to build artificial design systems for anything but relatively small clearly understood design tasks. Also, the techniques we have available for building such systems makes it very hard to build anything but limited systems."

Therefore, the difficulties experienced in studying design, and the likely problems of acquiring design knowledge, may have unnecessarily hindered realistic attempts at knowledge elicitation in design. Manifest problems surround the study of design, but it is argued here that the task of design elicitation should not be fettered by the doubts, fears and suspicions associated with design. The difficulties are genuine, are unlikely to disappear, and may indeed frustrate progress, but it is argued here that current endeavours towards design elicitation are lamentable, and it is timely to address design elicitation with the same fervency that has been afforded to scientific knowledge acquisition research in recent years.

Secondly, current knowledge acquisition methods take little account of the observation that design is not 'scientific analysis' (Lawson, 1972; 1979a; Cross and Nathenson, 1980) or 'problem solving' (Bijl 1985; Landsdown and Roast, 1987). In a review of design literature, Cross (1982) concludes that "there is a distinct 'designerly' form of activity which separates it from typical scientific and scholarly activities." Gero et al (1985) argue that "Architecture lacks the scientific tradition of disciplines such as Chemistry, Medicine or Geology, the fields where most work on expert systems have been carried out." Arbab (1987) argues that 'Geometric Knowledge' forms an essential aspect of design knowledge, and Darke (1979) argues that design solutions are greatly influenced by arbitrary, personal, or idiosyncratic decisions, and these appear characteristically 'unscientific.'

Thirdly, procedures for knowledge elicitation in design demand extensive improvements (Magee, 1987; Landsdown and Roast, 1987). Landsdown (1988) argues "Perhaps the greatest difficulty arises from the paucity of good tools for knowledge elicitation, acquisition and evaluation." It is asserted here that many elicitation techniques fail to account for fundamental issues of design, and they are, perhaps, unappealing for the ICAD constructors to utilise, and awkward for the designers who are to provide the design knowledge. Smithers et al (1989) argue that "the role of knowledge in the design process has hardly been studied, at least not explicitly." Magee (1987) argues that attitudinal and value-laden judgments are important factors in the process of design, presently not covered by methods of knowledge elicitation. It is therefore argued that current techniques for the elicitation of design knowledge are deficient, in particular, it is observed here that spatial and holistic aspects of the design task are poorly considered.

Oksala (1989) argues that "In order to understand design processes more deeply we need some basic knowledge about cognition," and indeed, design research has recently drawn upon neurology. Our current understanding of the human brain and its organisation suggests that design may not be open to study in the same way that scientific behaviour has been. However, explanations of the design activity, based on clinical and psychological findings, are starting to emerge (Edwards, 1979; Tovey, 1984) that assert the importance of duality, and hemispherical specialisation. In particular, it is postulated that the phenomenon of bilateralisation may account for anecdotal and experimentally observed differences in styles of thinking (Cross and Nathenson, 1980) believed to be important to the design activity (Cross, 1982). It is asserted here that these factors warrant special consideration when methods of design elicitation are to be formulated.

1.6 Towards Knowledge Acquisition in design

In summary so far, to create powerful Intelligent Computer Aided Design systems, there is a necessity to increase the intelligence embedded in them. Therefore, careful attention must be designated to acquiring the underlying knowledge source(s). Many attempts have been proffered to improve the intelligence of CAD systems (Bibliography A), but it is argued here that their success is highly questionable due to the lack of cognisance of the most rudimentary consideration of KBS practice: the significance of knowledge elicitation procedure. It is suggested that ICAD systems are inadequate because they fail to consider the quality of embedded knowledge, and the user is offered little intellectual support because of the paucity, extent and reliability of the design knowledge on which they are based. Current approaches to design elicitation favour familiar notions of problem-solving activity, component level constructions and hierarchical decompositions that are, in all probability, less relevant to design.

Akman et al (1988) argue that "Intelligent CAD is practised mainly by applying the already existing ideas of artificial intelligence and knowledge engineering in several aspects of the design process/object modelling" and Takala (1989) argues that "An apparent problem with expert systems is Knowledge Acquisition, which usually is a separate process done by knowledge engineers." Therefore, Computer Aided Design researchers do not, perhaps, recognise knowledge elicitation as a problem that they must deal with, relying on knowledge elicitation research to provide the methods and knowledge engineers to provide the knowledge for their systems. Perhaps they consider that the 'knowledge' can be installed at a later stage of the system's development, and for them is not a burning issue.

Perhaps the interesting research for ICAD constructors lies in the development of the deliverable computer facilities; the computational methods, the computer representations, and the user interface facilities. Indeed, the problem of knowledge representation is predominant in 'knowledge engineering in CAD' literature (eg Gero et al, 1985; Dietterich and Ullman, 1987; Tomiyama and ten Hagen, 1987; Bijl, 1987; Akman et al, 1988; Bibliography A). Knowledge elicitation is difficult, time consuming, and labour intensive. The absence of convincing procedures, in design, results in the task being even more arduous. Perhaps the length of time required to undertake a thorough knowledge elicitation study is considered too costly, since many applications are principally academic or experimental development projects. The above factors may also account for the current embracement of automatic and inductive methods appearing in the ICAD literature (eg. Kamal et al, 1989; Guena and Zreik, 1989), simply because considerable knowledge elicitation research literature promotes a belief that short-cuts are possible (Boose and Bradshaw, 1987b). It will be argued that the principle objective of knowledge engineering should be to acquire *quality* knowledge, not *fast* knowledge (eg. Fox et al, 1987; Johnson and Johnson, 1987b) and that although automatic elicitation methods may yield information rapidly, the resulting knowledge is, however, often shallow (Welbank, 1987). Hence, given that design can be studied from the knowledge engineering viewpoint, it is essential to consider methods for obtaining maximum information with minimum bias (eg. Cleaves, 1987).

In what follows the development of an approach to knowledge acquisition for design is discussed. It builds on traditional methods based on the inherent skill of people to communicate with each other, thereby attaining a shared understanding. Computer and automated methods of knowledge acquisition do not, as yet, possess this advanced ability. The personal interview is argued to be a suitable strategy. The knowledge elicitation methods identified here are chosen to offer a likely approach, in the light of current research theories and practices, but no claims of optima are made and other approaches to knowledge elicitation may prove useful.

The main thrust of this thesis, then, is that thorough knowledge acquisition methods are needed for the elicitation of design knowledge. It is asserted that such methods can be applied to the class of problem known as design, given great care and attention. To test this hypothesis an exemplifying study in the domain of page layout design was devised. The potential of the method is indicated in the success of the study, the generation of a communicable report, and in the results of an evaluation procedure. It is suggested that if fruitful results can be demonstrated in one, albeit restricted domain of design, then the implication is that others can also be explored in a similar manner. However, care is taken to ensure that the study is not so severely restricted that it no longer exhibits the essential characteristics of design, or the domain in question.

1.7 The Structure of the thesis

The thesis consists of eight chapters. The introduction outlines the context of the discourse and highlights the necessity for better knowledge elicitation methods in the development of Intelligent Computer Aided Design systems.

Chapters two, three and four cover three literature surveys pertinent to the postulates of the thesis. The multi-disciplinary approach results in a broad survey which is presented in a bottom-up fashion, dealing with the background literature of Brain Research first, moving through Design to the more specific literature on Knowledge Elicitation.

The concept of brain lateralisation (the split brain) is addressed in chapter two, where evidence is discussed to support the view that certain types of thought processes are located in, or are dominated by, a given hemisphere. The right brain is specialised for visual, spatial, and holistic types of information processing, in contrast to the predominantly verbal and analytical nature of the left hemisphere. Chapter two plays a largely supportive role and may be passed on first reading.

Chapter three covers literature presented by design practitioners and design researchers. To conduct knowledge elicitation in design, information about the nature of the problem needs to be addressed first, particularly as design cannot be treated as a problem-solving activity of the kind currently supported by Knowledge Based Systems developments and Knowledge Elicitation procedures. Recent trends in design research have recognised that the evidence of brain lateralisation, identified in chapter two, may have important implications for understanding the cognitive processes engaged by designers, and this link is explored.

The survey of knowledge elicitation, in chapter four, covers the many strategies that are currently available. It also introduces some of the background psychological issues pertinent to the nature of verbal (and other) data, such as validity and biasing. The chapter concludes with a critical account of current methods of design elicitation, and a strategy for design elicitation is proposed.

Chapter five details a method of knowledge elicitation in design. A two-phase procedure is described that involves many experts in the first instance, followed by a second 'teachback' phase, using a single designer over a much longer period. The chapter describes how the data is gathered and developed into a communicable form, and the application of the technique is illustrated through examples from the study of page layout design.

To support the interpretation placed on the data, and to indicate the success of the approach ventured, the acquired understanding is tested in an evaluation study. The evaluation procedures, and the results of the evaluation study are discussed in chapter six. The principal expert used in the knowledge elicitation process, and also a panel of ten experts having no previous involvement in the project, are tested.

In chapter seven, the thesis concludes that knowledge elicitation in design is practical for design problems, when the nature of the design task is taken into account. Future developments and speculations arising from the work together with other general or secondary notes of interest are discussed in chapter eight.

2 The Dual and Asymmetric Brain

2.1 Introduction

This chapter describes research into the nature of the phenomenon of brain bilateralisation and provides background for the discussions on Design (chapter three) and verbal reporting of .information (section 4.5). It is also ventured that brain physiology can offer valuable ideas for the purpose of constructing models of cognition (ie. Johnson-Laird, 1983; Norman and Rumelhart, 1975) and, hence computer systems. The human brain is vastly complex and our understanding of its operation is still in its infancy. However, observations of behaviour and structure provide broad theories about its possible organisation.

To conduct Design Elicitation the problem of information transfer needs to be addressed. Reviewing the likely form and structure of Design knowledge will enable the best choice of methods that will reduce.biases and help focus study. Certain 'modes of thought' can be identified, and largely attributed to the dominance of one or the other of the hemispheres. Spatial processing is important to the Design activity (Ward, 1984), and it appears that the right brain is characteristically specialised for this type of process (ie Gazzaniga, 1983).

The human brain is physically separated into two parts and the significance of the phenomenon, bilateralisation, is explored here. In the following discussion the normal orientation of left and right lateralisation is assumed. Although some people possess the 'reverse polarity' of lateralisation, (ie. most 'left-handers'), the arguments are essentially same.

The independent operation of the hemispheres cannot be measured in people with normal healthy brains. Over a significant period of time, evidence has been obtained from the observation of patients who have had partial brain damage, or removal, as a result of illness or accident. In recent years, information has been obtained through clinical studies (Table 1). The most significant of the studies involves a group of subjects who, after surgery, are termed 'split-brain' patients. As a remedy for otherwise incurable epilepsy, in these patients the interhemispheric connecting fibres (the Corpus Callossum and the Anterior Commissures) are severed. After the operation the patients appear to behave normally. However, when the patients are tested in specially devised experiments, astonishing results are obtained.

Language is a significant, easily testable aspect of human intelligence, and it has been historically shown that the left hemisphere is important for language. People with damage to the left part of the brain suffer loss of speech, Aphasia. Early experiments attempted to fathom the abilities of the right hemisphere, in terms of language, comparing it to the language dominant left hemisphere (eg. Geshwind, 1965). Language is not dominant in the right hemisphere and the early studies term the right hemisphere 'dumb,' with the usual conotations of inferior intelligence. However, latter views of right brain function clearly identify that the right hemisphere is as powerful as its counterpart, is specialised towards a different form of processing (to language), and is especially powerful with spatial information.

2.2 Differing styles of thought ?

Many observations exist on the different types of thought processing performed by humans, for different tasks. Bogen (1969) identifies a number of dichotomies of lateralisation discussed in brain research literature (Table 1) and argues that the terms 'propositional' and 'appositional' can encompass the previous distinctions. The terms 'Holistic' and 'Analytic' are preffered in this discussion, and a definition is cited in section (2.7).

Jackson (1864)	Expression	Perception
Jackson (1874)	Audio-articular	Retino-ocular
Jackson (1876)	Propositionising	Visual imagery
Weisenberg and McBride (1935)	Linguistic	Visual or kinesthetic
Anderson (1951)	Storage	Executive
Humphrey and Zangwill (1951)	Symbolic or propositional	Visual or imaginative
McFie and Piercy (1952)	Education of relations	Education of correlates
Milner (1958)	Verbal	Perceptual and non-verbal
Semmes, Weinstein, Ghent, Teuber (1960)	Discrete	Diffuse
Zangwill (1961)	Symbolic	Visuospatial
Hecaen, Ajuriaguerra, Angelergues (1963)	Linguistic	Pre-verbal
Bogen and Gazaniga (1965)	Verbal	Visuospatial
Levy-Agresti and Sperry (1968)	Logical or analytic	Synthetic perceptual
Bogen (1969)	Propositional	Appositional

Table 1 : Dichotomies with Lateralisation suggested (Bogen, 1969).

2.2.1 The split-brain experiments

In an extensive review, Gazzaniga (1983) critically assesses three series of experiments. The patients are usually tested using a split screen, with a central fixation point (Figure 2). In this way, pictorial information (including words) can be independently displayed on each half of the screen.

The configuration allows only images from the left half-screen to enter the right hemisphere, and the images from the right half-screen to enter the left hemisphere. The images are displayed for very short intervals of time, preventing automatic eye-scan from presenting the images to both hemispheres. The first of the clinical trials, known as the 'west-coast' experiments were conducted by Gazzaniga, Bogen and Sperry on three epileptic patients. These experiments contributed significantly to the understanding of hemispheric functioning for visual processing, language processing and the unity of consciousness.

Two independent cognitive systems are demonstrated in the split-brain patients. The left hemisphere is shown to be concerned with functions of a verbal and analytic nature, such as the analysis of a whole into its component elements. The right hemisphere is more apt at visuo-spatial and holistic (Gestalt) non-verbal functioning such as synthesis of a whole from fragmentary and incomplete information (Gazzaniga, Bogen and Sperry, 1963; 1965; 1967; Bogen and Gazzaniga, 1965; Sperry, 1968; Gazzaniga, 1972).

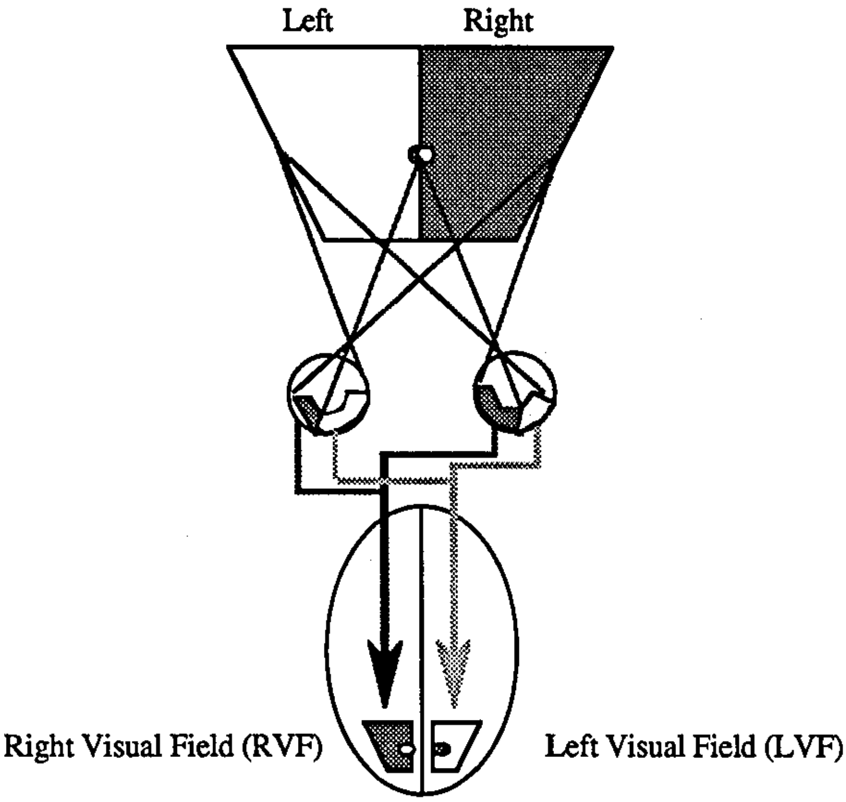

Figure 2 : The split screen enables information to be presented to either visual half field. Information is presented almost equally to both hemispheres but the fixation point allows the projection of the Right Visual field to only the Left hemisphere and vice-versa (Gazzaniga and Le Doux, 1978).

The second set of experiments conducted in the early seventies by Sperry, Levy, Travarthen and Zaidel focused on showing the differences between the hemispheres, and also that language is not insignificant in the right hemisphere (Levy, Travarthen and Sperry, 1972; Levy and Trevarthen, 1977; Zaidel, 1978a). The experiments also provided information on other aspects of behaviour (Zaidel and Sperry, 1973; 1974; Zaidel, 1976). However, Gazzaniga (1983) argues that their findings were based on just six patients. Two of the patients were from the original three (who were later shown to be unusual in terms of right hemisphere language) and the other four were not assessed correctly.

Gazzaniga (1983) in review of right hemisphere language, suggests that the two trials, above, were misleading through poor experimental method, and questionable subjects. The first trials were based on just three patients. One of these suffered damage early in life, and would have experienced brain reorganisation.

In the third series of trials, Glass, Gazzaniga and Premack (1973) studied twenty eight patients, of which only a small number (three), exhibited the right hemisphere language characteristics that had been earlier discovered. They argue that the previous results are simply unrepresentative and Gazzaniga (1983) concludes that "...our findings imply that right hemisphere language is not common. When present, it can be attributed in almost every case to the presence of early left hemisphere brain damage."

In reply, Levy (1983) generally agrees with Gazzaniga, and acknowledges the criticism, but remarks that the right hemisphere contributes to the language process in its own particular way. Levy argues that it is the lack of verbal expression of the right hemisphere that promotes the view that it has little to do with language, but it might, for example, perform a key role in extracting semantic meaning from sentences, that are otherwise just a list of words.

Evidence of left hemisphere language is considerable, and recent trials of non split-brain patients also support Gazzaniga's view that right hemisphere language is extremely limited (Geshwind, 1965; Galaburda, Le May, Kemper and Geshwind, 1978; Milner, Branch and Rasmussen, 1966; Lassen, Ingvar and Skinhijie, 1978; Hilyard and Woods, 1979; Kutas and Hilyard, 1983).

It is widely believed that the two hemispheres demonstrate roughly equal levels of intelligence but different strategies are used in each. Also that each hemisphere is specialised for certain tasks, yet each has some capabilities for all types of processing. For example, Bradshaw and Nettleton (1983) argue that "Interhemispheric differences are relative, quantitative and a matter of degree rather than qualitative or absolute. Apparent absolute superiorities in the clinical literature may stem from interhemispheric inhibitory influences." To prevent unnecessary processing in a non-specialised hemisphere, the dominant hemisphere, or the one which is specialised to the task in hand, may 'block out' the other (Inhibition is discussed in section 2.6).

Gazzaniga (1983) concludes that "our cognitive system is not a unified network with a single purpose and train of thought. ...our sense of subjective awareness arises out of our left hemisphere's unrelenting need to explain actions taken from any one of a multitude of mental systems that dwell within us." This argument is discussed further by Gazzaniga and Le Doux (1978).

Levy (1983) postulates that the regime of control is task dependent "My conclusion is that whether a hemisphere is passive or dominant depends on the nature of task demands, with the left hemisphere passive in some circumstances and the right in others ... the human right hemisphere has a deep and superior understanding of geometric and topological relations, of set-defining characteristics in these domains, and an ability to abstract and relate these properties to new and different exemplars."

In addition to language, other interesting observations were made from the split-brain trials :

1 Tactile information passed between the Left and Right hands is severely degraded, or totally lost in the split-brain patients.

2 Two completely separate visual systems are present in split-brain patients when the rapid eye movements, that allow both hemispheres to see a unified picture, is prevented (eg. Gazzaniga, 1970).

3 An impairment of binocular visual depth is suffered by split-brain patients (Mitchell and Blakemore, 1969).

4 Bi-manual motor coordination is degraded in split-brain patients (Preilowski, 1972; Zaidel and Sperry, 1977).

In summary, the results of the above studies indicate that, as far as language is concerned, the right hemisphere plays a largely supportive role to the left hemisphere. However, some caution has to be exercised when dealing with results from commissurotomy patients, since there may have been massive cerebral reorganisation as a consequence of preexisting epilepsy, and the patients inevitably suffer from post surgical trauma. As discussed below, there are no natural procedures for testing the patients for these effects, before the damage occurs, or before the operation.

2.2.2 Non Split-brain studies

Additional support for the view that people posess two separate cognitive systems is provided by studies of patients with hemisphere lesions, by using a drug to suppress one of the hemispheres, from animal studies (particularly monkeys) and studies of normal people.

Patients with lesions (removal of parts of the hemisphere, or even a whole hemisphere) are also suspect, as it much depends on the age of the patient when the trauma occurs, and the post-operative delay before test. Little is known of the state of the patients before the operation and they often experience massive cortical reorganisation and compensatory functioning, possibly before and after the operation, both within and between the hemispheres. The effects of compensation are greater and more evident in patients who are operated on in youth.

However, some useful information has resulted from such studies. The left hemisphere usually remains dominant for speech production, even if damage occurs at an early age. Support for the slight role of the right hemisphere in terms of language is also evident, as damage to the right hemisphere has little effect on language. Yet a restriction in the use of creative language is observed. The right hemisphere shows some ability for comprehension, but is far less than that of the left hemisphere. Further, the expressive ability of the right hemisphere is insignificant, if present at all.

It is experimentally possible to suppress one of the hemispheres for a short period by injecting a subject with Sodium Amytal (Wada tests; Milner, Branch and Rasmussen, 1966). The procedure tells us much about the lateralisation of the speech process, but little of speech comprehension. When the left hemisphere is suppressed there is an immediate loss of speech (temporary aphasia). Thus, the abilities of right hemisphere language can be tested, and shown to be slight, such as the ability to understand simple commands.

However, since the above procedure is hazardous, it is usually only administered to patients who have had previous, and often extreme, trauma. A degree of brain reorganisation is inevitable in such patients. Therefore, right hemisphere language shown in such patients is again suspect.

2.2.3 Studies of healthy brains

The testing of ordinary people can demonstrate broad differences in lateralisation, and are useful to map broad areas of information processing in the brain. However, in such studies, the hemispheres can not operate independently, and they tell us little about actual differences between the two hemispheres.

Experiments have been devised to test the very slight time differences between the hemispheres in response to certain stimului. The experiments attempt to discover the direct processing of information in one of the hemispheres by comparing the time it takes for the other to respond, since there is a latency period due to information transfer across the Corpus Callosum.

Visual tests, similar to those used in split-brain experiments are often used (eg. Young, 1981a), in which a split visual field projects images that appear for a time interval that does not allow the eye to present the image to both hemispheres (Figure 2). A vocal or manual response triggers a clock. The experiments are repeated a considerable number of times, and on many subjects, to counter random delay errors. Statistical analysis is required to show that such time differences occur, and they are extremely small (milliseconds).

It is shown (eg. Bryden, 1965; 1966) that the Right Visual Field (RVF, Left hemisphere) is superior for letter and digit recognition, word recognition and recall, for determination when difficult (slight) differences are present, when categories are to be determined and when decisions of a lexical or phonological nature are needed.

The Left Visual Field (LVF, Right hemisphere) may be superior when matching relies on spatial, physical attributes of shapes, or letters. More significantly, there appears evidence of a non-verbal functioning superiority with respect to depth perception, dot location, lightness and hue and for recognition of simple (familiar) shapes and, especially, for the recognition of faces. There are many problems with the above experiments, and the results are sometimes contradictory in nature.

Other auditory experiments (reviewed by Krashen, 1976; 1977) echo the above findings, with the Left auditory (Right brain) specialised for nonverbal information such as musical or environmental sounds, emotional and intonational speech tones. And the Right auditory (Left brain) for verbal sounds.

Three dimensional computer imaging is more recently used in conjunction with regional blood-flow measurement (Lassen, Ingvar and Skinhojie, 1978), nuclear magnetic resonance, positron emission tomography, and most significantly brain electrical activity mapping. These techniques are used to isolate the location of processes both within and between hemispheres (Gevins et al, 1983) and the results of these different methods have produced roughly similar findings. Duffy (1982) shows that speech induces Electroencephalogram (EEG) (eg. March, 1978), and sensory evoked potential (EP) change in the left hemisphere (Kutas and Hillyard, 1980). Music induces a change in both the left and right hemispheres, the greatest change occurs in the right hemisphere, but changes in the left hemisphere are more likely if the subject is an experienced musician (and indicates that specialisation may take place). The above techniques and other normal brain studies are comprehensively reviewed by Bradshaw and Nettleton (1983).

2.2.4 Summary of section (2.2)

Split-brain research, backed by other experimental evidence, has shown that the two (separated) hemispheres operate with specialistic functionality and possibly in parallel (Trevarthen, 1962; Gazzaniga and Young, 1967). For example, Bogen (1969) argues that "... one way of interpreting the considerable evidence now available is to postulate the existence of two ways of thinking ... The right hemisphere recognises stimuli (including words), apposes or collates this data, compares this with previous data and while receiving the very same stimuli as the other hemisphere is arriving at different results."

The power of possessing two hemispheres, and two 'modes of thought,' is summed up by Bogen and Bogen (1969), who argue that "If learning can proceed simultaneously but independently and differently in each hemisphere, so may problem solving ... specialisation of the hemispheres for different modes of thought greatly increases the flexibility and creativity of the ensemble."

2.3 The Organisation and Structure of the two brains

Bogen (1969) cites evidence from Teuber, who argues that there may be different modes of organisation in the two hemispheres (Teuber, 1965; Semmes, Weinstein, Ghent and Teuber, 1960) and that brain organisation is discrete in the left and more diffuse (distributed) in the right. In simple terms, 'packets' of information in the left hemisphere represent detailed pieces of information, in single lumps. However, packets of information in the right hemisphere reflect only partial detail, and many packets are used.

Belyi (1979) also supports the theory of a distributive organisation of information in the right hemisphere, comparing it to holographic principles. A (large) number of tumour patients are tested visually by a sequence of drawings conveying a theme of action. It is shown that patients with left frontal lobe tumours are unable to connect separate themes into a logical whole using abstractions and generalisations, but they have no difficulty in perceiving the components. In contrast, patients with right frontal lobe tumours interpret the sequences as a whole, often using partial details and a proportion of imagination, but perception is fragmentary and they cannot perceive all of the components. Therefore, Belyi (1979) argues that "A common feature of these disorders (right frontal lobe tumour) was that in those cases only a small part of the material presented was perceived; the tendency towards perception of the whole visual pattern, but indistinct and blurred, was intensified. This tendency toward infilling to produce a whole but indistinct pattern on the basis of partially perceived information was intensified as the degree of brain damage increased. This fact is evidence that memory for visual patterns in the right hemisphere is not imprinted in localised areas of the cortex, but is spread over considerable parts of it. This type of information recording is known as distributed."

Gazzaniga and Le Doux (1978) argue that it is unlikely that any physical differences exist, and differences are a matter of internal organisation. It is further argued that it may be the need to accommodate language itself, that provides the key to the occurance of lateralisation " ... lateralised functions do not reflect the genetically specified cognitive styles of the hemispheres but represent specific, localised differences in cerebral organisation that are closely tied to the inter- and intrahemispheric localisation of linguistic mechanisms...There are no data to bear directly on why language is lateralised ... it seems that it is really the expressive speech mechanism that demands lateralisation." (Gazzaniga and Le Doux, 1978).

2.4 Duality of consciousness ?

The subject of 'two people in one mind' is controversial and has still not been successfully resolved. Two trains of argument exist. Firstly, if it has been shown that the two hemispheres operate in different ways, and experiments on split-brain patients and other studies show that the two hemispheres do operate independently, then we have two minds. For example, Sperry (1964) argues that "Everything we have seen so far indicates that surgery has left each of these people with two separate minds, that is, with two separate spheres of consciousness." and this view is supported by Bogen (1969) who argues "One of the most obvious and fundamental features of the cerebrum is that it is double. Various kinds of evidence, especially from hemispherectomy, have made it clear that one hemisphere is sufficient to sustain a personality or mind. We may conclude that the individual with two intact hemispheres has the capacity for two distinct minds. This conclusion finds its experimental proof in the split-brain animal whose two hemispheres can be trained to perceive, consider, and act independently. In the human, where propositional thought is typically lateralised to one hemisphere, the other hemisphere evidently specialises in a different mode of thought, which may be called appositional."

The opposing argument is that a split-brain patient is an artificial creature that can give no useful insight as to the operation of a normal human. Conceptually it is likened to cutting a chip out of a computer's printed circuit board, and then attempting to see what the resulting system can or can not do. Yet the brain is more complex, the dynamic nature of the human body allows repair and reorganisation, the brain may start to cope with certain losses (before questioning occurs) and a renewal of language capacity after aphasia is particularly noticeable. For example, Gazzaniga and Le Doux (1978) argue "We believe that the interhemispheric pathways transfer highly specified neural codes that serve to maintain an information balance across the verbal midline, and in doing so, provide for mental unity. Once one accepts such a view of commisural function, it becomes difficult to work with the two-brain model of normal cerebral organisation that has evolved out of the split-brain work."

This view is also echoed by the distributive nature of identity, that is, there is no change in the personality of any of the subjects mentioned above, even in cases of complete hemispherectomy.

However, there is some evidence that subjects (both normal and commissurotomy) may process stimuli simultaneously, but the parallel functions need to be relatively simple due to integration, comparison, and cross-matching overheads. On timing studies of normal humans (above) it has been shown that delay and signal degradation would not impose any limiting factors on the communication process.

Since we are not consciously aware of two personalities and evidence that hemispherectomy patients exhibit no change in personality or awareness indicates that the 'self' is distributed between the hemispheres. Further argument of whether or not humans posses dual consciousness contributes very little more to the present discussion.

However, the organisation of control structure remains a problem, is integral to the question of communication and inhibition, and is discussed in more detail below. An interesting supposition is postulated by Bradshaw and Nettleton (1983) that "Perhaps whatever neural subsystem currently has access to response or output processes automatically attains a level of conscious self-awareness, with response selection perhaps more important than stimulus identification in these respects."

2.5 Interhemispheric communication

So far it has been shown that the human brain can possess two modes of thought. The conflict is whether or not, in normal circumstances, the hemispheres operate in an independent fashion. The obvious advantages are only possible if there exists a comprehensive mediation by the commissures (information transfer) and sensory-motor gap structures; it is believed that, for instance, speech information can be passed between the hemispheres by the movement of the speech musculature. Thus Bogen and Bogen (1969) argue that the "... possession of two independent problem-solving organs increases the prospects of a successful solution to a novel situation although it has the hazard of conflict in the event of different solutions."

There is considerable evidence to support the view that interhemispheric exchange of information occurs, particularly in learning tasks (Myres and Sperry, 1953; 1958; Myres, 1956; 1965; Sperry, 1961; 1961a), for example, Bogen and Bogen (1969) argue that "It is now certain that the commissures can transfer information from one hemisphere to the other. But these experiments do not tell us what information is ordinarily transferred under normal circumstances."

Bogen identified that there was a failure to transfer information in split-brain patients, especially in spatial discriminatory data when contrasted with the intact brain, and argues that "... Integrated use of verbal and visuo-spatial thought may be dependent on interhemispheric communication, including an important contribution from the Corpus Callosum." (Bogen and Bogen, 1969).

Kimura (1966, 1973a) accounts for the asymmetrical structure as a form of 'privileged access.' Information may be passed across from the non-specialised hemisphere to the hemisphere most competent for the specialised processing required, via the commissures.

Gazzaniga (Glass, Gazzaniga and Premack, 1973; Gazzaniga and Le Doux, 1978) compiled additional material on the transfer of information between the hemispheres :-

1 Early theories postulated that the information is coded before being transferred. Thus, only the actual result of a learning experience, or engram, is transferred (Russel and Ochs, 1961). Initially, it was believed that the amount of (visual) sensory information would be too great for the network to handle, however, this is countered by recent findings that the eye has only a narrow field of concentrated visual sensory apparatus, and the network is adequate. Also, it is clear that the hemispheres can be trained by straightforward sensory stimulus, either directly, or cross commissural. Thus, the engram theory is dismissed (Petrinovich, 1976). Yet it is believed that neural codes of some form are transmitted and they are highly complex.

2 Both semantic and attentional interactions occur within and between the separated hemispheres. Processes in one hemisphere can be influenced by cognitively based information activated in the other hemisphere. (Holtzman, Sidtis, Volpe, Wilson and Gazzaniga, 1981).

2.6 Inhibition, collaboration and comunication

A supplementary theory to duality, is inhibition, which may explain some of the anomalies associated with experiments on split-brain patients. The hypothesis is that each of the hemispheres actively interferes with the processing of the other, for example, Bradshaw and Nettleton (1983) argue that "Numerous accounts in the clinical literature of severe aphasia after left hemisphere trauma report considerable alleviation after removal or disconnection of the damaged left hemisphere areas, which leaves the right hemisphere to perform its not inconsiderable verbal functions free from inhibitory influences from the left. In health these inhibitory influences may help to eliminate maladaptive bihemispheric competition."

Butler (1967) conducts a series of experiments on monkeys, where tasks requiring some collaboration between both hemispheres is examined. Monkeys with commissurectomies cannot perform tasks requiring right tactile and left visual collaboration. Monkeys with intact commissures, but having the opposing centres of stimulation surgically removed (left tactile and right visual processing areas) could perform the task, and remarkably, learned the task faster than control monkeys. Further evidence is cited by Head (1963), in the study of a patient who was a professional singer before suffering trauma, which left him aphasic. He is now able to sing melodies quite perfectly without words. However, he is unable to perform if he tries to sing the words. Head argues that the damaged left hemisphere's verbal processing is (incorrectly) interfering with processes that otherwise operate quite normally. Similar examples are given by Bogen and Bogen (1969), who argue that "... there may be a good deal of inhibitory activity. If so, certain kinds of left hemisphere activity may directly suppress certain kinds of right hemisphere action."

Thus it seems likely that the dominance of the left hemisphere and propositional thinking may adversely effect the appositional activity of the right hemisphere. Thus, a further role of communication is highlighted by Bogen and Bogen (1969), who argue that an "... inbuilt antagonism between analysis and intuition requires subtle mediation to attain common ground."

Since language is a dominant feature of human intelligence, the analytical left brain often appears to achieve control, but the two brain system can not be in serious conflict, otherwise we would be incapable of any useful thought, or perhaps the significance of inhibitory actions is considerable.

2.7 A definition of the terms 'Holistic' and 'Analytic.'

In summary so far, many researchers have identified that the two hemispheres operate in different ways and possess specialities for processing different types of information. In particular the right brain is specialistic for spatial processing and the left brain for linguistic processing.

Unfortunately, the terminology used to describe such differences is imprecise and contentious. Bradshaw and Nettleton (1983) attempt to clarify the terminology, and this is presented verbatim as a reference point:

"The term analytic properly applies to perceptual processing, rather than, for example, to the preparation of a response sequence, in the context of a segmental breakdown of a visual array or an auditory grouping into separate components, features or elements. In theory at least, such a breakdown may be performed either serially and sequentially or in parallel. In contrast, global, holistic, or gestalt processing can be viewed as a more immediate and possibly primitive mode of apprehension; it places more emphasis on the whole configuration and on the patterns of interrelationships between and otherwise independent of, the component parts. W.R. Garner (1978), without reference at all to the laterality literature, argues for two classes of stimulus properties, component and holistic. The component class he subdivides into dimensions (eg. brightness, loudness, form) and features (eg. presence of a horizontal line, an intersection and so on). The holistic class of stimulus properties he subdivides into 'simple wholes' (eg. 'blob processing' where an entity is not or cannot meaningfully be further subdivided or analysed), 'templates' (the simplest 'canonical' or idealised form of configuration) and 'configurations' (where the whole constitutes something over and above the sum of the individual component elements)."

Left brain	**Right brain**
Speech	Understanding metaphor
Reading	Facial recognition
Writing	Drawing
Verbal memeory	Visual memory
Abstract categorising	Orientationing
Musical ability	Musical sense
Fine manual sequences	Kinesthesia
Sequential thought	Parallel thought
Analytic process	Integrating process

Table 3 : Crude characterisation of lateralised specialisation (Tovey, 1984).

2.8 Summary

The earlier beliefs that the right hemisphere is in some sense minor, in terms of intelligence, to the more language dominant left hemisphere is shown to be simply untrue. The right hemisphere has a specialism in other modes of thinking, and is particularly dominant for visual processing tasks. The right hemisphere is superior at perceiving relationships between components and forming an opinion as to the nature of whole configurations.

The distinction between the verbal and non-verbal processing abilities is considered to be less significant than the more general analytic and holistic difference (section 2.7). The analytic mode is not necessarily restricted to serial, sequential processing. Holistic processing is believed to be a more primitive mode of thought (since simple life forms can recognise patterns) and is used to recognise whole configurations from otherwise independent component parts, and the construction of relationships and patterns. For example, the ability to form a complete gestalt from incomplete information is a right brain function, and the ability to separate a meaningful shape from irrelevant background information, is a left brain function (Nebes, 1978). The holistic or Gestalt processing is shown for visuo-spatial information in the right hemisphere, but it can only be postulated that this type of processing is the general method of right hemisphere activity.

It is unlikely that physical differences exist between the two hemispheres because people who sustain damage to, or loss of, a hemisphere in early life can reorganise. However, the internal organisation of information in the hemispheres is likely to be different, to accommodate for the specialistic processing abilities. The need to facilitate language has been identified by Gazzaniga and Le Doux (1978) as a possible factor for the phenomenon of lateralisation.

Interhemispheric (and possibly intrahemispheric) interference may be used to reduce cognitive competition, or crowding, by avoiding redundant duplication. In this respect it is not yet known whether this strategy allows for the independence of the two modes of thought or not.

Creativity, may be attributed to the independence of the hemispheres with mediation from communication. It is suggested (Bogen, 1969) that there are two types of processing activity and there exists a need to resolve the differing results. Therefore, competition and collaboration yields a system more able to adapt to new and unusual circumstances, which is the essence of creativity. However, an interesting concept is that the separation of ideation, that leads to the above creative process, relies on the fact that the interhemispheric exchange cannot be completely free, ie the hemispheres must operate with a degree of independence. The further discussion of Creativity contributes little to the postulates of this thesis.

It is also believed that meta-control is dispersed through both hemispheres, as is personality, emotion, and essentially 'the self.' Thus split-brain, or total hemispherectomy patients appear to have two brains within a single persona. The ability to use inhibitory actions across the Commissures to suppress competing cross-hemisphere processing indicates the single mind approach, with the non-dominating hemisphere providing (specialistic) support to the dominating hemisphere.

The human brain is made of two cognitive systems, although they do not normally operate in an independent fashion, as they do in split-brain patients. However, it is clear that the two cognitive structures offer different and specialistic processing abilities. Much of our established body of knowledge appears to be the type that can be associated with the left hemisphere, especially the verbal articulative (language, books) and analytical, mathematical and sequential forms. For example, Smythe, (1988) discusses the differences between propositional and skillful knowledge. In contrast, we possess little knowledge about visual and spatial information processing expertise.

Design, and visual design tasks, in particular, use a significant contribution from a spatial form of processing, that is dominant in the right hemisphere. It is argued here that design is better understood, hence studied, when the nature of right brain functionality is taken into account. The holistic nature of the right brain is postulated to be an important consideration for design elicitation procedure. In particular, design elicitation methods should capture visual and spatial information without causing distortion, for example, through a shift in cognition (ie. from right brain spatial, to left brain verbal processing). This is discussed further in chapter four.

Design research recognises that different types of thought processing are utilised at different stages of the design activity. The recent trend in Design Research identifies that Brain, and Education Research, offer important insights as to the nature of the Design activity, and the Holistic and Analytic dichotomies, amongst others, are identified (eg. Tables 3 and 4). In particular, design activities that use visual and spatial contributions are associated with the specialistic dominance of the right hemisphere. The above link is investigated further in chapter three, where characteristics of the design process are discussed.

Left	Right
Verbal: Using words to name, describe, define.	**Nonverbal:** awareness of things, but minimal connection with words.
Analytic: Figuring things out step-by-step and part-by-part.	**Synthetic:** Putting things together to form wholes.
Symbolic: Using a symbol to *stand for* something.	**Concrete:** Relating to things as they are, at the present moment.
Abstract: Taking out a small bit of information and using it to represent the whole thing.	**Analogical:** Seeing likeness between things; understanding metaphoric relationships.
Temporal: Keeping track of time, sequencing one thing after another: Doing first things first, second things second, etc.	**Nontemporal:** Without a sense of time.
Rational: Drawing conclusions based on *reason* and *facts*.	**Nonrational:** Not requiring a basis of reason or facts; willingness to suspend judgement.
Digital: Using numbers as in counting.	**Spatial:** Seeing where things are in relation to other things, and how parts go together to form a whole.
Logical: Drawing conclusions based on logic: One thing following another in logical order; a mathematical theorem or well-stated argument.	**Intuitive:** Making leaps of insight, often based on incomplete patterns, hunches, feelings or visual images.
Linear: Thinking in terms of linked ideas, one thought directly following another, often leading to a convergent conclusion.	**Holistic:** Seeing whole things all at once; perceiving the overall patterns and structures, often leading to divergent conclusions.

Table 4 : A comparison of Left-mode and Right-Mode characteristics (Edwards, 1979).

3 Design

3.1 Introduction

The following discussion centres on the assertion that in order to conduct knowledge elicitation in design, the characteristics of the activity called *Design* should be carefully considered. Design research literature is reviewed to identify important considerations for the elicitation of design knowledge.

Although design remains difficult to define, or describe, important observations can be noted about the nature of the design process. In particular, design is a process that should be considered different to the traditional notions of problem-solving and scientific method. For example, the solution-focused approach, and holistic type processes are predominant in design. Understanding, and taking account of these differences will enable better studies of design to be conducted, and help reduce distortions in design knowledge acquisition.

Design and creativity are subjects that are inevitably linked. However, creativity is considered here to be a separate issue to design, and is not addressed because the lack of clarity about its nature. For example, in review of creativity, Lawson (1980, p106) argues that "A very great deal has been said about the phenomenon of creativity and yet it stubbornly remains one of the most unclear, perhaps even confused, concepts in the literature of the psychology of thinking."

In this thesis the term *aesthetic* will be used to describe the appearance of a design, or artifact, that is somehow (visually) pleasing (or unpleasant). It is acknowledged that alternative views exist. For example, aesthetic is often considered to mean the overall success or working of a design, or artifact.

3.2 Structure of chapter

This chapter is split into two main parts. The first introduces some of the more general concepts of design and design methodology. The second part deals with psychological aspects of design pertinent to the discussion.

The paucity of information on the nature of design, and the lack of scientific description of methods of designing, propagates a belief that the design process can, and should be, mapped out in the same way that scientific methods are. To present a more acceptable and 'scientific' foundation to design, design researchers attempt to formulate structured procedures of design, optimistically termed *design methods*. However, design methods fall woefully short of convincing descriptions of the design activity, and it is now widely accepted that design methods cannot be constructed to form compatible counterparts to scientific method (Cross, 1984). This situation indicates that, in comparison to scientific knowledge, design knowledge is more difficult to access and the structure and its form are perhaps different.

3.3 Design and design methods

3.3.1 Design

Current definitions of design remain less than clear, but some characteristics of the design activity can be identified. The range of activities now covered by the term *design* has expanded and diversified to such an extent that doubts can be raised to whether any agreement between differing viewpoints can be achieved. That is, design means something different to each designer and we are all 'designers.' For example, Landsdown (1988) argues that "There is little agreement either among practitioners or academics on the exact processes and procedures that have to be gone through when we design."

It is clear that designers are able to produce designs and hence 'design,' but they appear unable to state, directly, what this is. Lawson (1980, p6) argues that design is multi-faceted, complex and involves elaborate thought processes, and further argues that design "involves a highly organised mental process capable of manipulating many kinds of information, blending them all into a coherent set of ideas and finally generating some realisation of those ideas." Hence, Lawson (1980, p3) asserts that there is never likely to be a satisfactory definition for design although much can be learnt about the design activity in the search, and argues that "perhaps design must be learnt rather than taught. We each have to acquire our own processes, for it is we, not others, who must design with it."

The solution-focused nature of design, in contrast to the problem-focused nature of science has also been identified by Lawson (1972, 1979a). The solution oriented approach results in tangible products initially conceived as being required. This key point is elaborated below (section 3.3.3).

The building metaphor is commonly attributed to the design process and de Bono (1981) briefly describes design as "the assembly of different elements to achieve some purpose." Thus, the aim of design activity can be thought of as the satisfying of some initially conceived need. However, the nature of the desired product or, in fact, the initially conceived objective, can dynamically change throughout the design process. Since the design task involves a form of directed information gathering where the designer learns about the problem, another common metaphor for design has been that of likening it to a research activity. Jerrard (1986) identifies that definitions of the design activity commonly incorporate descriptions of an enhancement or development process, but the process of improvement differs from research per se, and Jerrard (1986) argues that "Designing appears to be the consequence of research or associative analysis; it must not be confused with research as research does not itself include the act of making."

In summary, the design process appears to constitute the development of a product, but the type and form of design products may vary considerably. The process of design is so complex that it is unlikely that a concise definition will emerge.

3.3.2 Design methods

Common features of the design activity can, perhaps, be identified. It is the structuring, representation and communication of these features that forms the basis of design methods.

From a psychological standpoint, Thomas and Carroll (1979) take an initial view that design is a class of problem that is 'ill-defined' (Reitman,1964;1965, Simon,1973;1981). However, Thomas and Carroll (1979) argue that this definition is in fact inadequate, and design is better described as a problem-solving activity that is somehow ill-defined in the goal specifications, the initial conditions, or the allowable transformations. Through an assessment of studies drawn from diverse domains of design, and utilising different testing methods, Thomas and Carroll (1979) argue that there are common features of the design process, irrespective of domain, and it is concluded that the specification of goals is an important aspect of design, but the activity greatly depends on individual interpretation. Further, it is argued that although design problems appear to be structured into sub-problems, the sub-problems themselves can not be specified initially, and they are dynamically produced through the design process.

It is highly probable that designers use mental processes that are not directly open to introspection and too careful thought about the precise nature of the design activity during design hinders the natural flow of consciousness, causing an unwelcome shift in cognition, adversely affecting the design process. Psychologists suggest that verbal reporting provides questionable information of mental activity (section 4.5). Design processes may be automatic and involving high levels of skill, or just not verbalisable and are typically attributed to right hemispheric brain function (chapter two). Therefore, the value of design models based on introspection are suspect.

Protocol Analysis has been used in studies of design (Eastman, 1970; Akin, 1979). Interpreting the data is difficult but some useful information emerges from these studies, for example, Akin (1979) concludes that the Analysis-Synthesis- Evaluation cycle, promoted by design theorists (Figure 5, discussed below), is not evident as distinct stages of the design process.

3.3.3 Some examples of Design methods

Design methods (or methodologies) attempt to aid the design activity by facilitating greater systematisation to an otherwise intuitive, ad hoc, and little understood process. Clearly the main accomplishment of such methods is in their ability to teach some of the more basic concepts to student designers, rather than forming useful models of the design process per se. Jones (1970) compiles the various design methods into a single text book and Cross (1984) comprehensively traces the history of design methodology.

The early attempts to formalise design methods, in the sixties, concentrated on defining a systematic method of design. Christopher-Jones (1963) claimed that systematic methods reduce the amount of error and wasted time in the design activity by reducing the need to redesign. He further claimed that more imaginative and advanced designs are possible by making more effective use of the designers' time. Thus, the simple three-stage model of Analysis-Synthesis-Evaluation (Figure 5) was proposed, and each classification developed to yield a multi-stage methodology.

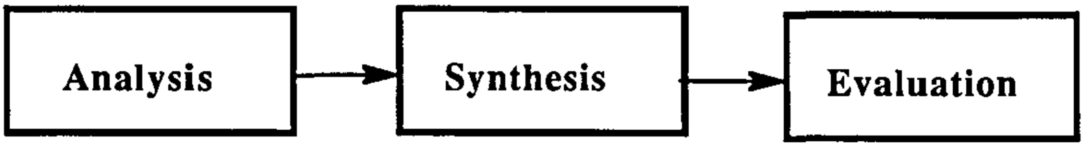

Figure 5: Simple Analysis-Synthesis-Evaluation cycle.

The Analysis stage is an ordering procedure by which the available information is classified, the objectives formulated, and relationships in the data explored. Synthesis is a process by which solutions are generated. In the Evaluation stage, suggested solutions are criticised against the objectives that are first identified in the Analysis stage.

However, it is apparent that most design problems are not readily amenable to systemisation, neither in simplistic nor complex terms (Lawson, 1980). Also, the choice of words describing the activity, *systematic* and *method*, deters designers since the notion of a rigid, inflexible, step-wise formalism is suggested, that has everything to do with logic and automation, and little to do with the usual connotations of design (and creativity). In actual fact, the method proposed by Christopher-Jones facilitates both the creative and the analytical phases of design, and impulsive and divergent thoughts (section 3.4.1) are encouraged by requiring the designer to make a note of ideas, no matter how strange, conceived during creative (divergent or impulsive) thought. The above method also advocates a suspension of judgment on creative ideas, until a later stage of the design process.

The systematic method of Christopher-Jones recognises and separates two different ways of thinking. Further, these ways of thinking are pertinent to identified phases of the design activity. Thus, the method attempts to help the designer resolve conflict between the logical, step-wise and analytical (serialistic) nature of certain aspects of the design task with the more creative nature of other activities. This is accomplished by externalising (writing down) all information and thoughts, hence, freeing the mind to concentrate on the current design phase, removing the need to remember issues pertinent to other design stages, and thereby reduce interference. Thus, Christopher-Jones suggests that it is more productive for the designer to be devoted to either one style of thought or the other, and it is less productive to be in-between. Stated simply, the systematic design method prevents the (early) appraisal of design solutions until the creative, generative stages have proposed alternatives and Christopher-Jones summarises his methodology stating that "Systematic design is primarily a means of keeping logic and imagination separate by external rather than internal means."

People have preferences of style (section 3.4.1) and forcing the designer, by method, to consider all styles will yield better results because all modes are required, at different stages of the design activity. The above method encourages an ordering to the application of the different modes or styles, but it is interesting to note that it is based on traditional observations of design, rather than experimental observation methods (discussed in section 3.4.1).

The systematic method for designers described by Archer (1963) makes use of feed-back loops that require successive, creative leaps to move the process on to subsequent design phases. Archer (1963) notes that perfect information is rarely available and designers use their experience of previous designs to make decisions, and provide additional information when incomplete. However, most systematic methods require a predetermined starting point for their organisation (for an organisational strategy is what they are) to contain preexisting solution components. Alexander (1963; 1964) argues that design methods should start from scratch and, hence, proposes a more elaborate method that starts with the earliest stages of the design activity. For example, a list of requirements is drawn up, from an observation of the context of the problem.

The Analysis-Synthesis-Evaluation model (Figure 5) is adapted to the Generator-Conjecture-Analysis by Hillier et al (1972), and refined in terms of the *Primary Generator* by Darke (1979). Darke argues that design is a process of reducing a large number of possible solutions by external constraints imposed by the particular design task, and the internal constraints imposed by the designers' own thought processes. A simple mechanism or piece of information can be used to initially reduce the huge number of possible solutions. Thus, the design rapidly develops through a tight, nearly inseparable analysis and synthesis process that is recursively applied to the problem (Figure 6).

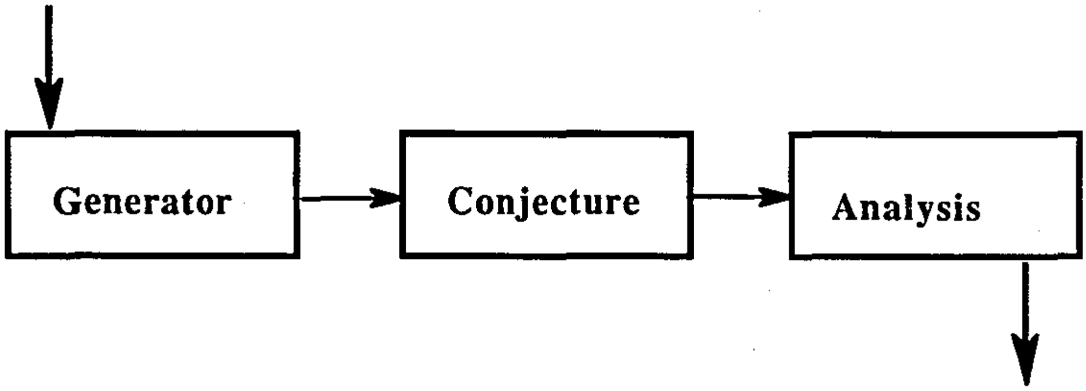

Figure 6: Darke's partial map of the design process (Lawson, 1980).

Often design activity proceeds through cyclic, rather than step-wise processes, the evaluation of the results of each cycle generating further information not previously available in the analysis stages (initial or subsequent).

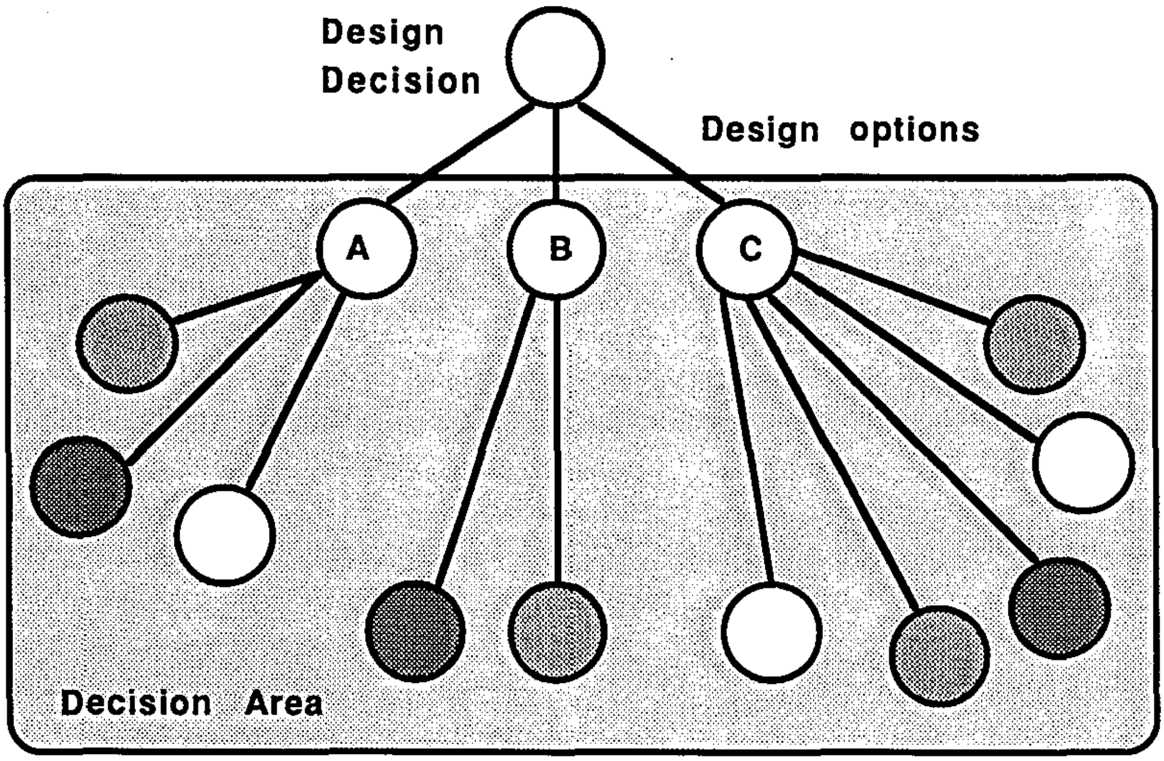

Figure 7 : A, B and C represent co-occurring decision paths. Branches indicate alternative choices and nodes of similar shade indicate compatible alternatives within the decision area. Thus decisions are based on all information in the decision area and not just on a single decision path taken in isolation.

Luckman (1967) views the basic three stage model of Analysis, Synthesis and Evaluation not as a linear process, but as a cycling recurrence through different levels of the problem area proceeding from the more general to the more detailed. Luckman also argues that the combination of interdependent sub-solutions is unlikely to give the desired overall optimum solution (Figure 7). At any level of problem detail, solutions to sub-problems are interrelated, therefore, the AIDA method allows the designer to define a 'Decision Area' that enables the simultaneous choice of acceptable sub-solutions that are compatible, opposed to making sequential decisions that lead to incompatibility amongst sub-solutions. This appears to be a holistic design methodology since all decisions within the determined boundary are viewed and the complex interrelationships explored, to some extent. The extent depends on the depth of the decision area that is used.

Lawson (1980) argues that even early stages of the design processes are subject to feed-back loops, and feed-back loops are necessary in even the most basic description of design activity (Figure 8). Hence, maps of the design process are of little use to the designer because they say nothing of the route to be taken through the sequence of design activity. For example, Lawson (1980) argues "So we are inevitably led to the conclusion that our map should actually show a return loop from each function to all preceding functions ... Knowing that design consists of analysis, synthesis and evaluation linked in an iterative cycle will no more enable you to design than knowing the movements of breaststroke will prevent you from sinking in the swimming pool."

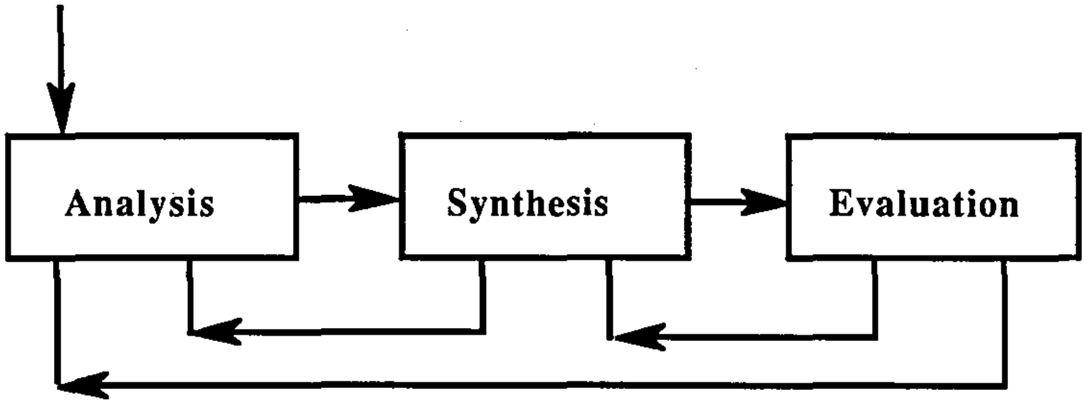

Figure 8: Feedback loops are necessary at every stage.

Lawson (1980) further argues that design methods and maps are merely the product of thinking about the design process, rather than from experimental observation, which inevitably results in logical and systematic procedures.

In a study of final year undergraduate students, Lawson (1972, 1979a) established, experimentally, that science and design students adopt different problem-solving strategies. (Architectural) Design students use a solution-focused approach. They generate a solution to the hidden problem, first, and then attempt to define the problem. However, their scientific counterparts use a problem-focused approach. The scientists define and understand the problem first, and then propose solutions. Although the overall performance of the groups is roughly equal, the two distinct strategies are clear. Further, when the same test is applied to first year students, no clear problem solving strategy emerges from either group of designers or scientists, and the overall performance is much less successful.

Therefore, the two very different problem-focused and solution-focused approaches are acquired through study and practise. However, Lawson argues that the methodologies and maps (described above) more closely resemble the scientists approach; first look at the problem (analysis), then attempt to propose solutions (synthesis). Whereas designers, in actual fact, prefer to integrate the synthesis and analysis stages. The above argument is reinforced by Eastman (1970) who experimentally observed bathroom designers, and Akin (1979) who studied the design of garages. The protocol recordings reveal that there is no clear distinction between the analysis and synthesis stages, but simultaneous problem formulation and solution generation.

Bijl (1985) compares and contrasts the differences between design and problem solving activity and observes that design parts are not readily decomposed, and that there is a 'wholeness' in design. Bijl argues that problem solving activity is adopted for Computer Aided Design systems, rather than design activity, due to the internal function of problem solving systems "What we see is the selective decomposition of ill-defined design practices into well-defined sub-tasks that are amenable to a problem solving approach. So we get programs that perform analytic functions...in most cases, these systems contribute nothing to our understanding of design synthesis, where synthesis has to reconcile disparate interests in a design object."

Carroll and Rosson (1985) recognise four important characteristics of design:- *Design is a process;* it is not a state and cannot be adequately represented statically. *The design process is nonhierarchical;* it is neither strictly bottom-up nor strictly top-down. *The process is radically transformational;* it involves the development of partial and interim solutions that may ultimately play no role in the final design. *Design intrinsically involves the discovery of new goals.*

Two important conclusions emerge from the above discussions. Firstly, differences between scientists and designers have been experimentally observed that must be acknowledged by students of design. Hierarchical decomposition and bottom up construction strategies for design elicitation (section 4.8) are reductionist, scientific approaches that are less appropriate to design. The inadequacies of design methods, as the counterpart to scientific methods (extensively criticised above), is perhaps a failure of the design methodologists to recognise that design is different.

Secondly, studies of design require the activity to be observed (through protocol analysis, for example) or experimentally studied. Introspective accounts of design do not appear to be very useful. In contrast, scientific problem solving methods, models and procedures, can perhaps be documented with greater success. For example, one can introspectively consider accountancy in order to identify sequential procedures and methods, map the process, and draw upon authoritative books, rules, and guidelines. It has been observed (eg Landsdown, 1988; Lawson, 1980) that design literature does not adequately describe the design process.

3.4 Design and Cognition

3.4.1 Design, learning and styles of cognition

The design process has often been described as a learning activity where the designer explores the problem area, gathers data, and proposes tentative solutions in order to learn about the problem. After completing the design, the designer is assumed to have more experience and to have learned something new during the process. Thus, Jerrard (1986) speculates that design is a 'living' activity because it is non-static and has direction, movement and motivation.

Considerable effort is afforded to Education and Learning research, and valuable experimental data is obtained through scientific methods, that are rarely applied to design. Hence, Cross and Nathenson (1980) explore the possible impact that Learning Theory may have on Design Theory, specifically relating 'Cognitive Styles' to the context of design practice and design education.

Cross and Nathenson (1980) discuss four dichotomies of cognitive style emerging from educational psychology. However, although such distinctions are identifiable and meaningful, it is important to recognise that individuals will *tend towards* a particular style, and rarely can classification be made at either end of the spectrum. The four dichotomies of Cognitive style are :

1 Divergent / Convergent
2 Impulsive / Reflective
3 Field-independent / Field-dependent
4 Holistic / Serialistic

3.4.1.1 Divergent/Convergent

Divergent thinking involves the postulation of many possible alternatives and convergent thinking will attempt to focus on a single 'correct' solution. While both styles are usually present in everybody, there is usually a preference towards a particular style. For example, Hudson (1966) classifies art students more divergent and science students more convergent. In education research, experiments involve the matching and mismatching of teacher and students learning styles. The performance of the mismatched students is considerably worse than the cases where the teachers and student styles are matched.

Cross and Nathenson argue that design requires both divergent and convergent thought, for example, the method of Christopher-Jones (1963), promotes both dichotomies, where an initial divergence of thought will generate a large number of possible solutions, subsequently evaluated to converge on a smaller number, leading to a single solution. Researchers devising tests for divergent thinking, Guildford (1967) and Torrence (1962), claim that the tests are also a measure of 'Creativity,' but Meeker (1969) argues that divergency has been adopted as a measure for creativity only in the absence of any other reliable method. Although the link between creativity and divergency is pronounced, Meeker argues that divergency is a necessary, but not sufficient condition, since divergent thought can exist without creativity, but creative thought requires divergency.

The design process is not uniquely convergent, since rarely will a single, correct result be produced. More often design activity involves the assimilation of a number of satisfactory solutions, sub-solutions or design alternatives, of which, one or more may be chosen in the light of additional information, personal style or even the arbitrary decision. However, convergent thinking is often necessary at the earlier stages of problem definition, focusing on the information relevant to the particular task.

Design methods also tend to promote either one or the other of the styles, presumably reflecting the preferred style of the designer of the method, and Jones (1966) appears to classify design methods in this way.

3.4.1.2 Impulsive/Reflective

In a study of learning abilities, Kagan (1965, 1966) establishes that children either instantly report the first answer that comes to mind (impulsive) or deliberate for a little time before responding (reflective). Reflective children take longer, consider the merits of alternative answers, are aware of making mistakes and the answers are often correct. The speed of response is the most important issue for impulsive children, who are less concerned about giving the wrong answer.

In the study of six-year old children, Kagan et al (1966) report a significant relationship between reflectivity and inferential skills. Also, Kagan (1965) reports that the children classified as reflective at the age of six are better readers at the age of seven, even when individual differences in intelligence are taken into account (through an intelligence test).

Although on first appearances, impulsive thought appears an unattractive style of cognition, Cross and Nathenson (1980) argue that it is useful in design. The impulsive style of thought enables designers to generate a large number of possible design solutions (as divergent thinking) without stopping to consider the merits of the ideas, as to do so may stem their flow. Thus, reflection may hamper the ability of designers to propose completely different solutions to a design problem or develop novel ideas.

However, singularly impulsive thought is of little benefit to the designer since it is also necessary to focus ideas to produce a solution. Perhaps a successful design strategy is to generate many possible solutions, impulsively, in the early stages of design, and then reflectively analyse the merits of those proposed. The 'tentative solution' approach is commonly adopted by designers and provides a successful design strategy that clearly utilises the methodology of being initially impulsive and subsequently reflective.

The usefulness of impulsive thought, in design, is contrasted to the dominance of reflective thought in science, where decisions are well considered and precise, and impulsive thought is perhaps considered less than scientific. This is not suggesting that scientists do not use impulsive thought, but that scientists are perhaps unlikely to acknowledge that illogical, undefined and unstructured methods of thinking can be successful in science. However, it is worth noting that 'brainstorming' is a respected scientific strategy, perhaps because it has carefully defined rules of method and procedure, persuading scientists that it is scientifically based. In actual fact, brainstorming is in essence the design method postulated by Christopher-Jones (1963), discussed above.

3.4.1.3 Field-Dependent/Field-Independent

Witkin (1969) reports that the field-dependent style of perception is significantly influenced by the surrounding context of the object(s). The field-independent style allows the consideration of (individual) objects in a way that is less constrained by the particular context.

Witkin reports that people tend to be either field-dependent or field-independent. Field-dependent people are inclined to view the overall structure of the field, objects are perceived as organised and non-discrete, hence unsegmented in terms of figure and background. Field-independent people (classified as analytical by Witkin) discretely discriminate individual objects in the field.

Designers appear to utilise both field-dependent and field-independent styles of cognition and switch between the two. The study of page-layout design, discussed later, provides many examples, for instance, the consideration of individual elements like *Headlines, Pictures, Body text, blocks of White space* etc appear field-independent objects while the consideration of the 'whole' page, the overall tonal colour (darkness), and aesthetic unpleasantness are perhaps field-dependent.

3.4.1.4 Serialistic/Holistic

Two very different learning strategies, the serialistic and holistic, are established through a number of experiments by Pask and Scott (1971, 1972).

Serialists proceed by small steps and attempt to establish each point before moving to the next, without digression. They learn and remember string-like structures that are initially linked by low-level relations. The recall and teaching abilities of serialists directly reflects the particular mechanisms and order in which the information is originally acquired.

Holists approach tasks (and learning) in a less logical fashion, grasping and remembering information from various places in an apparently ad hoc way, perceive broadly, and view problems from various perspectives. High order relations are (initially) used by holists to remember whole structures. Explanations may take many forms, reflecting the multiplicity of the holist learning style, and teaching often differs in method, and order, in which concepts are initially learnt.

Cross and Nathenson (1980) speculate that, in retrospect, the methodology described by Archer (1965) explicates a serialist's perspective of design, through incremental decision making, and Jones (1970) postulates holist theories, where an exploratory viewpoint, back-tracking, and change of search paths is recommended. Hence, it is perhaps unreasonable for designers to be comfortable with both styles of design methodology, and the style that reflects the individual's own preference is likely to be most productive.

3.4.1.5 The use of identifying styles of cognition

Cross and Nathenson (1980) argue that design education should not be unduly constrained by particular (cognitive) styles of teachers. That is, a student may not be a poor learner or a difficult student, it may be a clash of learning styles between the pupil and teacher. Thus, the teacher should be aware of his own preferences, and present material in diverse ways, perhaps against preferences, to enable all the students to learn. For example, teachers are recommended by Anita Cross (1984) to devise activities to develop students' abilities across all perspectives of thinking styles, and to develop spatial as well as the traditional literacy and numeracy skills. The important implication for this discussion, is the that the design activity requires a diversity of cognitive styles, at different stages of the design process.

Smyth (1988) summarises the shifting of cognitive styles as the design progresses, through stages in the design activity (Figure 9). For example, the designer is initially in an impulsive and divergent style. Through successive iterations of the design cycle, he will move towards the reflective and convergent styles.

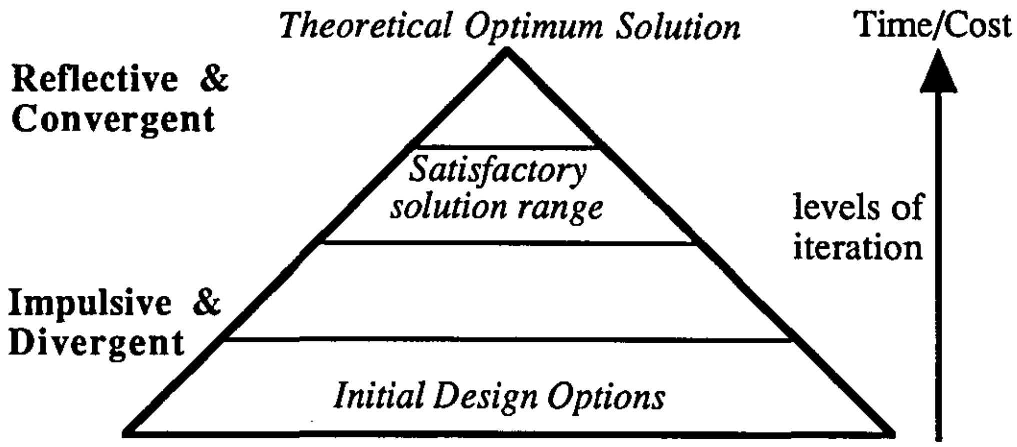

Figure 9 : Changing Cognitive Styles throughout the design process (Smyth, 1988).

In summary, different styles of cognition have been experimentally observed. It has been argued that designers adopt many different styles of thought as the design process progresses. Further, it appears that some modes (eg impulsiveness) are less dominant in science-based problem solving, in contrast to design, where it is desirable to adopt the full range of cognitive styles, and suggests that traditional methods of knowledge elicitation need to be reviewed in order to examine whether they impose restrictions on the type of information being acquired. In particular, important styles of design cognition, such as divergency, impulsiveness, holism, field independency need to be addressed in design elicitation. This point is discussed further in the summary (3.5).

3.4.2 Psychology of design and Brain Research

The link between the psychology of cognitive styles, described above, and the work on Brain Research is pronounced. A number of authors discuss the evidence drawn from the field of neuroscience (covered in chapter two) and the following section presents a review of the link between Design, Psychology and Brain Research.

Anita Cross (1984), reviews the link between neuroscience and the modes of thought associated with brain lateralisation, suggesting that the education process, as a whole, has consistently undervalued the needs and abilities characteristic of appositional modes of thought (Bogen, 1969). Hence, as previously discussed, for design education to progress, it is recommended that spatial thinking should be respected as a curriculum activity, and introduced at a much earlier stage in our education.

Ward (1984) explores the link between perception and the creative construction of models, and argues that designers develop methods that enable more effective use of the right brain process, particularly for creative aspects relying on contributions from both hemispheres and utilising different methods of representation. Further, Ward argues that design in general, and creative design in particular, deteriorates when information is presented in a form greatly different to the form of representation easily accessed by the right brain. It is argued here that the transference of design information is clearly an important issue for both knowledge elicitation and for the Man-Machine Interface. To avoid distortion, care must be taken to ensure that designers communicate naturally. This point is discussed further in the summary.

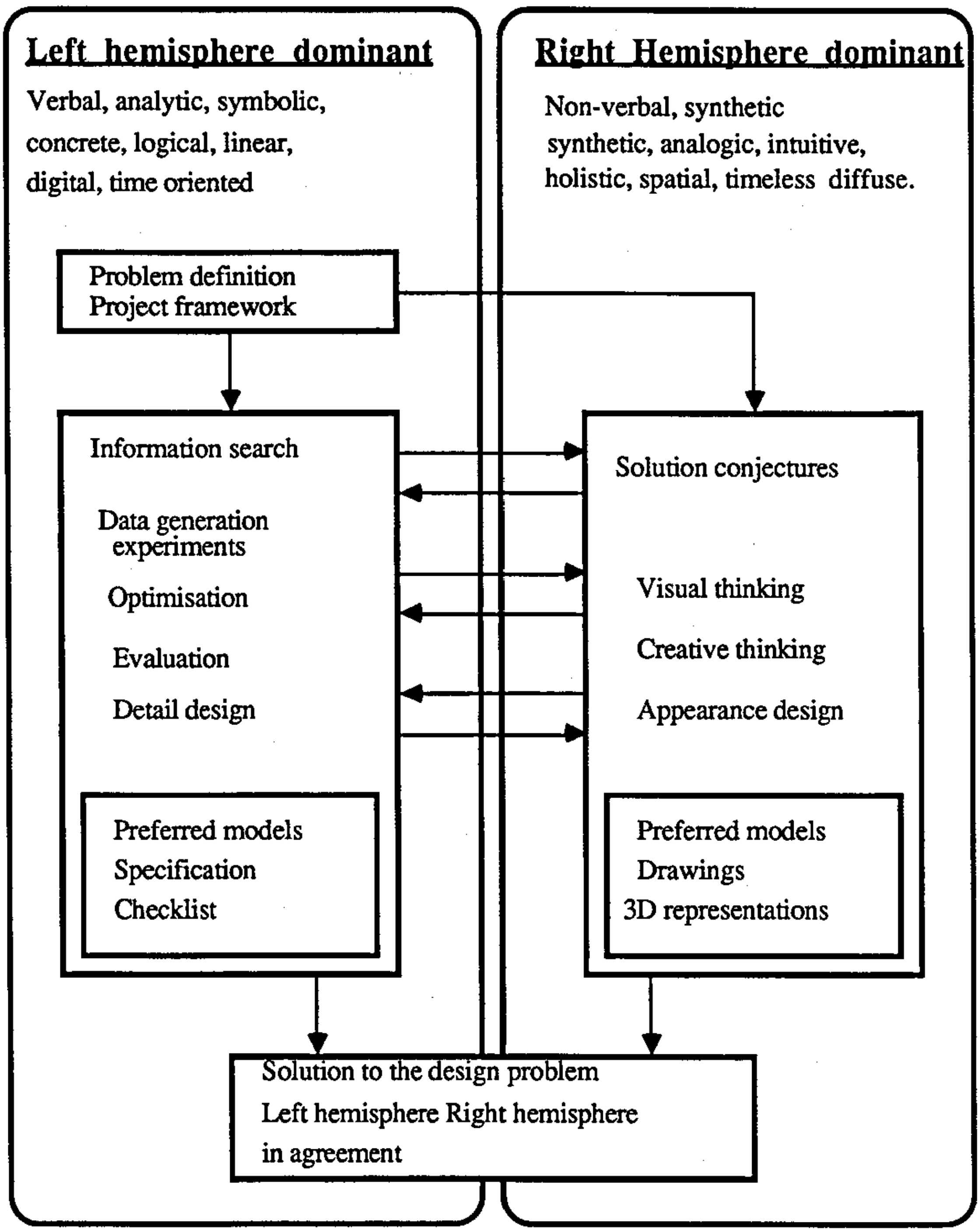

Figure 10 : The dual processing model (Tovey, 1984).

Tovey (1984) describes a method of design called the dual processing model, linking the observed differences of cognitive styles with the experimental evidence of the duality of the human brain (Figure 10). Hence, the cognitive styles associated with the left hemisphere are convergent, reflective, analytic and field independent. Those of the right hemisphere are divergent, impulsive, holistic and field dependent. Tovey (1984) argues that "There appear to be distinct differences between the two hemispheres of the human brain in terms of preferred styles of thinking. In designing, it seems necessary that both styles are engaged, with the designer switching from one to the other as appropriate."

Therefore, Tovey (1984) argues that certain aspects of the design activity can, perhaps, be associated with the dominance of the hemisphere best suited to that process. He argues that design is far too complex an issue to be simply attributed to a mode of thought, or assigned to a single hemisphere, it must involve many processing skills across both hemispheres, in a way that is still not properly understood. However, Tovey argues that the right hemisphere's mode of thinking is particularly important in areas such as creative exploration (by divergency or impulsiveness), visual thinking (Mc Kim, 1980), and of significance here, drawing. The left hemisphere is, perhaps, suited for the acquisition, comprehension, organisation and planning of information.

Edwards (1979) claims that the artistic skills innately present in everyone can be greatly enhanced by enabling the right hemisphere, and associated modes of thought, to become more dominant. Thus, for example, when drawing a face, the left-mode thinking would produce a stereo-typical token of a face that would centre on providing as much information as possible; two eyes, nose, mouth, two ears, hair etc, irrespective of what is actually seen. However, in reality, only a single eye or ear are usually seen, and the nose is rarely in the centre of the face. It is argued that methods can be adopted to enable artists to draw what is actually perceived, and not what is known.

Thus, Edwards describes 'tricks' to help prospective artists to disable the verbal analytical nature of the left hemisphere and to allow the right hemisphere to apply its specialistic processing abilities, that are suited to the drawing activity. The methods typically involve preventing the left hemisphere from directly recognising the objects to be drawn. For example, in copying from a picture, the picture is placed upside-down, or sketching the background (negative) image rather than the foreground. Hence, Edwards (1987) argues that "... developing a new way of seeing by tapping the special functions of the right hemisphere of your brain can help you learn to draw, and the sequences of exercises is designed to do just that ... the two cognitive modes and the related principles presented in this book have empirically been proven to be successful with students at all levels."

The results of the tutorial described above are impressive, and the techniques are worth trying. The case histories documented by Edwards (1979) demonstrate the rapid transition of students from child-like to competent artists, and are potent illustrations of the usefulness of postulating methods based on theories of cognition, irrespective of the actual validity of the given explanation.

A study of twenty-two interactive computer systems designers by Rosson et al (1987) reports that two significant strategies occur, and that categories of procedure used by the designers are clearly definable. In the study, roughly half of the experts developed an iterative process (as described by Darke) whilst the other half adopted the phased approach of systematic incremental design (Christopher-Jones). When asked about the origin of their creative ideas, the designers (obviously) could not articulate on the formation of an idea, or even the distinction between the initial emergence and development of the idea. However, Rosson et al (1987) report that overall, the result "fits well within the traditional psychological literature on problem solving and creative thought."

3.5 Summary

The above discussion indicates that design practitioners and design researchers consider design to be a problem that they cannot, as yet, define. However, some agreement exists on the notion that as a result of design activity, a product initially conceived as being wanted or needed is produced.

In review of design methods, Archer (1979) concludes that "It is widely accepted, I think, that design is ill-defined. An ill-defined problem is one in which the requirements, as given, do not contain sufficient information to enable the designer to arrive at a means of meeting those requirements simply by transforming, optimizing, or superimposing the given information alone ... 'the problem' in a design problem is not the statement of requirements. Nor is 'the solution' the means ultimately arrived at to meet those requirements. 'The problem' is the obscurity about the requirements, the practicability of envisageable provisions and/or misfit between the requirements of provisions." The failure of design theorists to define design, in scientific terms, and the unspecifiable nature of design goals (Thomas and Carroll, 1979) are important features that need consideration for design elicitation.

Landsdown (1988) reviews evidence that suggests that designers consistently ignore, or fail to apply, established design techniques, and argues that "There is considerable evidence to support the observation that many designs are executed without necessary and relevant information being taken into account (See for instance Whyte, 1975; Scott, 1976; Bignell, Peters and Pym, 1977; Allen 1984; Bignell and Fortune, 1984). Indeed, it is clear that most design failures arise not because designers are working to the boundaries of current knowledge in their particular disciplines. They generally arise because designers have not employed well-understood and often well-documented principles, procedures and practices. They have simply not made use of existing results (BRS, 1978)." Of particular concern are the areas where safety is paramount (Nader, 1965; McConnell, 1987; Stewart, 1988) and where the financial impact of failure in high-cost applications is substantial. Three important points emerge.

Firstly, the need for computer tools to aid the design process is highlighted, and in theory, the above failures are to a great extent avoidable. Therefore, it appears that designers require relevant design information, when engaged in the design process, and the development of IKBS systems in design applications is important. It follows that acquiring design knowledge becomes a primary concern.

Secondly, the design failures in disciplines of automobile (Nader, 1965), aerospace (McConnell, 1987; Stewart, 1988) and architecture (Mills, 1988) are domains where advances in computerisation are considerable. Perhaps there is a failure to make use of available technology, or perhaps the computer systems are themselves inadequate.

Thirdly, the true complexity of design is indicated by the fact that designers themselves fail to make use of design practices and procedures, and it is unlikely that such failures would be tolerated in scientific problem areas, once again suggesting that design and scientific problem solving differ.

There is little doubt that design strategy is subtly different to scientific strategy. Lawson (1979a) recognised, through experimentation, that student scientists learn problem-focused strategies whereas design students learn solution-focused strategies. Darke (1979) argues that a large number of possible solutions to a design problem can be extensively pruned by a small piece of information, a personal preference, or an arbitrary decision. For example, in Architectural design, a designer may choose a particular building material simply because of knowledge of the surrounding area, choosing a stone that will compliment existing buildings. The same designer may again choose the same building material for a subsequent design, in a completely different area, simply because the first design was successful, perhaps the material itself allowed design flexibility, perhaps it was cheap, perhaps possessing properties of construction. However, the choice may have been made on the basis of a personal like, the appearance, colour, or texture of the stone may have pleased or interested the designer. Alternatively, the choice of building material may have been completely arbitrary. In contrast, arbitrary or idiosyncratic decisions seldom have significant implications for the solution of scientific problems, for this would be characteristically 'unscientific.'

In design, the designer contributes additional information not explicit in the design objectives (Archer, 1979) and such information may have dramatic effects on the eventual design solution. The additional information may take the form of, but is not limited to, personal preferences, style and knowledge of the real World. Thus, Bijl (1985) argues that "It is characteristic of design that both the process and the product are not subject to explicit and complete criteria. This view of design differs sharply from the more orthodox understanding of scientific and technological endeavours which rely predominantly on a process of analysis."

Design methodologies do not appear to contribute to the fundamental question *what is design* and researchers can only speculate on the processes involved. However, introspective models are based on considerable design practice and experience and can be useful teaching aids.

The design activity is, perhaps, better observed than introspected, and protocol analysis of task situations appears a useful method of learning about design activity (Eastman, 1970; Akin, 1979). So far, studies have attempted to identify, and generalise the process of design, and in this respect they are, perhaps, not particularly successful. However, when attempting knowledge elicitation in design, the focus of the study is on the identification and modelling of a particular domain of activity, and not on drawing general conclusions about the process of design for design research. For example, identifying the use of a particular strategy, in one specific domain of design, is of little or limited use to design research, but this is a successful result in terms of knowledge elicitation.

Recently, those interested in design research have realised that the work of neurologists may offer pertinent explanations to observations emerging from their own field. Thus, spatial skills and the 'creative' and holistic styles of thought appear to be centred in the right hemisphere whilst the linguistic, sequential and analytic (organisational) processes appear to be dominant in the left hemisphere. The process of design may be considered unusual because it thrives on the full contribution of a range of information, processes and styles (perhaps in contrast to the predominantly analytical nature of science, or creativity of fine art). The design methodologists (eg. Chrisopher-Jones, 1963; Archer, 1963) attempt to teach prospective designers to broaden their preferences and make use of the spectrum of thinking that is clearly needed for the design task, or encourage them, practically, through the provision of design methods.

Citing evidence from education, and other research literature, Cross and Nathenson (1980) argue that people show preferences towards identified styles of thought, and that these distinctions can form valuable contributions to cognitive-based accounts of design theory, and raise practical implications for design education. An expert will adopt personal preferences (of cognitive style) for both problem solving and for explanation (ie teaching). The two may be quite distinct and the information obtained when in problem solving may be completely different to instructional explanations. Also, the knowledge engineer has preferences that may not match the expert's. A parallel can be made with the process of Knowledge Elicitation, which can also be viewed as a learning task (Johnson and Johnson, 1987b), and this raises two important points.

Firstly, in knowledge elicitation, expert designers must not be forced into a cognitive style (or mode of thought) that is intrinsically and diametrically opposed to their preference, is unnatural to their usual process of design, or is inappropriate to the particular stage of design (ie early, late). Hence, design elicitation procedures should allow the expert to problem-solve in a natural way (ie. Protocol Analysis of design situations), be flexible (ie. the flexible personal interview), and incorporate various methods that cover a diversity of teaching/learning styles (ie. adopting a global approach to knowledge elicitation, with an emphasis on human-human communication in order to learn and develop a shared understanding).

Secondly, care should be taken to address the medium by which designers communicate. The value of drawing in design is well known, for example, Landsdown (1987) argues that "Drawing in all its various forms, from freehand sketching to detailed technical layout, is a type of modelling that designers find indispensable. In many cases, indeed, drawing is the only form of external modeling a designer uses. It has two basic functions: to assist in the *externalisation* and development of mental concepts and to help in the *presentation* of those concepts to others." Therefore, the use of diagrammatical methods appear an appropriate medium of communication with designers, and Li and Bourne (1989) argue that diagrammatical, qualitative networks are useful in the development of inspectible models of design.

Ward (1984) argues that designers adopt specialistic representations and procedures (that are characteristically right brain), to acquire and communicate spatial information. However, the form and nature of communication is likely to change throughout the various stages (eg Christopher-Jones, 1963) of the design process. For example, at the divergent stage, communication may be predominantly spatial, with many drawings and quick sketches, whereas in later, convergent stages, the communication may be more verbal and explanatory. Care must therefore be taken to cover all likely forms of design communication, both verbal, and spatial and drawing.

In summary, it is essential for design elicitation techniques to incorporate natural drawing tasks for design problems that involve visual and spatial information. Diagrammatical methods appear a potentially useful, natural and convenient medium of communication with designers.

4 Knowledge Elicitation for Knowledge Based Systems

4.1 Introduction

There are many approaches to Knowledge Elicitation. Some of the methods are complementary, whilst others propose a choice between alternative viewpoints. The multiplicity of philosophies and approaches, discussed below, provides background to the field of Knowledge Acquisition and forms the basis from which a likely method for knowledge elicitation in design applications is proposed.

4.1.1 Structure of the chapter

Following the introduction, general considerations and objectives of Knowledge Elicitation, that need to be taken into account irrespective of methodology, are discussed in section two.

Section three introduces background psychological issues and testing methods that form the basis of, or background to, elicitation techniques. In conjunction with section three, a number of important psychological theories concerning the likely extent and validity of verbal reports are also discussed in section five.

There appears a dichotomy of Knowledge Acquisition techniques. Computerised methods are discussed in section four, and the personal interview in section five. Section six reviews current research in methods of knowledge elicitation for design.

The chapter is concluded in sections seven to ten. A summary of the review, and the two approaches (personal interview and automatic) are discussed, with respect to design, in section seven. Section eight proposes an approach to design elicitation. Section nine summarises the practical implications of design elicitation, and the chapter is concluded by summarising the proposed method of elicitation for design in section ten. The method of design elicitation is illustrated through the study of page layout design, and section eleven introduces the page layout design task.

4.1.2 Knowledge, and Knowledge Elicitation

It has become widely accepted that the task of knowledge elicitation remains the major 'bottleneck' of Knowledge Based Systems development (Hayes-Roth et al 1983; Feigenbaum, 1984). However, some authors argue (Gammack and Young, 1985) that the stumbling block centres on the weakness of encoding knowledge directly into predetermined computer formats (eg. rules).

It is widely accepted that the term *Knowledge Acquisition* covers all methodologies of information gathering, in the context of Knowledge Based Systems, including cases where no domain experts have been directly involved. For example, where computer programs infer information directly from a data-base of facts, or in studies where the knowledge engineer extracts knowledge from books. The term *Knowledge Elicitation* implies that experts are directly involved, in interviews, for example. This discussion centres on Knowledge Elicitation.

It has been argued that *knowing that* and *knowing how* are distinct (Ryle, 1949; Anderson, 1983) and that conscious introspection may be valid for the procurement of *knowing that* knowledge but the tacit form of *knowing how* knowledge may not easily be decomposed or consciously inspected (Collins et al, 1985), although an important aspect of skilled behaviour (Foder, 1968; Neves and Anderson, 1981). Kornell (1987) argues that two types of thought (narrative and formal) are of interest to knowledge engineers, where "Formal thinking has to do with constructing publicly scrutable chains of reasoning, using explicit premises and methods of combination. The power of formal thinking is in allowing us to be confident in the outcome of a chain of reasoning as we are in the premises. Narrative thinking has to do with implicit assumptions and plausible (or habitual) methods of combination." In a review of current elicitation tools, Kornell argues that there remains a lack of distinction between the two that "impairs our ability to model expert problem solving." Smythe (1988) contributes an excellent discussion on the distinction between propositional knowledge and skillful knowledge.

Landsdown (1988) suggests that published design information is inept, and such information fails to capture the essence of *what it is to design*. Therefore, approaching design from the perspective of knowledge elicitation, as the observation of designers whilst engaged in design activity, appears both a plausible, and useful endeavour in the attempt to acquire an understanding of design, as opposed to the propositional introspections of design theorists.

The terms *deep* and *shallow* knowledge are widely used in KBS literature, but unfortunately there is little agreement on their definition (Basden, 1985). In general, the terms indicate the extent, or detail, of acquired information (Cohn, 1985). In this context, the five levels of expertise discussed by Dreyfus and Dreyfus (1986) are pertinent. Price and Lee (1988) identify a number of characteristics of deep knowledge. Hart (1982) argues that *deep* knowledge represents an attempt to model the cognitive structures of causality and intent, whereas shallow knowledge elicitation makes no such attempt. Cognitive modelling is argued (Clancey, 1985b; Johnson, 1985) to be important for *competence*.The terms *deep* and *shallow* are used in the following discussion to express a measure of belief in the quality, or competence of knowledge. Intuitively, *deep* knowledge elicitation results from the extensive involvement of experts and usually requires considerable time and effort. *Shallow* knowledge is easier to obtain and rather simple. The terms *high* and *low* refer to a scale ranging from basic perception to World knowledge (ie Marr, 1982; Schank, 1986). In this discussion, *low levels* refer to autonomous (building blocks) of visual recognition and perception, whilst *high levels* refer to more sophisticated (but not necessarily more complex) concepts such as strategy, motivation, reasoning and explanation. The term *global* knowledge indicates general or additional information that is supplied or inferred by the expert, but is not explicitly stated or known to be relevant before problem-solving, whilst *specific* knowledge is task dependent, such as detailed information or problem specifications that are given, easily calculated, or found in a book.

Johnson (1983) describes knowledge elicitation as paradoxical since the most valuable knowledge (ie deep knowledge) is the hardest to obtain, and the kind that the expert is least able to communicate. Newell (1982) argues that knowledge can never be adequately represented (as rules, frames, predicate logic etc), because it is an observed activity.

The question of *what is knowledge* remains a difficult area of debate and is not explored here, but Dreyfus and Dreyfus (1986) discuss the nature of expertise in some depth. The identification, classification and likely methods of acquiring different forms of knowledge (Bainbridge, 1986) is important, and discussed in section (4.5.2). However, as a broad introduction, Hart (1987b) refers to the human qualities of knowledge :

"There are many types of Knowledge. Knowledge is not simply a collection of facts and rules that are learned easily. An Expert augments documented facts and procedures with knowledge gleaned from years of experience in his particular field. He needs to practice to become skillful, using rules of thumb or heuristics, learning which rules work and when they work. He develops judgment, insight and informed opinions. It is the quality of this undocumented knowledge that determines his level of expertise. The way in which this process takes place is by no means fully understood, and so it is hardly surprising that the subsequent process of Knowledge Elicitation is very difficult."

Nancy Johnson (1987) identifies that the purpose of the Knowledge Engineer is to learn, and share, some of the expert's domain concepts: "Elicitation involves creating an environment where an expert, and others, can generate some kind of description of their activities which the knowledge engineer comments upon, analyses, and moulds into a body of knowledge. Thus knowledge elicitation is not the discovery of heaps of mature, internalised cognitive structures; nor is it the mapping of incompletely expressed concepts into the seductive precision of a formal system. It is closer to a learning or research activity where one, usually a knowledge engineer, comes to understand something of the concerns of the other (the expert)." The notion of 'acquiring an understanding' is important, and the terminology is adopted in the case study of page layout design, discussed in chapter three.

There are many methodologies and strategies that have been adopted to attempt to *externalise the thought processes* (obvious misnomer) of the expert. It is widely accepted that care must be taken when choosing particular methods for given domains so that the quality of resulting data is high for any given effort. However, it may not be adequate to isolate any single field of study when attempting to rationalise the complex issues of knowledge acquisition, and Brian Gaines (1987c, p3) supports the multi-disciplinary approach that has been adopted here, arguing that "Knowledge acquisition and transfer processes in human society are complex and poorly understood. Neurology, Psychology, Linguistics, Education, Sociology, Anthropology, Philosophy and Systems Theory all have significant contributions to make. However, integrating them, disambiguating jargon, and combining different objectives and perspectives are major problems."

4.2 General Considerations of Knowledge Elicitation

Expertise portrays the usual characteristics and qualities of people; it is idiosyncratic, unreliable, and often not amenable. Techniques based on sound psychological principles are advantageous (Shaw and Gaines, 1986; Gammack, 1987c), but caution must still be exercised (Kidd, 1987a; Cleaves, 1987; Burton et al, 1987). One approach is to identify likely types of Knowledge (or classes of knowledge), in order to provide context for the choice of elicitation methods and guidance to the elicitation and analysis process (eg. Bainbridge, 1986, section 4.5.2).

Woods (1986) recommends that for cooperative computer systems, it is necessary to identify areas of human weakness, and situations where humans are notoriously disadvantaged. Thus, computer systems should give help or advice where help is needed most. Repetitive and boring tasks can easily be performed by computers. Also, of relevance to knowledge elicitation, computer systems may help in cases where cognitive fixation may be problematic; where humans tend to stick with an idea or concept formulated after the presentation of only a small fragment of the whole data, ignoring, to a greater extent, subsequent information. Humans have a tendency to ignore counter evidence, even when substantial. Awareness of self preservation criteria are also recognised as important social factors of threat, such as loss of face, loss of money or job security. Computer systems should, in theory, be able to provide support for people in these cases too (Norman, 1986).

The other salient factors of designing cooperative systems are those of system modality. Kidd (1987a) argues that an understanding of system operation (automatic, advice, tutor etc.) is necessary from the outset; end-user functionality should be explicitly known before thoughts of implementation. The knowledge engineer should be aware of the types of information that the end-user will ask of the system (Kidd, 1985), and the type and format of the answers required. For example, a selection of solutions with a list of advantages or disadvantages of each may be appropriate, as an alternative to the dialogue message. In the context of design, a series of diagrams or visual stimulus may be more suitable.

Further, Kidd (1987a) argues that it may be possible to elicit these requirements at (in parallel with) the knowledge elicitation stage, asking the end-user (experts, in the case of an expert system) what they want from the computer system and discovering what sort of information is entered into, and subsequently generated from, the expert's domain. For cooperative systems, thoughts of modality are necessary to help drive the system to become a useful tool rather than an optional, unused academic exercise. Norman and Draper (1986) discuss user-oriented system requirements more fully.

To this end (modality), an appreciation of the knowledge elicitation task is required so the acquired data and the underlying expertise bears some relationship, to ensure that the specific domain knowledge of the expert is modelled. Modelling is an important issue and many researchers argue that the real purpose of knowledge elicitation is to build models (Bennett, 1985; Clancey, 1985b; Johnson, 1985; Kahn et al, 1985; Marcus et al 1985; Regoczei, 1987; Hayward et al, 1987; Morik, 1987; Steels, 1988; Brown and Chandrasekaran, 1989; Musen, 1989; Wielinga and Schreiber, 1989). For example, Musen (1989) argues that "The goal becomes to understand a system's behaviour in terms of an abstract model, rather than by means of a specific set of notations." This point is discussed in detail later.

4.3 Psychological Testing and Structure Elicitation methods

Elicitation techniques based on Psychology have general use and are widely applied and adapted in many elicitation methods. Commonly used psychological methods are briefly discussed below.

4.3.1 Personal Construct Theory and the Repertory Grid

Personal Construct theory (Kelly, 1955) centres on the natural ability people possess for the recognition and classification of similarities and differences, between elements, and to form explanations of the similarities and differences. The naming of *why* is the construct, a label for the distinctions. Personal Construct theory is essentially a predictive mechanism that people use to classify new data, in terms of templates. These predictions, in time, will be shown to be either true or untrue. Alterations to the system of constructs will occur in the presence of incorrect predictions.

It seems that people find making predictions both natural and easy, and often perform such judgments without conscious effort. Further, decisions are performed on many levels of conception, from rough grouping to fine detailing. Shaw and Gaines (1986, p154) recognise the importance of this philosophy and argue that "Kelly's Personal Construct Psychology is important because it develops a complete psychology of both the normal and abnormal, which has strong systemic foundations. In the long term these foundations may be more important to knowledge engineering than the techniques currently based on them."

4.3.1.1 An example of personal constructs

The two elements *pen* and *paintbrush* may be described in terms of similarity;

functionality (both are used to make marks on paper),
size (approximately six inches long),
shape (thin cylinders) etc.

Also, dissimilarities can be described;

ink (paintbrushes use paint, pens use ink),
tip (the paintbrush has soft floppy hair, and the pen has a roller),
functionality (paintbrushes are used for painting, and pens for writing)

Two perspectives exist for each construct, first viewing one item to describe the similarities and dissimilarities of the other, but also from the perspective of the second item to describe similarities or dissimilarities of the first. The two opposing views are termed *poles,* but they are not necessarily diametrically converse (this is more apparent in the Repertory Grid form, of triplets, discussed in section 4.3.2).

In the above example, the same construct *functionality* appears in both similar and dissimilar classification systems, and this may happen in practice. It is possible that there is some relationship between the two concepts (and the relationship needs further exploration), however, more realistically the label describes two separate and distinct concepts. Hence, two distinct labels are required to avoid confusion. Humans often make use of the same terminology to describe different concepts, and in practical situations monitoring is required to avoid such problems.

Another important feature is that of grain size, or delicacy. The case of a coarse identification is clear, for example, *the Pen is a writer's instrument, the Paintbrush is an artist's.* A more delicate distinction may be made to the fact that *the ink in a Pen is more viscous than the paint of a Paintbrush.* Yet also, if the subject is presented with two virtually identical Pens, and asked to describe differences, then this is also possible; *this Pen has a slight scratch on the barrel, this one has a globule of ink on the tip* etc. Humans are very good at picking out the even the smallest detail, especially in the absence of course distinctions.

Personal Construct Theory provides a means by which the ideas of one person can be communicated to another. The terms of the constructs, or explanations, that are used by one person are seldom the same as those used by another, however the constructs should convey enough information to allow for the reconstruction of the relationships, as a simple interpretation. It is not claimed that constructs represent the inner thought processes, but are merely a labelling mechanism, and a way of remembering how distinctions are made, for example, Shaw and Gaines (1986, p155) argue that "Thoughts and feelings, objective and subjective descriptions, attitudes and rules-of-thumb all constitute valid constructs. The verbal description of the construct and the labelling of the poles need not be a publicly agreed meaning in the outside world, but only a memory aide to the thinking process."

Further, since different people justify exactly the same concept in terms of different explanations (constructs), then there is a high degree of individualism, and hence the term *Personal* Construct. However, it is possible for more than one person to independently describe the same construct by using the same, or other names, that are directly intelligible. This has significant implications when used in the context of a group of experts or subjects (4.4.2).

4.3.2 The Repertory Grid

The Repertory grid is a systematic procedure of personal construct theory, to extract and represent constructs. The method is well defined and easily computerised, and is therefore the instrument of many automatic computer-based elicitation methods.

Quality Newspapers   *Gutter Press*
Observer ________ Sun
Times

Figure 11 : Simple triad

Quality Newspapers   *Gutter Press*
Observer ________ Sun
Times   Daily Mirror

Figure 12 : Elicitation and addition of another construct

Quality Newspapers   *Gutter Press*
Observer ________ Sun
Times |
Daily Mirror

Figure 13 : Additional elements placed on a scale, rather than just at the poles

Daily Newspapers   *Sunday Newspapers*
Times ________ Observer
Sun

Figure 14: Elicitation of another construct using original elements

In its most basic form, the *triad method* (Figure 11), three elements are (initially) involved rather than two. The subject is asked to say either which two are similar to elicit the *emergent pole,* or alternatively which one is dissimilar from the other two to elicit the *implicit pole,* and then name the construct (why). Another element in the group is selected and scaled to the identified poles (Figure 12). The process is repeated for all the remaining elements until each has a (relative) position on the scale. A more sophisticated system (Figure 13) allows for the rating of new items on a scale (usually discrete, say 1-5). The process may be repeated to elicit other constructs for the same, initial triad of elements (Figure 14). Another triad is selected, and the process is again repeated.

Thus a two-dimensional representation (Grid) of the relationship between the elements and the constructs is acquired. When completed, the interpretation of the data commences, often using cluster analysis. Hart (1989) gives a clear and simple explanation and Fransella and Banister (1977) discuss the topic in greater detail.

However, there is little control over the quality of the resulting constructs, which may, realistically, be meaningless to all but the originator. Shaw and Gaines (1986) have identified a number of points that need to be remembered if the Repertory Grid is to be successful for Knowledge Acquisition:

1 The simple negation of a term used to describe one pole of the construct will not necessarily give the same information as the direct description of the second pole. In the above example (Figure 14), the pole "Sunday Newspapers" is clearly more descriptive than the label "Non-Daily Newspapers." Thus, both poles need to be expressively elicited. New and novel constructs are often discovered during the elicitation process, and it would be inaccurate to classify these (alone) as the expert knowledge, so care must be taken to ensure that the traditional, well formulated constructs, are elicited.

2 Clarity; the underlying ideas and the construct names should be in a form directly intelligible, or communicable, to other experts. The concepts should also have a global applicability (logical relevance) to the whole set of elements being examined and not just to those that are currently under review (locally). (See *functionality* in example above).

3 The construct of the relationship of the elements to the subject differs to that of the construct of the relationship between elements. Both types of relationship should be elicited, as should all relevant constructs pertinent to the triad (eg. Figure 14). For example;

* Relationship of subject to elements (eg. editorial like/dislike)
    I like the style of the Observer and the Times,
    I dislike the style of the Sun.
* Relationship between elements (eg. size of pages)
    The Observer and the Times have large pages,
    The Sun has small pages.

A modification to the standard Repertory Grid technique, the Laddered Grid (Hinkle, 1965), allows for additional and more generalised constructs to be elicited. Firstly, constructs are identified as in the Repertory Grid and the poles labelled. Then one of the constructs is selected and new constructs are elicited by asking the subject which pole he wishes to explore further, why the particular pole was chosen, and what the alternative choice would have been.

The repertory grid technique has general implications and is used, for example, in the study of individual management decision making (Shaw, 1980), Education (Pope and Shaw,1981) and Clinical Psychology (Shepherd and Watson, 1982) as well as in the traditional Knowledge Acquisition arena (section 4.4.1).

4.3.3 Multidimensional Scaling (MDS)

The most common form of Multi-Dimensional Scaling (eg Gammack, 1987c) involves choosing one of the elements from a set of entities and then rating it in terms of the closeness, or relatedness, between the one chosen and all the other entities in the group. The measure of similarity, the 'spatial metaphor,' allows for the scaling of the matrix in a number of chosen dimensions in order to determine the global structure of the system. Whole systems can be produced when each element in the group is scaled against every other. However, this can be time consuming and is not recommended when a large group of elements are to be classified.

MDS is most useful when attempting to determine some basic grouping or class organisation that is believed to exist in a number of related elements, especially when there is little other evidence of structure. An expert may be reluctant to divide entities into conceptual groups that can be clearly recognised, but can not be easily described (at the time of elicitation). One advantage MDS has over the Repertory Grid is that the naming of classes (concepts) need not take place until after the task has been completed, therefore MDS is probably more useful in applications where immediate verbal classification may be detrimental or inappropriate, such as tasks requiring perceptual classification or visual groupings. This latter point is particularly relevant for design elicitation. Kruskal and Wish (1978) discuss suitable applications for MDS.

However, Multi-Dimensional Scaling is time consuming and hard on the subject, particularly when many dimensions are sought. The resulting data usually only prescribes the structure of the domain and not details, other procedures such as cluster analysis (Everritt, 1974) may be required for support, involving considerable statistical analysis to interpret the results (Burton et al, 1987), and the resulting information may be of little use anyway. Null (1980) discusses experimental design considerations, and an in depth discussion with worked examples is presented by Schiffman et al (1981).

4.3.4 Card Sorting

A large work area is randomly covered with a number of cards, each of which has written (displayed) one concept from the domain. A *view* is a completed sorting of the cards from a particular perspective, and many such perspectives may hold for the group of cards. Then, for any given view, the subject is required to break down the concepts into subgroups of their own choosing. The subgroups are named, and the procedure is repeated for all subgroups until no more divisions can be made with a minimum of two items.

Gammack (1987c) argues that interference may occur between successive sorts. Therefore, providing a break between tests can disrupt the short-term memory recall of previous viewpoints. Other procedural techniques can be interlaced with the card sort, for example, a free-recall test requiring the subject to name all the classifications, and a regrouping task that is recorded in a 'talk aloud' form. Card sorting is flexible, adaptable and is a relatively easy procedure for the experts to group meaningful items in their own way. Further, card sorting is suitable for structuring concepts such as pictures and sentences as well as for single words. Card sorting is most suitable when there are a large number of concepts to the given domain (in contrast to MDS), and can be focused to provide useful insights into smaller sub-domains, as well as yielding overall hierarchical domain structure.

In summary, the techniques of the Repertory Grid, based on personal construct theory, Multi-Dimensional Scaling and Card Sorting provide basic psychological testing methods that have been used and adapted for different forms of knowledge elicitation. Their psychological basis appears to be the main reason why such methods are fervently promoted, with a belief that they constitute scientific rigour. However, psychological testing is not a natural form of communication and experts may view the procedures as threatening, and treat their knowledge unsympathetically. Domains not suited to psychological techniques (card sorting, MDS) are those where concepts can not be decomposed into hierarchical structures. It is important to note that design elicitation is unlikely to be suited to hierarchical decomposition techniques (eg Bijl, 1985; Carroll and Rosson, 1987).

4.4 Computer based Knowledge Acquisition methods

Automatic knowledge acquisition tools are classified here into the four groups[1];

1 Psychologically based (repertory grid) tools,
2 Automatic elicitation tools not based upon the repertory grid,
3 Conceptual model-based tools, and
4 Inductive techniques.

4.4.1 Repertory Grid based elicitation tools

Repertory grid based knowledge acquisition tools provide software for elicitation, and an additional suite of software for the subsequent analysis of the information. Brian Gaines, Mildred Shaw and John Boose are the principal researchers in this field, and the general approach is illustrated in the following examples.

4.4.1.1 The PLANET system

Shaw and Gaines (1986) maintain that manual elicitation is tedious and time consuming, and that computerised tools can speed up the process of knowledge acquisition, and argue that a successful strategy is to provide experts with feedback, as helpful comments, through on-line elicitation and analysis techniques. For example, the 'Planet' system (Personal Learning, Analysis, Negotiation and Elicitation Techniques; Shaw, 1982) is central to a multiplicity of software that interactively elicits Personal Constructs in the form of Repertory Grids ('Pegasus').

Checkland (1981) argues that 'soft systems analysis' offers a useful metaphor for

[1] O'Connor et al (1988), in review of automated knowledge elicitation tools propose an alternative classification, in terms of the 'knowledge level' addressed by the tools.

knowledge engineering, and that KBS are typically ill-defined and their development should proceed through a step-wise hierarchy consisting of seven stages. Thus, for KBS development, the model is started at the very top level, but the model may start lower for well-defined tasks. For example, Systems Analysis may start as low as level four. Shaw and Gaines (1986, p159) adopt Checkland's approach in the 'Planet' system using the seven categories below:

"1) The problem situation - Unstructured.
2) The problem situation - Expressed.
3) Root definitions of Relevant Systems.
4) Making and testing Conceptual models.
5) Comparing Conceptual Models with reality.
6) Determining feasible, desirable changes.
7) Action to improve the problem situation."

Shaw and Gaines (1986) argue that the 'Planet' software suite can handle data from a single expert in the form of a single grid, pairs of grids, or whole systems of grids. A variation of the above system developed by Shaw and McKnight (1981) can elicit (many) sets of grids, from various viewpoints of the (single) expert. The expert can take on many roles, including his own, to give different perspectives of the domain in question.

Analysis packages, such as cluster analysis ('Ingrid' and 'Focus'), are also included, and comparative software measuring similarities ('Core') and differences ('Minus') between grids. The software can deliver production rules to be directly installed into an expert system shell.

Shaw and Gaines (1986) argue that complex problem solving tasks rarely rely on the skill of any individual expert, but it is usually a team of experts who constitute the most significant body of expertise. Therefore, it is necessary to develop knowledge elicitation techniques to acquire information from a substantial number of experts. Thus, a KBS can supply advice on the basis of a consensus opinion of expert opinion.

4.4.1.2 Integrating Expertise on a domain from Multiple Experts

Boose (1986b) develops the 'Planet' software to allow for many experts to contribute to the Knowledge Base development in the Expertise Transfer System (ETS).

ETS has the facility to interactively 'interview' human experts, analyse the generated data (as above), and build Knowledge Bases. Feedback is provided to help the expert clarify, and combine knowledge with stored knowledge from many experts. It is argued that, once the data has been elicited, it can then be tested or compared against other experts.

ETS allows decisions to be made from the choice of a single expert, or a selected subset of experts. Thus, a majority opinion can be sought. A sensible inclusion is to allows access to 'opinions' that disagree with the decision made on a majority basis.

Boose(1986b) argues that ETS allows the "Rapid Acquisition and Combination of Knowledge from Multiple Experts in the Same Domain." However, the system is acknowledged to be poor, or even ineffectual, at accessing deep causal knowledge and has severe limitations of applicability, for example, Shaw and Gaines (1986, p179) argue that "... the methodology is better suited for analysis rather than synthesis problems, for example, debugging, diagnosis, interpretation, and classification, rather than design and planning, and that it is difficult to apply deep causal knowledge or strategic knowledge."

Shaw and Gaines (1987b) argue that the 'Kitten' software package encompasses the above methodologies in a system allowing multiple perspectives of a single knowledge base, concentrating on techniques that are claimed to be successful, or have had a 'proven track record.' Again the system is based on Personal Construct Theory, and can directly generate production rules from the expert's interactions. Also the 'Aquinas' system of Boose and Bradshaw (1987a,b), is argued to be the development of the ETS system into a "Knowledge Workbench."

In summary, interactive tools based upon the repertory grid have been developed for knowledge elicitation. The researchers claim that they are successful in domains of diagnosis and classification, but are acknowledged to be severely limited for design and planning applications.

4.4.2 (Non Repertory Grid) Automatic Knowledge Elicitation tools

Marcus (1988a) has compiled a number of automatic elicitation tools that are not based on repertory grid techniques.

'Salt' (Marcus and McDermott, 1987) is one of few knowledge elicitation tools aimed at domains of constructive problem solving (Mitchell, (1985) and van de Brug (1986) also develop tools in this category). In particular, Salt is intended for domains of constraint-satisfaction and is claimed to be a useful tool for acquiring knowledge in domains of designing an artifact, or constructing a schedule, where a *propose-and-refine* problem solving strategy is adopted. Marcus (1988) argues that "our experience with human designers and schedulers is that they are fairly good at describing individual considerations for constructing a solution for their domain. They can extemporously list many of the constraints that the solution needs to satisfy. They can consult manuals of formulas and tables for producing values for individual design parameters." Hence, Salt follows a bottom-up, piecemeal strategy of knowledge elicitation. A critical discussion of the bottom-up approach follows later (sections 4.6.2 and 4.8)

The 'Mole' heuristic Expert System builder (Eshelman et al, 1987) makes assumptions on the type of data being entered. The assumptions are themselves heuristically based about the state of the world (ie. how experts are likely to express themselves and what sort of information is likely to be accessed). The 'Mole' system is designed to acquire knowledge for heuristic classification expert systems and obtains its power from making assumptions about the problem solving methods of the expert. Another tool for acquiring knowledge in domains of diagnostic problem solving is 'More' (Kahn et al, 1985). Design has been argued (chapter three) not to be 'diagnosis' or 'heuristic classification' and is too poorly understood to accommodate harsh assumptions about likely design (problem solving) activity.

Diederich et al (1987), argue that a hybrid knowledge elicitation tool is required to elicit and combine knowledge from different sources (book and problem-solving procedural knowledge). An 'intermediate' representation of frames, rules and constraints are automatically constructed from the results of many knowledge elicitation and text analysis techniques. The philosophy of multiplicity is also promoted by Kahn et al (1987).

4.4.3 Model-based automated techniques (The KADS methodology)

The Knowledge Acquisition and Document Structuring (KADS) methodology (Breuker and Wielinga, 1987) constructs a model of expertise at a common, high, epistemological level (Clancey, 1983) to structure and elicit knowledge.

The KADS methodology is based on the theories of 'Roget' (Bennett, 1985), where generalised concepts believed to be applicable to more than one domain are used to recognise common problem-solving strategies, in tasks whose nature is similar. Bennett (1985) uses synonyms to transfer the domain dependent language from one application to another, where the problem solving procedures are perceived as being the same, but described by different names or terminology.

Breuker and Wielinga argue that a high level, structured approach to knowledge acquisition and system building is a useful strategy, and present a framework methodology, in conjunction with tools for the knowledge engineer, called the 'Knowledge Engineers Workbench'. It is argued that analysis yields high level, functional descriptions of the data, *the conceptual model* and a domain dependent specification of the information, in terms of the *knowledge level.*

Abstracting the conceptual model into a more general form, *the interpretation model,* is argued to provide a suitable structure that can be used to guide the construction of other conceptual models, in different but similar domains. Breuker and Wielinga (1987) argue that the approach provides a useful tool that enables the right questions to be asked of the experts. Further, it is suggested that the methodology may be able to determine whether domains under scrutiny are suitable for Expert System development. Thus Breuker and Wielinga, (1987, p41) argue that

"1) The knowledge and expertise should be analysed before design and implementation starts; ie. the major efforts in knowledge acquisition should occur before an implementation formalism is chosen.

2) Because of its inherent complexity, the analysis should be model driven as early as possible. Models of expert problem solving not only enable - at least, facilitate - the analysis of data, but also provide references to known implementation solutions (cf. ROGET, Bennett, 1985).

3) To sail between the Scylla of natural language (with ambiguous but rich semantics) and the Charibdis of a formal language (clean but unimpressive semantics), a model of expert problem solving should be expressed at the epistemological level (eg. Clancey, 1983).

4) The analysis should not only include the knowledge and reasoning of the expert(s) but also the functionality of the prospective system, ie. data on the environment and users should be collected and analysed. These data are used for defining the communication tasks - modality - of the system.

5) The analysis should proceed, preferably, in an incremental way. Because there is a wide variety of topics, such as tasks, functions, knowledge etc, which are not unrelated, the analysis should be breadth-first and cyclic to allow successive refinement and inclusion of results of analysis of related topics.

6) New data should only be elicited when the previously collected data shows the need for

clarification and augmentation. As a result, elicitation and analysis will alternate. This should both keep the data manageable, and lead to more specific topics for,and methods of, elicitation (Breuker and Wielinga 1984).

7) Collected data and interpretations should be documented. On line documentation of the analysis in a condition *sine qua non* for team work."

In KADS the need to structure knowledge is emphasised through the role of different types of models, to interpret the underlying structure from (a set of) data. The analysis stage produces a high level specification, the *conceptual model* (Norman,1983) of expertise, achieved though a four-layered structure (Breuker et al. 1987);

* Domain layer.
* Inference competence.
* Task level.
* Strategy level.

Diederich et al (1987) adopt an approach that is similar to the KADS methodology in the 'Kriton' system. Rajan, Motta and Eisenstadt (1988) develop the stage-oriented approach of modelling, in 'Keats-2' and 'Aquist' to provide support for data analysis and domain conceptualisation. For example, a hypertext editor is provided to help the knowledge engineer structure and manipulate transcripts and theories, supported by a graphical map. In particular 'Aquist' provides bottom-up text analysis with a top-down model-driven approach.

The model building philosophies, described above, promote two highly relevant issues; that the design and implementation stages of a KBS should be separate and distinct, and that knowledge elicitation must be viewed as a modelling process (Wielinga and Schreiber, 1989). Ideally, the procedures for obtaining and analysing information should be separate, to give a clear implementation (representation, machine) independent record of the data to serve as a permanent base for development. This latter point is discussed further in section (4.5.3).

Musen (1989) argues that a knowledge acquisition tool generator can be constructed by using Generic Tasks (Brown and Chandrasekaran, 1989) to model problems of knowledge acquisition. The resultant knowledge elicitation tools ('knowledge editors') are tailored towards the particular class of problem being addressed. Thus, "Protege...Allows construction of a model of the application area that is complete except for the content knowledge required to specify particular tasks." (Musen, 1989). Then, the application expert uses the knowledge editor to supply the specific information (planning tasks). Generic Tasks are discussed in section (4.6.1).

4.4.4 Automatic Induction Techniques

A distinction can be drawn between using a computer as a tool to acquisition, described above, and using induction to generate rules or prototypical KBS automatically from data. Inductive mechanisms attempt to structure raw data into a predetermined format, usually as rules. The structure being ascertained from a given set of examples. Hart (1987b) identifies that induction has two purposes, although the first is often underestimated:

1 To organise and explain the structure of the given examples.

2 To predict and hence classify the category of new examples.

The argument for inductive knowledge elicitation methods stems from the belief that traditional elicitation techniques are too slow and, hence, too expensive. Also, it is assumed that experts can easily describe examples of domain situations and then say what decisions can be made from these, or comment on different decisions made in the past. However, descriptions provided by the expert seldom assert how the data is analysed or how the judgment is resolved. Further, it may not be possible for the expert to generate the rules. Thus, induction is argued to offer a way of determining (some) of the salient factors of the underlying decision process from an example set of data, and corresponding example decisions, but it is assumed that the data is free from errors and contradictions.

Hart (1987b) discusses the popular Iterative Dichotomiser 3 (ID3) algorithm of Quinlan (1979). The terminology uses *classes*, which are the actual categorical decisions of the expert, and *attributes*, which are the data. The original algorithm uses discrete data types (age in years, number of children etc), although real values can be substituted, when categories can be implied. For example, a persons height (h) can be described as Small ($h < s$), Average ($h >= s$ and $h <= t$) or Tall ($h > t$) where (a), (h), (s) and (t) are real values, but the categories (Small, Average and Tall) are discrete. The ID3 algorithm recursively selects an attribute to best divide the data into new categories, statistically, and a decision tree is constructed. The intermediate nodes correspond to rules and the terminal nodes correspond to decisions.

Quinlan (1987a) suggests that the most serious drawback of induction is the obscurity of the resultant knowledge, and the decision tree representations are so complex that they can not be easily examined by the knowledge engineers or the experts. Therefore, (Quinlan, 1987a, p221) argues that "It is questionable whether opaque structures of this kind can be described as knowledge, no matter how well they function" and that it is necessary and desirable to produce Knowledge structures that are easier for people to understand and modify, and allow the knowledge to be more amenable to Expert Systems development.

Quinlan (1987a) develops, and compares four procedures to simplify the decision trees resulting from induction, and tests them on a set of data from six domains. However, the cost of simplification is a degradation of the efficacy with which the structure describes the sample set. Two of the methods requiring additional information, in the form of additional training sets, perform little better than the two that do not. Quinlan (1987a) reports that significant simplifications are obtained, and that the ability for predicting new cases is *better* in the simplified structures than in the unsimplified decision trees. The most successful method can also generate production rules directly.

Advocates of induction argue that it is an unbiased and consistent technique that, given a good training set, can rapidly generate hypotheses in the form of easily understandable rules that experts may fail to construct (Hart, 1985b). Success has been claimed in the analysis of soyabean disease (Michalski and Chilausky, 1980) and the technique is supported by Dieterrich and Michalski (1981) and Cohen and Feigenbaum (1982).

However, the automatic generation of decisions without explanation is an obvious worry in the context of Expert Systems, where an explanation of the advice is often a fundamental requirement. Fox (1984b) criticises induction, and argues that the information is still subject to the usual distortions originating from people and information transfer (section 4.5.2). Hart (1985b), asserts that caution must be exercised with inductive techniques, and argues that "Extravagant claims about their powers are misleading." Induction is perhaps inefficient because the separation of vital information, that is pertinent to the decision, and passive data, of no actual relevance, cannot be directly determined by the computer. In contrast people can often recognise such distinctions. It is also, perhaps unreasonable to assume that the training set is accurate and error free in domains of complex problem solving where, for example, experts may behave idiosyncratically, or disagree with fellow experts. Instances of new, novel, and unusual examples tend to be poorly predicted and categorised. Further, induction is suitable in only a restricted class of problem, where the domain knowledge can be best represented in a 'rule' format.

Michalski and Chilausky (1980) generate rules by induction for soybean disease diagnosis, and argue that their expert system is better at diagnosing plant illness than actual experts. However such success needs to be tempered by the observation that the domain is relatively small, and well-defined. It can be argued that highly complex and largely ill-defined decision areas, where KBS are likely to be most valuable, are unlikely to be as well formulated. Design, for example, is understood to be an ill-defined problem (Simon, 1973; Archer, 1979).

4.4.5 Summary of Automated knowledge elicitation methodologies

Automated acquisition techniques aim to rapidly acquire knowledge through direct interaction with experts. Computers are partly, or wholly responsible for the elicitation, interpretation and representation of knowledge. Many tools are based on psychological testing methods, as discussed in section three, and they often produce production rules.

Inductive methods take a direct approach to determine 'knowledge' for themselves. The main argument for induction is that higher levels of expertise concentrated in automatic, or compiled forms, is unlikely to be available to direct conscious introspection, although the results of such processes can be communicated. Therefore, interview techniques requiring the expert to articulate tacit knowledge are argued to be flawed. However, it is clear that the results of cognitive behaviour (the data for induction), can be monitored just as effectively in a personal interview as they can in induction, but the same results may also be accompanied by plausible explanations and deep knowledge, that inductive techniques do not record.

Perhaps one benefit of computer elicitation techniques is that they can gather certain types of information more discretely than people can. However, the understanding and empathy that people can offer enables subjects to respond freely in all but a few situations, and further, computers may be viewed as a threat to personal liberty or job security.

The ability to make 'rapid prototypes' and to (quickly) generate a set of production rules for test is often promoted (Gaines, 1987d). Rapid prototyping (eg. Ince, 1988) allows for an early assessment of the conception (ie. is an Expert System really what is wanted, needed, or possible in this domain) and to rapidly construct a 'working system' test-bed open to expert criticism, to test ideas against, and to act as a springboard to get the Expert System off the ground. For example, Booth (1990) argues that "one of the most useful indicators of the difficulties that users are likely to experience with a system is the errors that occur during interaction."

However, the ad hoc test and evaluation methods (O'Keefe et al, 1987) that have been commonplace in prototyping are contrary to the trends of knowledge engineering (and computing in general); it is important to conduct systematic evaluation before notions of implementation (Benbasat and Dhaliwal, 1987). Hence, what is *rapidly* obtained must realistically be disregarded (Johnson and Johnson, 1987a). Although the prototypic stage is a worthwhile learning process in itself, the resulting data is usually too poor to be of any great value for end-user systems. Thus, thorough elicitation and evaluation methods are then needed. Hence, the expert and knowledge engineer time, initially targeted to be economised through prototyping, may be wasted. This inefficiency is in fact contrary to the purpose of the methodology. Further, Paul Johnson et al (1988) argue that "we believe that building a prototype system early in the knowledge-acquisition process may result in a commitment to a specific model of thinking (inference process) that does not adequately represent the expertise in question."

Many automatic elicitation tools are designed for 'heuristic classification' or 'diagnosis' type problems, that are well-defined. It is argued that design is ill-defined and that design is not 'problem solving' (eg. Bijl, 1985). Therefore, there are no grounds to assume that the automated approach is suitable for design elicitation.

Some general implications of recent trends in automatic elicitation techniques are important. The task of knowledge elicitation is argued to require greater structure and purpose and moves toward generating machine independent, or human understandable representations of knowledge is important.

4.5 Interviewing and psychological testing methods

It is widely asserted that the personal interview remains the most significant method of acquiring deep causal knowledge (Gammack, 1987c; Welbank, 1987; Johnson, 1987) and the technique is especially useful when psychological testing methods are combined (Welbank, 1983).

Burton et al (1987) compare personal interview techniques, and argue that the Laddered Grid has better efficacy, whilst Protocol Analysis takes longer and gives less information. The methods are compared against a 'Gold Standard' for completeness. However, in the tests, the 'Gold Standard' is assumed to be complete. The criteria of measurement is questioned here, principally of speed, and the measurement in terms of *percentages of coverage* appears meaningless. For example, does the 'Gold Standard' achieve one hundred percent ? does an expert possess one hundred percent ?, if so what is the measure for a group of experts ? It is suggested here that different elicitation techniques result in different types and extent of information. Such information will not necessarily correspond, directly or otherwise, to a preconceived view of the 'complete' domain. The task of knowledge elicitation is concerned with gathering as much information as possible, and some techniques may take longer than others, and concentrate on concepts that are more difficult to obtain (such as deep knowledge). Therefore, the argument that protocol analysis yields information that does not correspond to a predetermined standard perhaps indicates that the method obtains a broadness or depth of information that is not elicited by the other techniques. However, Burton et al (1987) acknowledge the temporal aspect of elicitation: that different methods will be appropriate at different stages, that usually more than a single pass is made, that more than one method will be used, and a combination of methods is often best.

Nisbett and Wilson (1977) argue that accurate psychological testing techniques require careful insight, planning or theories, about the form, type and possible content of the data before the tests are performed, to avoid errors of carelessness, or misunderstanding, that lead to significant errors of interpretation. On this basis, mapping appropriate testing method(s) to the situation appears a useful strategy (eg Gammack, 1987c; Bainbridge, 1986) but presupposing an understanding of the domain to the extent of knowing the form of the knowledge to be elicited is not always realistic (Burton et al, 1987).

Psychological testing methods should, however, be put into the perspective of their objectives. Bainbridge (1986) argues that they have been designed to meet the psychologists aim of attempting to explain why people do things (the effects of knowledge on behaviour) which is significantly different to the concerns of the Knowledge Engineer, who aims to discover how people do things (the behaviour or knowledge only).

A flexible interview technique that dynamically incorporates other psychological methods wherever appropriate has many advantages (Johnson and Johnson, 1987b). In such a strategy it is not necessary to determine the type of knowledge structure being sought prior to consultation since this is part of the learning process that is adapted to suit the needs of the particular situation. However, the interviewer needs to be skilled and aware of pertinent psychological testing methodology.

4.5.1 Verbal Reporting of data

It has been argued (Chapters two and three) that the specialistic nature of the right hemisphere, and its associated activities and mental processes, are perhaps of great significance to design elicitation. Yet, the mechanisms of speech are predominantly left hemispheric. Therefore the verbal communication of design information may be suspect, and the validity of verbal reporting is an important issue.

Nisbett and Wilson (1977) argue that higher order cognitive processes (perhaps including perceptual visual skills) are unlikely to be available to introspection. Hence, attempts to report such cognitive processes are not based on true introspection, but on *a priori* theories, in order to offer plausible explanations. Thus, people report their behaviour, although they have no direct observation mechanisms of cognitive processes, and do not really know where the explanations come from. Reports are likely to be accurate when the information leading to the response contains factors that are plausible a priori theories to the response offered, and inaccurate otherwise. Three important conclusions are argued by Nisbett and Wilson (1977).

"1) People often cannot report accurately on the effects of particular stimuli on higher order, inference-based responses. Indeed, sometimes they cannot report on the existence of critical stimuli, sometimes cannot report on the existence of their responses, and sometimes cannot even report that an inferential process of any kind has occurred. The accuracy of subjective reports is so poor to suggest that any introspective access that may exist is not sufficient to produce generally correct or reliable reports.

2) When reporting on the effects of stimuli, people may not interrogate a memory of the cognitive processes that operated on the stimuli; instead, they may base their reports on implicit, a priori theories about the causal connection between stimulus and response. If the stimulus psychologically implies the response in some way (Abelson, 1968) or seems 'representative' of the sort of stimuli that influence the response in question (Tversky & Kahneman, 1974), the stimulus is reported to have influenced the response. If the stimulus does not seem to be a plausible cause of the response, it is reported to be non-influential.

3) Subjective reports about higher mental processes are sometimes correct, but even the instances of correct report are not due to direct introspective awareness. Instead they are due to the incidentally correct employment of a priori causal theories." Nisbett and Wilson (1977, p233).

Ericsson and Simon (1980) argue that, in the literature surveyed by Nisbett and Wilson, there is a failure to take into consideration the time taken between task performance and its report. Hence, Long-Term Memory is used to report cognitive processes that have long since finished, and only the result is remembered. The subjects report information that can not be articulated, either because the access mechanism is not readily available, or the information is no longer present.

Ericsson and Simon (1980) propose a model of verbalisation based on the theories of Short-Term and Long-Term memory. They argue that significantly more accurate data will result from the immediate articulation of information during problem solving activity. Further, it is argued that access to higher order mental processes (with no other direct means of introspection) is also possible and that (Ericsson and Simon 1980, p215) "...verbal reports are data. Accounting for verbal reports, as for other kinds of data, requires explication of the mechanisms by which the reports are generated, and the ways they are sensitive to experimental factors (instructions, tasks etc) ... Verbalising information is shown to affect cognitive processes only if instructions require verbalisation of information that would not otherwise be attended to ... The inaccurate reports found by other research are shown from requesting information that was never directly heeded, thus forcing subjects to infer rather than remember their mental processes." A number of important issues are raised in this discussion.

1) Behaviourists have cast suspicion on the validity of verbal reports. This is due to there being no likely (or provable) resemblance between the given report and actual cognitive processes, especially when people describe procedures and strategies that are based on knowledge of how one 'aught' to perform a task. This form of 'book', or general knowledge has tremendous social biases and can be faithfully generated by people with no particular experience of the domain task but have only some general, often shallow, knowledge of the domain, an example of this is discussed by Collins et al, (1985) (eg, points 5 and 6 below).

2) Introspection can never be used as a means to verify actual thought processes. However, introspection may be a useful means of discovering (postulating) new hypothesis of cognition that can be criticised in order to generate further theories.

3) Further to above, although introspection is only a means to generate new hypothesis and ideas, the underlying methodological approach should be carefully considered to enable the generated results to be significant discoveries. (ie. the testing procedures should still be carefully

planned and scrutinised).

4) It is clear that people have actually reached a solution if they are able to report it. No one ever trusts a solution without a (plausible) explanation.

5) An observer of problem-solving activity can identify salient factors of the behaviour and motives of the subject as well as the problem-solvers can themselves, when they are asked to verbalise their actions retrospectively. This indicates the temporal nature of explanations, that are inaccurate when not immediate.

6) Inference may occur when subjects are asked to provide explanations to solutions without having direct access to the relevant information. Thus the actual thought processes and the verbal reports are unlikely to bear any close relation.

4.5.1.1 Protocol analysis

Ericsson and Simon (1980) conclude that reports given in problem solving, whilst thinking aloud, provide accurate records of the activity, and can provide data representative of the processing sequence of cognition. However, care must be taken to ensure that the task is typical, realistic, approached in the usual way and that the subjects normal working environment is preserved. Further, it is argued that instructions given to the subject will not adversely affect the normal processing sequence, unless the subject is asked to explain. Hence, simple reminders given by the (somewhat passive) interviewer, to keep thinking aloud, should not interfere with the situation.

The philosophy of Protocol Analysis emerged through 'qualitative' acquisition techniques and immediate verbalisation situations (Ericsson and Simon, 1984). In protocol analysis the interviewer takes careful notes of every possible detail, that are then transcribed in total, and analysed. A session is recorded and the interviewer makes additional notes to help decipher the non-verbal actions and gestures.

Protocol Analysis is appropriate for real-life problem solving situations. As discussed above, poor or inaccurate data is likely to result from 'think through' (where no actual task is being performed) or 'think back' (post-task reporting) situations. Thus, the heuristic nature of human problem solving is probably best elicited using Protocol Analysis (Bainbridge, 1986) because it is relatively easy to identify the tasks that are being performed, even if the *how* and *why* are more elusive. Welbank (1983) suggests that data obtained from Protocol Analysis may be compared to information gathered from other sources, to validate expert explanation, or the results of induction, but this speculation is suspect (4.5.1 point 2).

However, reports are not comprehensive. The articulated information may just be that of high level task completion; 'yes, that looks good', 'no.' Further, obvious procedures may be omitted. Protocol Analysis is rather messy and time consuming, especially transcribing, sifting and analysing the data. Problems of conscious awareness are also troublesome and subjects may need to practise thinking aloud to reduce the likelihood of the task being inhibited by self-consciousness.

Some work has been done using video recordings (Littman 1987) but the extension of Protocol Analysis to include visual data is poorly documented despite the obvious advantages. There is little doubt about the usefulness of the Protocol Analysis technique, but much literature strongly advises its use only in conjunction with other forms of testing (Burton et al 1987, Fox et al 1987, Bainbridge 1979, 1986).

Collins et at (1985) argue that the distinction between information and heuristic types of knowledge is less important to issues of Expert system construction than that of articulative and tacit (context, deeper meaning and 'taken for granted') types of knowledge. Thus, people are able to provide explanations on information that is irrelevant or not even present: "The mistake is to think that if knowledge elicitation tools and techniques are sufficiently refined, and if enough time and diligence are dedicated to the task, the whole of an expert's knowledge can be elicited. This is untrue; one cannot elicit that which no-one knows that they know - that which they cannot articulate." Collins et al (1985).

In summary, accurate accounts are likely when subjects are not allowed time to infer. Inference is less likely to occur in the problem solving task (design, analysis) where the expert solves in a typical fashion in environmentally normal conditions.

4.5.2 Factors affecting Knowledge Elicitation

The following section reviews in detail an important discussion (Bainbridge, 1986) that underlies many points raised in the chapter. It provides context, background and depth to discussions of methods already covered, especially the fundamental psychological foundations.

Bainbridge (1986) supports the argument that humans will give reports based on simple inference in the absence of actual information and reiterates that attempting to 'validate' cognitive processes from reported data is meaningless. The most important, but obvious, conclusion is that all elicited data contains distortion, the objective is to minimise the effect. Thus, common distortions, and common causes of distortion, are to be identified and their impact reduced. One strategy is to identify the probable class of knowledge, and use knowledge elicitation techniques that are best suited to the type being sought. Hence, Bainbridge (1986) describes the types of distortion, the types of currently identified knowledge, and the appropriate elicitation techniques that can be used with minimal distortion, with respect to the knowledge types. Broad categories of knowledge type have also been identified with classes of domain (design, analysis etc).

4.5.2.1 Distortions

Reporting always includes an element of distortion, regardless of source (Cleaves, 1987). Reporting whilst performing a task is often an unnatural process, and the changes to the working environment will cause interference, for example, the use of more reflective thought processes, when forced to explain. Also, it is unlikely that verbal reporting of (mental/visual) imagery will be accurate (discussed in chapter two and section 3.4.2).

Social factors provide a powerful source of distortion, such as job security and personal secretiveness, especially if the subjects feel threatened by the situation, or wish to report only what they believe they aught to for their own, their colleagues, or the interviewer's sake. Points that appear stupid or obvious to the experienced expert may be overlooked, or simply not reported. It is often the unusual activity of the individual expert that characterises the level of expertise attained, the sort that is least likely to be reported. Cleaves (1987) discusses in detail the likely biases of experts, and possible remedies.

"Automatic" thought processes are believed to be extensive in tasks involving high skill levels. There may be little conscious awareness of their presence, analogous to motor skills, like riding a bike. Hence, subjects will report simpler methods of task solving that can be easily verbalised, but such reports are unlikely to be representative of the high levels of skill and expertise that are actually used (eg. Dreyfus and Dreyfus, 1986; Smythe, 1988; also, Johnson et al, 1988).

It seems that the use of both language and memory varies in the cases of reporting a task after solution (off-line) to that of reporting a task whilst engaged on it (on-line). It is noted that people use a different kind of language in the two cases, indicating that perhaps the retrieval process to the knowledge may not be the same, and that memory recall is much poorer than most people appreciate. This is likely to cause inference, rather than to provide accurate reporting. Further, reporting whilst not in problem solving forces sequential rational reporting, which is seldom an accurate account.

In the case of off-line reporting (eg. post-task), the working environment, motivation, time considerations, working conditions, context etc, are not sufficiently accurate to stimulate the subject's 'working memory' to encourage decisions based on a sufficiently high level of expert skill.

Nisbett and Wilson (1977) also note that although people who have not had any actual experience of a task, but have only broad general knowledge of it (such as reading about it or watching others do it), are capable of answering some questions on the domain. Other questions can only be answered by the experienced task solvers.

4.5.2.2 Knowledge types

The first category of knowledge, identified by Bainbridge (1986, p145), are those that have some inherent structure, analogous to the representations identified by theorists, such as networks, frames and predicates, and are predominantly causal in nature, or knowledge of structures:

"1) Classes or categories: Represented by hierarchies of categories and members (is-a hierarchies) with attribute-value descriptors.

2) Components/mechanisms: Represented by hierarchies of wholes and components (part-of hierarchies).

3) Causals, conditions on actions and events, changes between phases of operation."

There also appears to be two classes of these three knowledge types above. The first is knowledge about *causality,* and can be verbally articulated and represented by predicates. The second class, *skill,* is not open to verbalisation and its presence can only be inferred from observation, or verbalised after execution of the skill. For example, if asked to explain how to whistle, this can only be done by whistling and attending to what is done, then attempting to explain it.

The above two-class distinction also holds for the knowledge category known as *Procedural.* Comprised of *strategies* and *routines* (specific, general, problem solving) in the first class, and *automatic* (heuristic, cognitively complex) in the second class. *Goal-based* approaches to problem solving driven by *Criteria* or *Probabilities* is also identified as a knowledge type of the *procedural* category.

The second main category involves Knowledge about *memory states*, that can give guidance by supplying context to the reasoning process. *Long-term memory* is that of past histories and experiences, *Short-term memory* is an understanding of the present state of the 'Real World.'

Thirdly, *automatic, perceptual* (including imagery), *motor* and other skills that utilise many parts of the brain, in a somewhat parallel fashion, are non-verbal in nature and are recognised to be held, or possibly accessed, in a different way. The classical difficulties of reporting this type of knowledge have been copiously reported (eg. Nisbett and Wilson, 1977).

4.5.2.3 Techniques

Firstly, verbal reports can be obtained by questions and answers in an interview situation, or in the form of written material such as questionnaires. However, it has to be noted that memory recall degrades at an alarming rate over time and reports are never immediate, there is inevitably some delay involved. Clearly, the sooner a report is given, the more accurate the account will be, since there is less time for other processes to interfere, like rationalisation for example. Canter and Brenner (1985) discuss the (optimum) choice of methodology appropriate to specific tasks.

Secondly, inferential techniques do not, in general, require prior knowledge of the knowledge types identified above. The subject is given some specific actual work task, the session is recorded (may include audio, video, eye-movement and ethnological data) and the behaviour can be analysed to determine (some) of the knowledge needed to perform the task in the given situation. Variations include solving a test situation from memory alone or from a static simulation.

Alternatively, other tasks, that are not performed in the 'usual' or everyday way may be used. These include solving only a small sub-set of the whole task, but allowing for greater detail, and a category sort or drawing task, performed in a way that differs from the normal situation, but utilising the same working knowledge of the problem-solving task.

4.5.2.4 Application of techniques to knowledge type

Grouping methods are appropriate elicitation techniques for the *classes / categories / is-a hierarchy* knowledge type. The interview, and part tasks (such as draw, diagnose and design) are recommended for the *mechanisms* knowledge type. For the *causal* knowledge types, interviews, questionnaires and reasoning tasks can be used to elicit "qualitative" data, and for "quantitative" data, questionnaires including a spatial response, opposed to that of verbal, is recommended. Interviews and (video, protocol etc) recording of data are appropriate for the *procedural* and *heuristic* knowledge types.

In the memory section, (specific) *long-term memories* may be accessed through an interview situation and *short-term memory* processing may be elicited through a problem-solving task, drawing, or performing a given task from memory. However, the accuracy of data obtained in this fashion is questionable since it is necessary for the knowledge engineer to infer knowledge, and is especially doubtful in the case of long-term memory.

Lastly, knowledge of *motor* and *complex neural skills* can be obtained through simulation, especially in place of work. It is important to note that *perceptual* knowledge can be obtained through a drawing task.

4.5.3 Methodologies

4.5.3.1 The Matrix and Proximity techniques, as adaptations of MDS and Protocol analysis.

Gammack and Young (1985) recognise that forcing expert knowledge into a rule format is not always appropriate. Thus, there is a need to identify and elicit different knowledge forms (concepts, facts, procedures and Meta-Knowledge) using relevant elicitation techniques. Hence, Gammack (1987c) describes a four stage methodology :

1) Concept elicitation (basic units of domain knowledge): Introductory talks (of little importance unless used for a teaching system), structured or unstructured interviews, case histories (protocol analysis), generating a glossary (by asking for a list of concepts !)

2) Structure elicitation (structuring the component terms in some way): Concept grouping, in a way that the expert is familiar and comfortable with. Card-sorting, Multi-Dimensional Scaling, Repertory Grids and many more. Grain size is an important concept and it is recommended to concentrate on either the global subgrouping structure or the detailed and specialised differentiations.

3) Structure representation (a formal representation of the structure): For example ACTs, networks etc, whatever is appropriate.

4) Transformation (using the representation in a specific way).

The principle of using an independent representational format before transforming the knowledge into a working system is an important issue, providing a contrast to the automatic and inductive elicitation techniques described in section (4.4). Gammack (1987c) summarises some of the more useful knowledge elicitation techniques, and presents a critical review of the strengths, weaknesses and compatibility of each.

Young and Gammack (1987) argue that informal interviewing is not enough on its own; Psychological testing techniques are also required. They argue that techniques not based on sound psychological foundations, such as informal interviewing, are weak because of the restriction to verbally articulated knowledge, and expert skill is often an automatic reaction that the expert cannot verbalise.

Gammack (1987c) argues that systematic psychological techniques should be used to elicit the domain specific entities, and the relationships between the entities. Hence, the deficiencies of informal interviewing can be overcome. Proximity Analysis is argued to be a more useful procedure than (but perhaps best used in conjunction with) Multi-Dimensional Scaling. The technique aims to determine a measure of association between concepts in the network and to highlight the meaningful, related concepts in the domain, and to produce an indication of the 'measure of relatedness.'

The Matrix technique is argued (Gammack, 1987c) to be a more useful adaptation of traditional Protocol Analysis because it identifies relevant domain information in a representational format, is faster, and can be automated. However, the technique is still being developed.

Gammack (1987c) argues that the stages of knowledge elicitation should consist of firstly, a hierarchical sort of domain entities, secondly, the rating of similarity between pairs of items, and thirdly, Repertory Grid to elicit domain concepts. The first stage is simply to obtain information on the major classes of the domain. Then a suite of three packages are to be applied to the matrix of proximities, the (pair of) ratings, to produce representations of the form:

1) Multi-dimensional scaling, to show the strong features of the domain (Atlas).

2) Single-link cluster analysis, yielding major groupings of items (Regional map).

3) Pairwise relationships, focusing on closely related pairs by using Pathfinder analysis (Schvaneveldt et al, 1985) (Local street plan).

The use of the Repertory Grid obtains data on how items in the domain can be distinguished in terms of attributes, and used to derive another proximity matrix that can be manipulated as above. The information is cross-checked, to determine the consistency of convergence, of the six representations. The accuracy of the elicited knowledge is checked by further (secondary) tasks in which the experts performance is predicted.

Young and Gammack, (1987) argue that coding expert knowledge directly into rules has the disadvantage that it is necessary to choose the scheme for representing the knowledge before any content is known. Also, it is argued that a single representational scheme is inadequate, and the use of Intermediate Representations is promoted to offer a suitable strategy for knowledge elicitation and Young and Gammack (1987, p4) argue that "using IRs (Intermediate Representations) in the process of knowledge elicitation has a number of advantages. First, the IRs serve as a record of the knowledge elicited that is independent of the technology used (such as a particular expert system shell), and so can act as a source for re-implementing a system later using improved technology, without having to repeat the whole elicitation procedure. Second, IRs can act as a medium of knowledge communication shared by the expert and the elicitor. Third, use of (particularly variety of) IRs can provide a more complete record of the knowledge than can be captured solely in a machine-interpretable representation. Fourthly, and finally, the knowledge recorded in the IRs can be used for purposes other than building a problem- solving expert system, such as for explanation, for tutoring and as a basis for system documentation."

4.5.3.2 Mediating Representations and the Teachback Methodology

Mediating Representations conveys the notion of a working representation, a learning process by which the knowledge engineer formulates an understanding of the domain, rather than of a static, and independent transitory state. Thus Johnson, (1987, p1) argues that "A Mediating Representation for Knowledge Elicitation is a computer language independent notion used as a conceptual aid in synthesising knowledge from talk with experts. It 'Mediates' between verbal data and standardised knowledge representation schemes found in AI software development environments."

A major argument for the use of Mediating Representations follows from the need to derive *data driven concepts* as opposed to *representational driven concepts*. Since it is necessary for the Knowledge Engineer to structure the information in some format, the paper system of

Mediating Representations allows for the description, and development of the domain knowledge in a form that is free from the limitations of machine-dependent structures (frames, networks etc). The choice of such structures can be decided after the Knowledge Elicitation stage has been completed and in the light of what needs to be represented and how. Mediating Representations, therefore, enable the recognition of salient features of the expert's knowledge, in a communicable form, so that the appropriate use of knowledge representations, and Man-Machine Interface issues can be addressed.

The philosophy of 'qualitative' information gathering is argued (eg Nancy Johnson, 1985; Silverman, 1985) to be a suitable strategy for knowledge elicitation, using interviews and problem solving tasks. Emphasis is placed on the need for two distinct stages in the process, the data gathering, and then the analysis, although they are not necessarily temporally exclusive events. The resemblance to software engineering is highlighted, where careful specification (elicitation stage) before implementation (analysis, system design) is essential for completeness and robustness, and this philosophy, it is argued, can save time in the long run.

Les Johnson (1985) argues that it is no longer sufficient to simply capture procedural skills, the conceptual structure is also important for the development of sophisticated models of human expertise, thereby, KBS can be developed with "increased effectiveness and acceptability" (Les Johnson, 1985). Hence, to satisfy the end-user's increasing demands for deeper explanations, KBS systems must be equipped with ever deeper levels of knowledge, that can not be provided through rule-based systems architecture. The corollary of this is that it is no longer satisfactory just to have a body of knowledge capable of modelling expert performance (first generation expert systems), but knowledge should also stand up to being scrutinised in terms of its *competence* (Clancey, 1985b) (ie, second generation expert systems). Kervanou and Johnson (1986, p39) argue that "...the more closely an expert system captures the underlying model of competence, the more satisfactory it will be as a component in a human-computer system." Mediating Representations are argued (eg Kervanou and Johnson, 1986) to offer a valuable step towards a 'Model of Competence' in the domain, collating the necessary independent collection of information, that includes background and deep causal knowledge.

Ogborn and Johnson (1984) discuss Conversation Theory as an interactive process between participants, aimed at making public the entities of concept and understanding. Relations are expressed by the expert to establish the content of the domain. A bi-level analysis follows; at $Level_0$ (L_0), explanations of how to do things (procedures and methods etc) occurs, and $Level_1$ (L_1) descriptions are explanations of explanations (how one formulates, remembers, trusts, teaches $Level_0$ explanations etc). Johnson and Johnson (1987) argue that there is not (necessarily) a commonality of thought processes, just an agreement, an understanding is achieved. Johnson and Johnson (1987b, p94) argue that the questions pertaining to the levels L_0 and L_1 provides a framework of sufficient power to subsume other interview methodologies; "At L_0 procedures define concepts, which, through teachback, lead to shared concepts; at L_1 reconstructions define 'memories,' which, through teachback, lead to understanding."

Hence, a complete methodology, 'Teachback Interviewing,' based on conversation theory (Pask, 1974; Ogborn and Johnson, 1984) is proposed (Johnson and Johnson, 1987b), where all notions of knowledge (ie procedural, declarative, meta) are made public. Johnson and Johnson

(1987b, p93) assert that language remains both expressive and complex enough to convey expert knowledge in the natural form of explanations, arguing that "Language, as our most cognitively sophisticated tool, is an obvious choice and is at its most flexible in a personal interview. Thus, we maintain that a flexible interview technique like ours is a viable tool for eliciting the global picture of an expert's knowledge necessary for constructing creditable expert systems."

Mediating Representations can be used as a tool in the elicitation process, as an interactive medium of communicating with the expert. The Knowledge Engineer attempts to explain back to the expert, in the form of diagrams and conversation, the acquired understanding learned from the expert, to be checked, or more realistically, revised. The teachback technique is an iterative process by which the subject teaches the analyst some domain concept or procedure. Indication that the concept is understood and shared, is provided by the ability of the analyst to teach the concept back to the subject, to the complete satisfaction of that subject. If an unsatisfactory explanation is given, then the process is repeated. Only when the explanation is judged acceptable to the subject, will another relation be chosen. The flexibility of teachback interviewing is argued to stem from the two levels of knowledge used. Other theoretical techniques, such as the Repertory Grid, can be used, perhaps less formally and locally, if or when appropriate, but not enforcing a rigid schema that may limit the natural flow of communication.

In summary, Johnson and Johnson (1987b) argue that the teachback methodology provides a flexible nonjudicial technique, that allows elicitation of global and specific structures, provides a suitable format for communication with the expert and others, it is independent of specific machine implementation considerations, and is suitable for appropriate and various analysis techniques. Other elicitation techniques can be dynamically incorporated if appropriate, or wanted. Further, it is argued that the gathered information is, to a large extent, free from the knowledge engineer's preconceived prejudices of the domain and is authenticated by the actual expert. The natural language format of the method (non-psychological) is argued to put the experts at ease, and allow the experts to feel valued for their contribution.

However, the teachback method places a heavy burden on the investigator, with the need for a good interview technique (like not losing the interest of, or threatening the expert), and the need for time-consuming transcription, analysis and reanalysis. The whole process is acknowledged to be mentally exhausting for the Knowledge Engineer. There are also some limitations to its applicability, and not recommended for tasks that involve perceptual or motor skills. The limitation is important here since Design, particularly visual design, is believed to be significantly reliant on perceptual skill, and by the adopted definition, *aesthetic* judgments are perceptual.

4.6 Current approaches to Knowledge Acquisition in Design

Knowledge Elicitation for design is starting to emerge as an important area of research, although reports of specific methods for design elicitation are few. Currently, the work of Chandrasekaran and Marcus appear the most advanced. The approach taken by these two authors is briefly outlined below, and critically discussed in section 4.8. Other design elicitation literature is discussed below.

4.6.1 Generic Tasks

Chandrasekaran (1988) presents a framework, called Generic tasks (GT), proposing a 'building blocks' philosophy to Knowledge Based Systems construction, and hence, knowledge elicitation. A Generic Task is a high level knowledge or control strategy that is pertinent to a particular problem solving activity. Chandrasekaran argues that all problem-solving activities share common high level units that depict core components of complex reasoning tasks, and that these "Generic Tasks" can be identified and structured. Hence, problem-solving activity can be described in terms of a number of Generic Tasks, and design and planning is used as an example. The philosophy of Generic Tasks has been compared to that of the high-level programming language approach of computer science (opposed to an assembly language approach), and modularity is suggested to be an important asset for KBS construction and debugging.

Thus, the generic processes identified with design are described as :

1 Design problem decomposition.
2 Design plan instantiation and expansion.
3 Retrieval and modification of similar designs.
4 Global satisfaction of constraint equations.

Four classifications of design are also identified, from open ended 'creative design' (class 1), down to 'product design' (class 4, a refinement of a product whose structure is well defined). The class called 'Routine Design' (class 3) being addressed by Chandrasekaran is described as the case where "effective problem decompositions are known, compiled design plans for the component problems are known, and actions to take on failure of design solutions are also explicitly known" (Chandrasekaran, 1988). However, design tasks of this class are still argued to be non-trivial because they remain "beyond algorithmic solutions or table look up", and "complex backtracking" is needed.

Hence, Chandrasekaran describes design as hierarchical planning, from a given set of specifications (DSPL: Brown, 1984; Brown and Chandrasekaran, 1986), where the result of the design activity is an object (device, program, plan) meeting those specifications. Thus, Chandrasekaran (1988) argues that "Hierarchical structure of the object to be defined is known in advance (making it routine design). For each node in the hierarchy, precompiled design plans are known for making choices...Top down control is typically used. Design plans are chosen, choices made at that level of abstraction, and design refined by calling on plans for the children (ie. components). Plan failures are passed up until failure handling knowledge is available to fix the design or choose alternate plan."

David (1988) argues that GT-like components can not be uniquely decomposed from complex tasks. Chandrasekaran (1988b) in acknowledgement responds "We have repeatedly pointed out in our work that tasks such as diagnosis and design are compound tasks, and depending upon the domain and the knowledge available, different decompositions into Generic Tasks would be appropriate. Enforcing one decomposition will in fact limit the utility of the GT view." Iwasaki, Keller and Feigenbaum (1988) argue that the tasks described by Chandrasekaran (1988) are only of the shallow knowledge form, and that deep reasoning would also be needed.

In response, Chandrasekaran (1988b) agrees that the given examples are of the shallow knowledge form, but argues that the Generic Task theory is not restricted to shallow knowledge systems.

4.6.2 The 'piecemeal' approach to Knowledge Acquisition and the SALT knowledge Acquisition tool.

Marcus (1988) argues that design experts can readily identify components and parts of artifacts, but they find it difficult to describe strategies for constructing complete designs. Hence, Marcus (1988) proposes a 'piecemeal' bottom-up approach to knowledge acquisition, where the expert is helped to describe, first the components, and then the high level strategies for grouping pieces of the design, and strategies for dealing with (the ordering of) design subtasks. The automated knowledge acquisition tool, SALT, for constraint-satisfaction tasks acquires knowledge from an expert and generates a domain-specific knowledge base compiled into rules. In summary, Marcus (1988) argues that "...SALT gets its power by making a strong assumption about the problem-solving strategy that will be used by any expert system it creates. SALT assumes a generic propose-and-revise problem-solving strategy for creative design."

4.6.3 Other design elicitation research

Magee (1986) reviews nonautomatic knowledge elicitation methods for design, arguing that an understanding of the design activity is necessary to assist in the selection of suitable elicitation techniques, and highlights the importance of attitudinal information, since designing is not only a knowledge-based process, but also a value-laden one (Landsdown and Roast, 1987). Magee (1987) concludes that Protocol Analysis and Repertory grid methods are presently best, but further developments are needed to interview and questionnaire techniques, because they are potentially more useful.

In the domain of structural design, Chung and Kumar (1987) review knowledge elicitation methods. Miles and Moore (1989) argue that using many elicitation methods has the advantage of sustaining the interest of the expert over the long period required for elicitation. In particular, Miles and Moore (1989) use structured and unstructured interviews and report that using pictorial information is productive.

Paul Johnson et al (1988) discuss a framework for specifying expertise, through a case study in industrial experimental design. Using Protocol Analysis techniques, design tasks are decomposed into goal states and a graphical representation of the expertise (road map) is constructed.

A representation known as 'typology by coverings' is discussed by Arciszewski et al (1987) in their methodology for a learning system for conceptual design knowledge. A distinction is made between quantitative (continuous) and qualitative (discrete) variables. Further, it is argued that the global nature of qualitative variables in the design task are themselves descriptive decisions of the general conceptual design solution (large, small, T-shaped etc). It is argued that the discrete nature of qualitative variables, whether measurable or not (eg shape), have a finite number of feasible states (rectangular, cylindrical, spherical). Arciszewski et al (1987, p24) argue that "A given qualitative decision can be formally identified by a combination of feasible states, when for all qualitative variables only one feasible state is taken at a time," and a table of qualitative variables and their associated feasible states can be constructed as the representation of the design knowledge, which is abstracted to form generalised decision rules by inductive techniques (section 4.4.4).

The design of AI programs is discussed by Littman (1987) where the knowledge engineering task is seen as a design problem itself. This is of interest only because video recordings were used for the study. It is reported that the vast amount of data recovered from the (six) sessions is so substantial that it facilitates greater depth of analysis than time permits. The project is still in its infancy and the difficulties encountered are documented, without trivialisation.

Knowledge elicitation methods for design appear to be emerging in the field of Computer Aided Design, and in a recent conference (Gero, 1989) the discussions at last include references to knowledge elicitation procedures. For example, in the domain of kitchen layout design, Kloster et al (1989) interview two designers using protocol analysis, however, the report does not include details of the elicitation methods. An inductive learning system is described by Kamal et al (1989), using the usual techniques, such as the ID3 algorithm (as discussed in section 4.4.4), and Guena and Zreik (1989) also adopt inductive learning techniques. Similarly, discussions of knowledge elicitation are starting to appear in the literature of civil and structural engineering (design) (Topping, 1989).

4.7 Summary of Knowledge Elicitation research

There are a large number of techniques and methodologies, each argued to be suitable for the acquisition of at least some types of knowledge. (Reviews by Neale (1988), Wielinga and Schreiber (1989) and Boose (1989) are pertinent). Comparisons of 'productivity' between some methods exist (Burton et al, 1987; Shadbolt and Burton, 1989), but the meaning of such studies is questioned here. The identification of likely methods to specific problem domains (Bainbridge, 1986; Gammack and Young, 1987) appears more useful. Disagreements exist between the proposers of various philosophies, but a consensus of opinion can be ventured:

1) The suitability of the domain should be examined prior to thoughts of development in terms of practicability and exploitability. Namely, investigating the viability of the KBS development in the light of current research, identifying the need, and delivering a KBS that fulfils that need (Kidd, 1987a). Some authors suggest that the assessment may be guided by a high level cognitive model, perhaps under computer guidance (Breuker and Wielinga, 1987), whilst others take a more pragmatic approach of progressive investigation.

2) It is advantageous to have some conception of the type, and structure, of the knowledge you are attempting to elicit (section 4.5.2). Many computerised elicitation tools rely on a strong model of the problem solving task (Clancey, 1985a; Eshelman et al, 1987; Wielinga and Breuker, 1986; Marcus, 1988; Musen, 1989). The basis of the above approach relies on the assumption that apparently similar domains have some commonality at a high epistemological level. However, the generality of such tools is severely limited since problem classes that have not been intensively investigated may be poorly understood, or ill-defined (design for example). An alternative strategy is to learn about the problem by gradual progression, from breadth-first

principles, or through step-wise development. A number of hierarchical or decompositional approaches have been discussed.

3) Some approaches are clearly inappropriate for certain applications. For example, induction is recommend only with caution, generally, and its use only favoured where the resultant knowledge is clearly in a 'rule' format. The advocates of computerised elicitation techniques acknowledge the limitations of its applicability, typically to diagnosis and classification problems, and of significance here, not design or planning. Therefore, the choice of elicitation strategy depends on the particular domain, and the assessment of the above points.

4) Different methods are likely to address different aspects, viewpoints, or knowledge types of the same domain. More than one approach is likely to be needed. Some authors identify different knowledge types (eg. Georgeff and Bonollo, 1983; Gruber, 1988; Musen, 1989) and propose different techniques to target various forms (Bainbridge, 1986; Gammack and Young, 1987). There is little doubt that the current state of philosophy is not sufficiently developed to identify (all) the possible classes, structures or retrieval systems of human cognition (Norman and Rumelhart, 1975; Rumelhart and Norman, 1983). Hence, it is fallacious to presume that there exists a single, complete, methodology to describe or elicit expertise. Adopting techniques that cover both the broad and shallow (situational task solving, card sorting, repertory grid), and also the deep causal (personal interview) appears an important strategy.

5) Many researchers argue that it is essential to separate the process of knowledge elicitation from that of machine representation and implementation. The automatic coding of knowledge, directly into production rules, appears to be considered less than satisfactory, but ironically, automatic methods are being developed, and applied, with increasing fervency. The trend towards automated knowledge acquisition is also evident in ICAD applications. With principles emerging from software engineering, it now appears that the rudiments of good Knowledge Engineering centre on the ability to produce a good design of the knowledge, before coding. It is argued here that the machine independent (or paper) form of representation provides a comprehensive methodology that enables a permanent record to be developed, unconstrained by current computer technology, representation, or implementation restrictions.

6) Further, many researchers argue that the objective of knowledge elicitation is to develop cognitive models (eg. Johnson, 1985; Clancey, 1985a, 1986; Regoczei and Plantinga, 1987; Morik, 1987; Musen, 1989; Wielinga and Schreiber, 1989). However, no universal agreement exists on the form, purpose or functionality of such models.

4.7.1 Computer Vs. personal interview elicitation techniques

Whilst modelling has been argued to be a (or *the*) major task of knowledge elicitation, the functionality, process, or strategies to enable model construction, remains the subject of fierce debate. Les Johnson (1985) argues that the next generation of expert systems should model expert *competence* through the cognitive modelling of expert strategy, structure and dialogue, opposed to merely modelling expert performance. Further, Nancy Johnson (1987) argues "In KADS terms we are persuaded to use a model to analyse the knowledge where the notion of models and levels of knowledge rests firmly upon a computer architecture which has never been shown to resemble a model of expertise. Looking to cognitive psychology for help is tempting but as yet not very helpful. A mature approach to KBS development based on personal construct theory (ETS or PLANET) uses cognitively real representations (in constructs) but falls far short of being able to represent a structure of an expert's tasks - a primary requirement of second generation Expert Systems."

Many knowledge elicitation researchers, particularly in North America, argue that computerised techniques offer the best way forward, for example, O'Connor et al (1988) argue that "It is now widely accepted that much knowledge is needed to automate or even aid in conventional knowledge acquisition activities" and Shaw and Gaines (1987d) argue that "A move towards a labour-intensive activity such as Knowledge Engineering is contrary to all trends in industry; in particular it is contrary to the trend towards automatic programming techniques in the computing industry."

Musen (1989) argues that computer tools can aid the knowledge engineer in the elicitation process, but acknowledges that the role of the knowledge engineer remains fundamental, "Although the system can help people build models of clinical trials, Protege certainly cannot formulate those models on its own. The development of models is, fundamentally, a human activity; like all creative endeavours, the development of models is difficult."

Adopting a number of elicitation techniques has been argued to be a useful, if not an essential strategy. Some researchers argue that a comprehensive strategy can be formulated from the provision of a large suite of computer programs to interactively assess, elicit, and analyse data in many ways, from many sources, and from many perspectives. Most computerised elicitation methods use algorithmic versions of psychological testing theory. Further, some computerised elicitation tools use the data to generate rules directly.

Alternatively, the knowledge engineer can develop personal interview skills, be aware of underlying psychological testing techniques and communication theories and adopt a flexible, dynamic strategy, based on the personal interview. Further, it is argued here that only the personal interview technique can offer the subtlety, sophistication, and social environment necessary to deal with people (especially experts), to probe, empathise and change direction as necessary, to understand the situation in order to choose the most appropriate methodology as or when required. It has been argued (Johnson and Johnson, 1987) that language is our most cognitively complex communication tool, and the personal interview still offers our most sophisticated information transference medium.

It is concluded that the increasing complexity of KBS developments demands greater emphasis on deep causal knowledge, and more energy needs to be allocated to the elicitation process, not less. For sophisticated (arguably deeper) models of cognition or competence, the human input remains vital. Whilst it is acknowledged that alleviating some of the drudgery may hasten the knowledge elicitation process, computerised tools currently offer less cognitive power than the human. For example, Rajan, Motta and Eisenstadt (1988) argue "For better or worse, automated knowledge acquisition hasn't yet reached the point of making the knowledge engineer redundant." Rapid elicitation techniques appear to be heading tangentially in the wrong direction, as speed of acquisition, rather than the quality of information, is their major objective. For example, Welbank (1987) argues that "Induction and automated repertory grid are very fast and successful for shallow classification problems. They elicit just that knowledge which is necessary to distinguish between the different conclusions, which makes them very efficient but liable to miss the real richness of the domain."

Making assumptions about the domain (eg Musen, 1989), prior to investigation, in order to speed up the process is inappropriate to fields of exploration that are believed to be different to current areas of KBS application. For example, Burton and Shadbolt (1987) argue "Certainly mapping KE techniques onto domains often seems plausible, but then alternative mappings seem equally plausible. For instance, it is all very well to recommend a procedural technique when tapping procedural knowledge, but how is a novice meant to decide what is procedural and what is declarative for a given domain." It has been argued previously that design must be viewed as a problem that can not be simply described by heuristic classification, diagnosis, bottom-up construction, or hierarchical or skeletal decomposition (chapter three).

Our current understanding is much too poor to make presuppositions about the form and structure of design knowledge. This situation is likely to be improved when thorough knowledge elicitation studies of design become more widespread.

4.8 An approach to the elicitation of design knowledge

Characteristics of the design activity have been identified by design researchers and others (chapter three) that aptly distinguishes design from those of planning, diagnosis and problem-solving. Current views of design knowledge acquisition view design, hence design elicitation, as hierarchical top-down decomposition (Chandrasekaran, 1988) and bottom-up construction (Marcus, 1988) and apply the reductionist approach of science. The approaches themselves are not disputed, but it is argued here that design research offers alternative viewpoints of design strategy, most notably that the holistic nature of design is important (Cross and Nathenson, 1980; Bijl, 1985).

However, 'routine design' appears different from the intuitive and reported characteristics of design discussed previously (chapter three) and is disputed here as an acceptable conception of the broad process of design. Routine design, where constraints are known and well defined, appears to be closer to a problem-solving planning task (Tate, 1985) than a design task. The discovery of constraints is integral to the ill-defined nature of the design process (Simon, 1973) and Archer (1979) argues that in design, "the requirements, as given, do not contain sufficient information to enable the designer to arrive at a means of meeting those requirements simply by transforming, optimising, or superimposing the given information alone." Further, Dreyfus and Dreyfus (1986) post a telling argument against addressing severely limited problems, where real difficulties have been excluded in the belief that they can easily be overcome with developments that progressively ease the restrictions. It is unlikely that the exploration of routine design will offer valuable cornerstones to the building of an understanding of creative design. It is argued here that a broad (holistic) approach is suitable, where restrictions must not transform the problem being addressed (design) into another (planning).

Marcus (1988) argues that a computer based framework can enable designers to describe higher level structures in a bottom-up fashion from components. The approach is based on the argument that basic components can be most easily identified, first, and then the task of progressively organising and structuring the information can proceed. It is argued here that for many design situations, the bottom level of decomposition may not be immediately obvious, and identifying components may not be simple. For example, the number and depth of characteristics that can be elicited from a collection of photographs is perhaps immeasurable, and is context dependent (ie, when viewing a photograph, new criteria can be established for any new group of photographs, and the number of possible groups of photographs is unbounded). It is further argued that whilst designers can identify components, they may not actually be able to provide information of how such components interact at the component level. The interaction may be too complex or involve perceptual processing. For example, in the page layout design example discussed later, the terms *weight, balance, colour, impact* and *emphasis* can be applied to the components *headline* or *pictures*, but attempting to elicit information about their interactions is unlikely to yield reliable information.

The reductionist theory of scientific analysis, diagnosis, classification, hierarchical decomposition or bottom-up construction appears less appropriate to design problems, and gestalt theories are more important. For example, Bijl (1985) argues that the process of analysis "is to decompose a problem into parts until individual parts are recognised as being amenable to known operations, and results are reassembled into a solution. This process has a peripheral role in design...the absence of well-defined and widely recognised criteria for design excludes it from the main stream of analytical developments." Therefore, design can not be generally described in terms of the function of ever smaller sub-components. Asking the designer to describe details of complex interactions in a bottom up manner will probably introduce inaccuracy in the knowledge elicitation process since the expert designer is unlikely to consider details of individual components, and Bijl (1985; cited in section 1.4) further argues that it is not practical to define, or decompose into discrete parts, entities that are subject to complex interaction.

4.8.1 A holistic strategy for design knowledge elicitation

It has been suggested that high-level strategic knowledge, and knowledge structures used by design experts depict complex interrelationships that are probably not decomposable. Thus, although explanations of the nature of sub-task or component level interactions may be ventured, they are unlikely to form accurate models of the design activity. They are more likely to be inferred explanations not based on any true knowledge. Simply, the designer is unlikely to comprehend the design at the component interaction level. However, it is likely that holistic strategies for representing and dealing with complex interrelations are cognisible by the designer, and some of this information may be available to (verbal) explanation mechanisms, even though details are probably not. It is postulated that high level holistic structures describe valuable information about design expertise. It is argued that reductionist philosophies of knowledge elicitation are less appropriate for design applications because design is intrinsically more dependent on a subtle, but nevertheless powerful contribution from a form of knowledge that is altogether more holistic in nature (Hatvany, 1985).

Kornell (1987) identifies two kinds of thought (narrative and formal) and argues that current knowledge elicitation tools fail to take account of the distinction. It is observed here that narrative thought appears more closely associated with the form of design information (metaphors, analogies and gestalts), and formal with that of science and problem solving (Darke, 1979; Ward, 1984; Bijl, 1985). This suggests that current knowledge elicitation tools may not adequately address the form of design information.

The need to elicit, and explicitly model preferences has only recently been recognised as an important consideration for knowledge engineering (Bradshaw and Boose, 1990). As discussed previously (chapter three), design is often greatly affected by personal preferences, and methods of design elicitation should address the acquisition of preference-based knowledge.

Autonomous visuo-spatial and visual perception mechanisms are probably utilised directly when designing, and are not open to verbal access. Such mechanisms are, as yet, largely unknown and not open to methods of knowledge elicitation. Perceptual and psychological testing studies offer promising methods of revealing information of this type, and research into visual perception may also be a source of enlightenment. It is argued here that investigations through empirical study are distinct from the process of knowledge elicitation, described here, because in such tests it is necessary to gather information outside of the expert's conscious awareness, or explanation mechanisms. Broadly, it is the expert-based explanation facilities of KBS that distinguishes them from other application programs.

Evidence that designers can communicate expertise is demonstrated by the 'apprentice' approach to design education and practice (Gero et al, 1985). It is postulated that considerable design information is still available to methods of knowledge elicitation. The task of design elicitation must be addressed because there remains a scarcity of realistic methods for design elicitation, and a paucity of the intelligence in design KBS. The identification, structuring and modelling of determinants may yield useful design information, and theories may also provide the necessary framework for focused empirical study.

Computer tools have already been developed to aid both bottom-up and top-down approaches to elicitation (eg. Rajan, Motta and Eisenstadt, 1988). It is argued here that the elicitation of design knowledge should progress in a global way, to elicit higher cognitive concepts (but not through hierarchical decomposition), and the lower cognitive concepts (but not through component level construction). Understanding is often most opaque in the centre of our conception, paradoxically where the information is most interesting. For example, we can easily identify products of the visual apparatus (red bus, tea cup, a stack of dead leaves) and science has revealed that the retina of the eye is constructed of numerous light detecting cells; understanding what goes on in between is not so simple.

It is postulated here that the knowledge engineer should become familiar with information *as it becomes available* from the most natural form of communication with an expert (human-human), preferably in a repetitive cyclic process to avoid fixed perspectives. Easily understood concepts may be learned first, and as more information emerges the process of organising, explaining and structuring the understanding will progress. Note that easily communicated concepts are likely to be both conceptually high and low, and mixed in natural discussion. The information emerging from the expert will almost certainly be unstructured and ill-defined since the designer will not know the extent or structure of his own knowledge and therefore asking him for high or low level concepts is rather impractical and inefficient. Nevertheless, when the expert is communicating naturally, the knowledge engineer should be able to acquire information in a global way, narrowing the understanding gap more rapidly than choosing a single top-down (decomposition) or bottom-up (construction) strategy. This is in essence a holistic learning strategy (discussed in section 3.4), and learning is surely the purpose of knowledge elicitation, but of interest here, it is also recognised to be an important strategy for design (Tovey, 1984). The teachback methodology, discussed above, promotes a progressive learning strategy to knowledge elicitation, and is argued to facilitate the acquisition of *global* knowledge structures (Johnson and Johnson, 1987b, p93).

Knowledge elicitation cannot be principally concerned with the automatic generation of computer representations of knowledge since, for example, the form and structure of design knowledge is certainly not yet clear. The construction of computer representations for design knowledge must develop from the data driven approach, when the form of the knowledge is clear and only after the elicitation of independent models. The use of Intermediate Representations is clearly an important strategy for the development of independent models (of cognition or competence), and Mediating Representations provide a suitable mechanism for the interactive and progressive development of models of design, using a global strategy, diagrammatical methods and human-human communication. Diagrams have been recognised elsewhere (eg Lee et al, 1990) to be a useful mechanism of knowledge transference.

The purpose of knowledge elicitation is to develop a model of understanding, which is neither simple nor easy, and computers are not yet capable of doing this (Musen, 1989). Constructing a model of design must therefore be performed by the knowledge engineer. The engineer must learn and develop an understanding from whatever information is available, initially, or can be obtained when progressive developments drive the learning process.

It is concluded here that current automated tools that rely on reductionist approaches to the elicitation of design knowledge fall short of the ability to understand, model, and represent design knowledge. Simply, they lack the cognitive power of the human intellect. Qualitative and personal interview strategies currently offer the most promising approach to the elicitation of design knowledge.

4.9 The Elicitation of design knowledge

Important processes, such as visual perception, probably contribute significantly to design but are unlikely to be available to verbal access. Elicitation procedures for design must at least provide the medium by which spatial and holistic forms of knowledge can be recorded, represented and communicated. It is assumed here that some useful design information is available through verbal access. Considerations for the elicitation of verbal design data centre on the need to accurately record data, and in the confidence that the obtained information is accurate, and not an inference of what the originator cannot feasibly introspect.

Psychologists (Nisbett and Wilson, 1977; Bainbridge 1979, 1986) question the validity of verbal reporting as a means of explaining mental behaviour. Distortions are, however, believed to be dependent on the type of reporting task and in review of pertinent literature Ericsson and Simon (1980) conclude that there is likely to be only minimal interference in think aloud situations. Instructions are unlikely to prevent the normal sequence of cognition. Interference may occur when subjects are asked questions, or required to explain actions. Even then, interference may not be substantial, in contrast to post task reporting, where explanations are ineffectual and inaccurate (Berry and Broadbent, 1984). Thus, Bainbridge (1979) argues that "Although verbal reports can be a poor reflection of what is going on in the speaker's head, if techniques are used with care then verbal data can be both interesting and useful."

Further, Bainbridge (1979) recommends that a combination of techniques, such as preliminary interviews, structured interviewing and verbal protocols will yield most information but may take considerable time, and also task-solving situations (Protocol Analysis) are probably most appropriate for design applications (Bainbridge, 1986). Welbank (1987) argues that "Protocol Analysis is really the only way of discovering the expert's problem-solving strategy, as most people are not aware of how they solve problems."

Design information may be obtained through protocol analysis techniques. For example, protocol analysis was used by Eastman (1970) and Akin (1979) in the study of the design process, and Paul Johnson et al (1988) discuss a knowledge elicitation case study in industrial experimental design. Non-verbal information may also be communicated, but unconsciously submitted (ie through gesticulation). A video camera can capture much of the non-verbal communication and will record the spatial aspects of the design task. Therefore, the view that "Video ... seems too expensive and impractical to recommend" (Gammack, 1987) is rejected. It is argued here that the visual and spatial data provides a useful, if not vital contribution to design elicitation. Anaphoric references are often used and gestures form an essential part of the communication. Asking the subject for clarification may interfere, and the explanations will be suspect if the designer attempts to rationalise that what he aught not. Video records can capture the holistic, diagrammatic, and dynamic nature of the task, and in addition, there is the soundtrack.

4.10 Summary : A method for the Elicitation of Design Knowledge

A two-stage elicitation process based on the personal interview offers an appropriate strategy for design elicitation, when considerations of the spatial and holistic nature of the task are taken into account. Video records (of design problem solving) and diagrammatical methods are believed to provide suitable mediums of communication.

Informal discussions with page layout designers indicate that they are capable of explaining their actions whilst designing, and they naturally provide (verbal) criticism of complete designs. Targeting subjects who are familiar with talking aloud, whilst designing, can help reduce the distortion, and alleviate the conscious inhibitions usually associated with the task. For example, lecturers in design are suitable candidates, although care must to be taken to ensure that the subjects are also competent designers, otherwise they may merely know design theory, which has been shown to be unrepresentative of design practice (Lawson, 1980; Darke, 1979; Jerrard, 1986), or possess knowledge of how others design, and explanations will be inference based.

Recording task situations, using protocol analysis techniques, provides the basis for eliciting task-specific aspects. However, protocol analysis is less effective at eliciting deeper causal knowledge. A flexible semi-structured interview incorporating other methods (as or when needed) in conjunction with protocol analysis provides a balanced approach.

The teachback interview technique is concluded here to be a potentially useful method by which design information can be developed, represented, structured and checked. In particular, the diagrammatical representation is believed to be an important method of communication with designers. The computer-independent representation scheme offered by this technique has been argued to be an important concept of knowledge based systems development. Design, as previously discussed, is poorly understood. Therefore, in the absence of realistic evidence of the form and nature of design knowledge, the structure can not be presupposed before elicitation and it seems manifestly wrong to impose computer representation formats that may guide or restrict the elicitation process.

4.11 The knowledge elicitation study of page layout design

'Visual' information, and spatial processing skills, are characteristic of many design applications, and it is asserted here that knowledge elicitation research should conduct studies in problems that involve this type of information. Therefore, a visual communication task is particularly targeted for study, through a *graphic design* task. Page layout design is a pertinent example of a design task that incorporates visual and spatial design skills.

Page layout design exhibits essential characteristics that are believed to exemplify design, such as arbitrary decisions, personal preferences (style), multiple solutions, and creative input[2]. To be a worthy subject for knowledge elicitation, the design task must also exhibit the essential characteristics of expertise; be grounded in established 'rules' and common practices of a highly skilled profession and also represent the experiential, idiosyncratic and personal nature of the individual expert.

The objective of page layout design is to produce a drawing, a blueprint for the subsequent printing process. The designer is provided with information about the design task, through a design brief. The area of the design is usually specified, as a design *grid,* and the designer will be given pictures, text and a headline. Perhaps additional restrictions are in force, such as limitations on the availability of typefaces, the number of pictures to be used and other 'rules of the house' that must be followed. However, it is worth emphasising that the specifications are very loose, and the designer often has considerable personal choice.

Page layout design encompasses a great range of design activity, and a restriction to the domain of *internal house magazine* design is necessary to constrain the investigation to manageable proportions. However, broad issues of page layout design and visual communications are also addressed through elicitation methods that explore global and general perspectives, through personal interview situations.

Chapter five describes the development of a method for the elicitation of design knowledge, through the example study of page layout design. To indicate the success of the method, and to qualify the interpretation placed on the data, an evaluation study is conducted. The evaluation procedures and the results of the evaluation study are discussed in chapter six.

[2] Creativity is not discussed here because of the lack of clarity and coherency of accounts of its form, and therefore, the difficulty of identifying or measuring it (Lawson, 1980). However, the creative input is not eliminated from the study, and a natural and typical design task is studied in the protocol analysis stage of the elicitation procedures.

5 A method for Knowledge Elicitation in Design, as examples from the page layout design study.

5.1 Introduction

In this chapter a methodical approach to the elicitation of design knowledge, based upon the teachback method (Johnson and Johnson, 1987b; Johnson, 1987), is described. The three stages of the procedure, outlined below, are discussed in detail following the introduction.

The review of knowledge elicitation procedures (chapter four) indicated that it is desirable to elicit both task specific information and also deeper underlying and structural knowledge. It has been argued that recording experts whilst completing a task (protocol analysis) is best for eliciting task-specific and procedural types of information (Welbank, 1983), whilst global and deeper knowledge can be obtained using the flexible semi-structured interview techniques (Johnson and Johnson, 1987b). As previously noted, the qualitative approach (Bliss, Monk and Ogborn, 1983) appears a suitable strategy for acquiring much information (Littman et al, 1987), and considerable feedback through expert participation is obviously desirable.

5.1.1 Outline method for the elicitation of design knowledge

The proposed method consists of a three-stage acquisition and analysis procedure. Following a Preliminary Stage, Stage One involves protocol analysis and semi-structured interviews with many experts. Stage Two concentrates on a single expert, in order to develop and check the understanding through teachback.

1 Preliminary
- Casual discussions
- Preliminary trial

2 Stage One
- Protocol Analysis of design task
- Semi-structured Interviews
- Categorisation of visual data

3 Stage Two
- Teachback
- Diagram development
- Communicable report

5.1.2 The designers

As noted in section 4.11, the page layout design task was selected for study. The experts were chosen from a variety of ages and backgrounds, to reduce the impact of personal or commercial styles. Lecturers of (graphic) design were particularly targeted because it was believed that they would be comfortable with the notion of talking whilst designing (protocol analysis) and be sympathetic to answering questions (semi-structured flexible interview, teachback interview). Four expert designers participated in Stage One of elicitation (E0, E1, E2, and E3) and one expert (E0) was used in Stage Two, involving the teachback method. All of the experts had considerable practical (commercial) design experience.

Computers are increasingly being used in page layout design, and a general aim of the study was to obtain knowledge that could be used in CAD[1]. The response to specific questions about the development of computer based page layout design tools is documented in chapter eight. However, in preliminary discussions it became clear that current computer systems for page layout design are not sufficiently advanced to accommodate a natural form of the task. Hence, basing the elicitation study around current computer technology would have added unnecessary restrictions and in addition using a computer was not the usual, or most common method of design for the designers involved. Page layout designers are, however, familiar with the traditional 'paper' methods, and hence this environment was chosen as the least biased and most typical and, in addition, the most flexible and acceptable to the designers.

5.1.3 Example concepts

Two main examples are used in the following discussion to illustrate the elicitation and development of concepts. The examples are chosen to be very different to indicate that the methods are capable of dealing with high and low level concepts and deep and shallow forms of design knowledge[2]. The first example is reasonably straightforward; the concept of not leaving one column of text a different length to the others *(short measure)*. The second example deals with a more complex, abstract concept, *image*. The relevant transcript excerpts for these two examples are collated for easy reference in Appendix 6, although context is important, and context can be appreciated through consultation with the full transcriptions in Appendix 2. The referenced notes appear in Appendix 9 and the glossary of terms (Appendix 5) may also provide additional assistance.

5.2 Preliminary Stage

The preliminary stage had four main objectives:

Communication and Familiarisation. Through discourse, the terminology and phraseology of the domain can start to be elicited, lessening the need for explanations in subsequent stages, particularly in the drawing tasks where the designer should not digress. At least a rudimentary understanding will enable the knowledge engineer to understand what the designer is saying in the design task, and provide basic terms for the interview discussions, without appearing a total novice and losing the interest of the designer. The study may be disadvantaged by the knowledge engineer appearing stupid, through an inability to communicate.

Feasibility and Practicability. It is important to investigate whether a Knowledge Based System is really needed or wanted, and if so what is required. Also, knowledge elicitation may not be a practical option, and the relevancy of procedure to domain certainly needs to be

[1] Care was taken to select experts from a mixed background of computer experience. E0 and E1 had some, but restricted knowledge of computer and desk top publishing systems. Designer E2 works for a company that develops computer technology for the publishing industry. Finally, E3 was not at all familiar with computer systems, or even basic desk-top publishing systems.

[2] The terminology adopted here is discussed in section 4.1.2.

addressed. It was important to establish that verbal reporting was possible, and reasonably natural for the page layout designers.

Design of Study. Further to above, the likely parameters, environment and requirements of the study can be assessed. For example, the problem-solving (drawing) task needs to be devised and relevant questions need to be prepared.

Social factors. The designers may have apprehensions concerning the objectives and motives of the study. Discussions can allay anxiety, and thereby reduce self-conscious inhibitions. A relaxed and friendly atmosphere will promote cooperation.

5.2.1 Preliminary (casual) discussions

The initial phase of the study, which was not recorded, involved a casual review of the design task, through informal discussions with expert designers. From these discussions it was possible to assess whether computer developments were needed and wanted, but more importantly, whether the designers were likely to cooperate freely in the knowledge elicitation process.

It was evident that automated methods of knowledge elicitation were unlikely to cater for the visual aspects of designing, where the expert draws and sketches. This result supported the suggested approach of a two stage elicitation process, based on the personal interview. Also, encouragement for the project was gained from the apparent value that the designers afforded to developments in computer aided page layout design, although expectations were varied, and occasionally unrealistic.

5.2.2 Preliminary Interviews

As a progression of the casual discussions, the preliminary interviews investigated the domain a little more closely, and were recorded. Two interviews were used, the first was a blunt discussion of the problem parameters, and the second was on the suitability and requirements of computer systems. The preliminary interviews also had the benefit of familiarising the designers with the notion and practice of being recorded.

The prepared statements took the typical form (Hart, 1989; Kidd, 1987a):

a (Q0001) What are the inputs to the problem ?
(Q0004) Which of the inputs are likely to cause difficulties to the designer ?

b (Q0031) Do you think computer systems can aid your task in any way ?
(Q0033) What would you like a computer system to do for you ?
(Q0037) And in what form would you expect it to communicate with you ?

The preliminary interviews were transcribed (Appendix 1), and domain terms were identified and checked back, in the form of a glossary, with the designer until an agreed vocabulary (Grover, 1983) was established (Appendix 5a). Thus, a basic conception of the language, terms and domain components were formed, which enabled the subsequent procedures to progress more effectively. To avoid problems that might have arisen from developing a fixed perspective, too early on in the elicitation process no further processing of the preliminary (or any other) data followed until all the interviews were collected.

5.2.3 Preparatory trial

As a means of preparation, a 'preliminary' trial was conducted that included extended interviews, to enable the elicitation of general concepts and background information before the subsequent study was attempted. The preparatory trial also facilitated the testing of the elicitation programme, the discovery of procedural anomalies, and the identification of changes that might be necessary (ie, whether the prepared statements of the flexible interview were yielding the information being sought). However, the 'preparatory' study yielded information too valuable to be disregarded[3], and the data from this source was included in the interpretation phase, although early interpretation was avoided.

5.3 Stage One: Protocol Analysis and semi-structured interviews

In Brief, the designers were first asked to design layouts, whilst their actions and explanations were being recorded (video and sound). Subsequently, data pertinent to deeper aspects of the design task were elicited through a semi-structured interview format. A simple grouping task was also included at this stage. A video recorder was used to record key visual aspects that otherwise could not have been easily captured.

Video recordings appear an effective method of capturing visual and spatial information such as drawings, actions, indications and hand gestures. The video tape recorder captures the dynamic nature of designing, and faithfully preserves the temporal sequence of drawing and layout development. Additionally, the video tape alleviates the need to carefully note indications, hand movements and sketches during the task, as they are effectively recorded. Thus, the knowledge engineer was able to concentrate on the knowledge elicitation task itself, although the designers themselves remarked that they initially felt uncomfortable being recorded by the video camera. A familiarisation period helped to reduce any tension; through an informal talk with the designers (before the main study commenced), where the camera was left running. Whilst self-consciousness initially hindered the designers, they soon became engrossed in the design task at hand, forgetting that the camera was present. The video camera was not used in Stage Two, since the interviews were primarily concerned with discussion, as opposed to problem solving, and a less formal atmosphere was desirable. Here, a note book was used to record diagrams, notes and comments, and the designers were encouraged to make sketches in the notebook. In principle, the video camera could also have been used in the second stage, although it is unlikely that it would have yielded much additional benefit. With the exception of the video tape, the procedures for recording problem-solving activity were typical of those documented elsewhere (Ericsson and Simon, 1984).

[3] The preliminary discussions often included clarification of very basic domain concepts, terminology, and procedure. The understanding arising from such rudimentary explanations is clearly needed for, and utilised in, the subsequent elicitation process. However, the explanation of the simple facets of the domain provides an extremely useful, if not essential, starting point for other people who wish to understand the domain.

5.3.1 Protocol Analysis

The qualitative nature of investigation allowed the study to be tailored to selectively address issues of interest, and to reduce the effort expended on clearly irrelevant data. Hence, the study was broadened by incorporating slight modifications to the problem-solving task, although remaining fundamentally the same for each designer. The variations are detailed below.

5.3.2 The design task

Each expert was asked to design a page from a given brief (Appendix 4a) that consisted of headline characters, pictures and sample text (Appendix 4c and 4d). The brief contained additional information about the nature of the task, and other restrictions such as the design grid they were to use (Appendix 4b). However, it is worth noting the openness of the design task.

To prevent the designers applying World knowledge, based on the content of the design elements, the pictures and text were obscured whilst preserving their visual properties as far as possible. For example, certain text characters were replaced by visually similar counterparts, rendering the text nonsense but still preserving the appearance of text. Below *r*, *t* and *e*, *n* are interchanged.

Textile trades were the first	Rnxriln rtadns wntn rhn fitsr
foundation of Derby's industrial	fouedarioe of Dntby's iedusrtial
growth, but through two hundred	gtowrh, bur rhtough rwo huedted
and fifty years the engineering	aed fifry ynats rhn negienntieg
industries have become dominant	iedusrtins havn bncomn domieaer

This precaution removed, to a certain extent, the context dependent nature of the design situation, and enabled more general, rather than article specific, concepts to be addressed.

The first expert (E0) was given the most natural and typical design situation. A given amount of text was presented to him, where neither the style nor size could be changed. A headline was provided, with a restriction on the choice of allowable typeface. A number of (natural) pictures were provided and specifications were given on the content ("one ship and one personnel") and on the number of pictures, a minimum of three, to be used. (The parameters of the text size (ie, total number of characters) and the number of pictures remained constant throughout the design tasks). Considerable time was taken by E0 on making decisions about the *content* of the pictures (what the pictures were of, and how they related to the rest of the article). Clearly, these decisions form important contributions to page layout design, but the information was too content specific to provide useful (general) data.

The second expert (E1) was given a simplified task. To avoid the designer applying World knowledge on the content of the given material, all of the design elements containing information were obscured. The body text and headline text were carefully altered so that the natural appearance was preserved, yet making the words nonsense by replacing certain characters with visually similar counterparts as before. The pictures were digitally obscured to prevent the designers from directly interpreting the information whilst preserving, as far as possible, the natural tonal content of the pictures (illustrated in Appendix 4d). Thus, the designer addressed basic visual qualities of the pictures, devoid of semantic meaning. In order to test this hypothesis, the digitally obscured pictures were included in a grouping task in the second part of the interview process, the aim being to establish if there was a basis for classifying or selecting the pictures, and whether the designers viewed the obscured pictures as being devoid of content. Since the *size* of the body text greatly effects the outcome of the design, the designer was given the choice of the size, but the *typeface* was stipulated *(Times).*

In the third (E2) and fourth (E3) layout tasks, the body text was not obscured, but the headline text and pictures were obscured as above. A variation of headline was incorporated. In these cases the designers were required to make more decisions about the choice of the body text style. A number of samples of text were provided, at various sizes and styles of typeface, with respect to the fixed number of characters. The given samples were chosen to be typical. The designers could use any size or style they liked, irrespective of whether or not a sample was provided, but they needed to calculate for themselves the details of text not given in the samples.

5.3.3 The flexible semi-structured interviews

To address some of the more global aspects of the design activity, a second interview procedure was designed. Interesting responses to questions, which were written on prompt cards, were further probed, whilst questions that were obviously not yielding valuable information were dropped or modified to suit the situation. Items of interest identified in the design task were also probed in greater depth.

The main purpose of the flexible semi-structured interview was to ask more subtle questions pertinent to the deeper competence of the designers, and also on how their skills are acquired (Ogborn and Johnson, 1984). For example, the experts were asked how long they had been practising design, how long it takes to become expert, how a trainee becomes expert, and what are the learning processes involved (ie, how did they learn, themselves). The aim was to elicit deeper underlying knowledge, as an addition to that which could be obtained through the recording of the design tasks.

As previously stated, to uncover information that might enhance the usability, suitability and functionality of computer systems in the domain, specific questions about the role of computers in the design task were also asked (Kidd, 1987a).

5.3.4 Grouping task

A grouping procedure was incorporated to provide an alternative perspective to the elicitation process, and perceptual data was used; the pictures employed in the design task. It has been argued that design concepts are highly interrelated and probably not amenable to hierarchical decompositions of the kind generated by more complex sorting processes. Therefore, a simple categorisation procedure was adopted as it was believed that, for example, MDS would be inappropriate and excessively tedious.

The pictures were spread on the table and the designers were asked to group them in any way they wished. The names of the groups were noted and the designers were asked to make further divisions of the categories, if they could, or wanted to. The pictures were once again dispersed and the process repeated until the designers could no longer make classifications.

For example, it was observed that pictures with the visual property of being light at the top and dark at the bottom, separated by a form of horizontal line were termed *landscape*. However, an interesting result was that the most important property of the pictures (after *content*) was their shape *(format)* rather than tonal or visual properties[4].

5.4 The knowledge elicitation process as a gradual refinement of an understanding through expert feedback : From transcriptions to a documented model of cognition

The following section describes how the generated data was transcribed, collated, refined and interpreted. Here, the knowledge elicitation and analysis procedures were intertwined.

Progressive stages of the analysis incorporated increasing levels of interpretation, using the transcriptions of the design tasks and the interviews as the starting point. The approach was based on Grounded Theory (Glaser and Strauss, 1967) where the transcripts were used to generate interpretations still rooted in the original data. Notes, diagrams and questions were put to the designer for comment, discussion or development. Casual questions relating to clarification of terms (for glossary definitions, for example) often produced diagrammatic illustrations and additional information. The page layout designer involved liked to use diagrammatical illustrations, and this method was used to great effect in conjunction with verbal explanations.

Much ambiguity was resolved fairly simply, although some concepts were complex and required many sessions before coherent interpretations emerged. Coherent interpretations sometimes failed to emerge, for example the definition of *weight* and the subtle difference between *impact* and *emphasis* proved extremely difficult to elicit.

5.4.1 Teachback

The second stage of elicitation involved the extensive interviewing of a single expert; approximately forty hours, spread over a nine month period. A semi-structured approach was taken, based on the 'teachback' methodology (Johnson and Johnson, 1987). A flexible and productive communication flow was aided by an intermediate representation format (SGN diagrams; Bliss, Monk and Ogborn, 1983). The elicitation of the spatial and visual components of design was supported by the expression of ideas through sketches and diagrams. However, sketches were often also accompanied by verbal explanations.

The designer was presented with diagrams, notes, summaries and other material to be discussed and worked over, with the knowledge engineer attempting to explain concepts identified in the first stage of the elicitation, back to the designer. The designer was also encouraged to discuss, sketch and criticise.

However, the teachback process often generated additional, useful, and more general information, through the investigation of simple concepts. This demonstrates the usefulness of adopting a global strategy to knowledge elicitation. For example (Appendix 9k), the exploration of the relatively simple concept of *short measure* results in more complex information about how "a house magazine will appear *inviting to read* by not having a *short measure*." Through many

[4] Some of the information resulting from this study is represented in Appendix 9p.

discussions, a conception of the design task was elicited, checked and modified through extensive feed-back.

5.4.2 Transcriptions

The first stage of analysis involved transcribing the data from the sound and video recordings. The sound track provided the basis of transcription and the video data was principally used to resolve visual and spatial references occurring in the design tasks. The video recordings formed a vital contribution to the knowledge elicitation process and were most useful when the written, static transcriptions proved inadequate for the purpose of interpretation. Thus, transcripts were annotated with comments, to indicate the nature of visual indications, and references to drawings or sketches. As familiarity with the transcripts and sketches progressed, this method was an effective way of capturing the data in a written form, that was checked by referring back to the drawings and the video records (refer to Appendix 3a for an illustration of the example below).

E0:140 If I were to put it in here [I7], I'm going to have a problem because
0:20:01 if I put 'Then & Now,' it might look okay in that space {below I7}, but that space may be too open. What we' re not going to see on the finished page is these nicely ruled lines {the grid}. It' s going to be blank there, so what we' re going to see is the space of that margin and an open space there {between edge of page and the headline} and then an open space down there {between headline and start of text block}.

To enable effective reference, the transcripts were divided into chunks believed to describe discernible statements, and indexed sequentially. The video-tape index number was also included. Besides allowing for the rapid selection of video data, the video tape index number provides a time-based counter, a useful reference point in hours, minutes and seconds. Hence, the transcripts (Appendix 2) also contained an indication of how long tasks, diagrams, or decisions were being considered by the designers.

5.4.3 Mapping of 'design procedures'

A document outlining the stages and procedures of the design task was formulated (Appendix 7) and presented to the designer as a basis of checking, development and (more importantly) further discussion. However, no special importance was attached to this account, but it provided encouragement, showing the designer that communication could be established, and that the whole process of knowledge elicitation was not just a waste of time. In fact, the document required few alterations and was quickly and readily accepted as communicating a reasonable account of the design method.

5.4.4 Identification of domain terms (Index of terms)

The next stage of analysis involved the scanning of the transcribed material for key references of the domain language (Figure 15, Appendix 8a). Verbs and nouns referring to domain procedures, objects or entities were identified (called concepts or terms in the following discussion). The preliminary discussions provided the starting point for the building of the 'common language,' which progressed through the preliminary trials, and the development of an initial glossary (Appendix 5a). The set of terms of the emerging language were identified through a cyclic, iterative process. Obvious references were identified first, and as a better understanding emerged, more subtle terms were added. Initially, the terms were collected into a simple list, for glossary definition. Then, each word was annotated with a reference number to where the word occurs in the transcript.

At first, only direct references were included, but statements that also referred to the concept in the absence of a direct reference, were gradually added. For example, the preceding line may have made an actual reference, or a reference was clear from the context of the situation.

For each term, references differ in degree of importance to the developing understanding. Highly informative references were highlighted, to facilitate a more effective access system by allowing the rapid identification of pertinent features of each term (Figure 15), allowing the interpretation phase to begin through qualitative decision making (ie, value judgments).

short measure (uneven lines)
0161, **0162**, **0163**, 1003, 1110, **1145**, 2026, 2075, 2081, 2083, 2084, **2089**, **2091**, 2094, 2095, 2097, **2114**, 2115, **2116**

image
0014, **0015**, 0016, 0049, 0050, 0084, **0085**, 0088, **0174**, **0175**, **0176**, 0260, **0307**, 1164, **2024**, 2025, 2041, 2042, **3014**, **3016**, **3017**, **3019**, 3055, **3057**, **3058**, **3059**, 3135, 3139, **3142**, 3150

light : Generally supporting the concept but actually giving little information.
Bold : Significant. Good information, either specific or general.
Underlined : Highly significant, giving valuable information

Figure 15 : Simple list of references, with highlighting

Also, the designers often used different terminology to describe the same concept, or apparently the same concept, and this needed attention. The concepts were resolved into a single term if the same, or where subtle differences existed, these were elicited. The expert provided direct feedback to help in the classification of such cases. For example, the term *picture* had many other equivalent terms; *photograph, half-tone, image, illustration.* Here, *picture* was the most general and widely accepted term. In Figure 15, *short measure* is preferred to *uneven line* although both terms were used interchangeably by the designers.

In summary, modifications to the indexes were progressive. Over several iterations many references were judged to be less informative, or described as other concepts that were catalogued more accurately elsewhere. These were removed from the list of references for a given term. Sometimes statements initially viewed as being of great value (highlighted) were later perceived as having little information, merely stating the obvious, and were deemphasised (not-highlighted). Also, some statements that previously appeared to contain little information emerged as being valuable, and were added to the list or were highlighted.

It is worth noting that the index is a simple collation of statement references describing terms of the domain language. The indexes and transcripts provide data that is virtually free from interpretation, facilitating a framework from which others can construct their own interpretations. For example, design researchers may find the data useful from another perspective.

5.4.5 Agreed Glossary of terms

As the building of interpretations of the transcribed statements progressed, a gradual assemblage of notes summarising interpretations of the statements was also developed (eg Appendix 9a, 9b). As the index was developed, each term was also given a form of definition. Some terms required several (eg *colour,* Appendix 5b). The glossary was compiled either interactively with the expert (ie. what does *that* mean ?) or a definition assembled and subsequently checked and modified through expert feedback. However, occasionally the experts found great difficulty in defining their own terminology and subtle variations in terminology existed between the different experts. Whilst many terms could be defined *(picture, headline, box-border, enlarge etc)* others, that were largely dependent on perceptual judgments, could not be adequately defined *(balance, weight, impact etc).*

5.4.6 Structured-index

The simple index actually contained very little information about the nature of the (rapidly developing) concepts themselves, merely a collation of references. To provide a further stage of analysis, and to increase the level of interpretation placed on the data, greater detail was provided through the development of the structured-index. The references were grouped into clusters of sub-categorisations. These sub-concepts often involved other terms identified elsewhere in the index.

short measure (uneven line)
  uneven lines/last line **0161**, (0162), **0163**, 2083, 2094, 2095, **2114**, **2116**
    layout/redesign **0162**, 2026, 2075, **2084**, **2089**, 2091, **2095**, 2097, **2114**, **2115**
    edit/manipulate/text 0162, 1003, **2081**, **2089**, **2091**
  rule/contain 1003, **1145**

Figure 16: The Structured-index containing sub-classifications[5].

Using the terms identified in the simple index, together with the first stage interpretation provided by the glossary and notes, each key term term was structured into clusters that contained groups of constructs under a relevant sub-heading. Thus, each key term was denoted by a list of references, or sub-classifications of references. Sub-classifications may contain further levels of sub-classification. Note that references may be duplicated under different sub-classification titles,

[5] The underline indicates that the particular concept, or cross-reference, is important. Indentation is significant and depicts successive levels of sub-classification, although the ordering within equivalent levels of sub-classification is less significant.

for example, the reference number 2095 in the above example (Figure 16).

Sub-classifications may occur multi-dimensionally and involve many terms and groupings. For example, the transcribed words "bold initial headline character" would have entries in all three key classifications *bold, headline* and *initial character*. The above statement can also be perceived as a *feature*, and an entry would also be made under this key heading, although not actually containing a direct reference. This example illustrates how progressive interpretations were developed.

The structured index gives an indication of the interrelationship between concepts. Figure 17 illustrates that references describing the concepts *typography* and *White Space* are important factors of relevance to *image*. The underlying context of the transcribed statements is also significant, and although this information is not evident in the reference structures, the summary notes represent additional interpretations (eg Appendix 9a, 9b).

image (presentation)

correct layout 0014, **0015**, 0016, 0049, 0050, 0084, **0085**, 0088, 0260, **<u>0307</u>**, 1164, 3055, **3057**, **3058**, 3059, 3135, 3139, 3150

function/market 0050, **0174**, 2025, **3016**, **3019**, **3057**, **3142**, 3150

typography/friendly **<u>0307</u>**, **2041**, **2042**, **<u>3014</u>**, **3016**, **3017**, **3019**, 3142,

<u>white space</u> **0174**, **0175**, **0176**, **<u>0307</u>**, **2024**, 2025, **<u>3057</u>**, **3058**, **3059**

Figure 17: Structured-index of image

Alternative views of categorisation and sub-categorisation were possible for any term. Thus, alternative sub-heading titles for the *image* might have been *pictures, friendly / serious, fashion / trend* and *aesthetics*. However, the particular choice of categorisation (Figure 17) was based on the development of an increased understanding, indicated by the terms and structure of the particular sub-classification. Several iterations were often necessary before structures were accepted.

All of the terms are, perhaps, related to each of the others other terms, in some respect. However, it was not possible to put every reference or classification for each and every term. For example, over three hundred and fifty glossary terms were identified in the page layout design study. Therefore, references under the key term only contained the most relevant entries describing the particular heading of the term. Thus, effective use of the structured-index required some knowledge of the domain, how it was represented in the index, where alternative or additional information for terms could be found.

Additional references may be traced by searching for terms that describe similar or related terms, or by viewing a term from another perspective. For example, by looking for the sub-classification term as a key heading in the main index, by matching the sub-classification headings (in the description of other terms) or by consulting the glossary[6]. Thus, it is possible to search for references to the term *short measure* (Figure 16) by tracing references under the key

[6] The index contains equivalent or related terms where additional references and definitions can be consulted, and the glossary also refers to identical or related terms.

headings *edit* or *manipulate*. However, references under the key term only contain the most relevant entries describing the particular heading of the term. Additional knowledge of the organisation of the index may be required. For example, the entry for *column* (Figure 18) contains references that may yield additional references to a particular view of interpretation, although not doing so in this case. The above example shows how increasing levels of structure, interpretation and inference are assimilated through the gradual understanding of the domain.

column
<u>uneven line</u> **0161, 0163, 1145, 2114**

Figure 18 : Cross-references can be found in the entries of other terms

The structure was pruned and reorganised to represent only the most important sub-classifications of references to each term. Some interpretation was needed to facilitate the grouping of constructs thought to be similar, related or identical so that related terms were managed in a single place. For example, as previously discussed, the terms *photograph* and *half-tone* defined the same class of object, and were accommodated by the term *picture*. Yet the terms *photograph* and *illustration* described subtly different concepts of the more general classification of *picture*[7]. Such classifications were only possible through the development of an advanced understanding, and the expert provided feedback to their accuracy and relevancy, through teachback.

5.4.7 Diagrammatical models of design

Confusion resulted from the emergence of a large number of interrelated concepts. Such confusion was dealt with by drawing and criticising diagrams, and getting the expert to criticise them. (SGN) Diagrams were progressively modified and refined through the feedback process, as shown in Appendix 9c to 9f. However, it was often realised that the diagrams were inadequate long before completion, and consequently an immediate development and redesign was required. Subsequent diagrams were interactively constructed utilising pertinent characteristics of the old diagrams, together with feedback.

The diagrams provided the knowledge engineer, and the expert, with a suitable medium by which more complex issues of the domain were communicated, using the basic depiction of structure as the starting point. The terms and structure were explained through the development of notes and diagrams (for example, Appendix 9i, top and centre). The initial understanding of the domain (represented in progressively sophisticated diagrams of structure) enabled a second level of interpretation to mature, where strategic aspects of the domain were investigated. As the teachback procedure continued, further interpretations that described strategy also required representation, however, the strategic knowledge could not be adequately integrated with the diagrams of structure, so separate diagrams were constructed. Thus, the initial attempts (Appendix 9c, 9d, 9e) focused on structure, but as the process continued the inadequacy of the representation emerged, as illustrated by the comment at top of Appendix 9d. For example,

[7] Refer to Appendix 5b for definitions, and Appendix 9p for an illustration.

Appendix 9g to 9k, chart further developments of the concept of *communication.*

The realisation that *image* was an important concept, relating to the high level functional structure, started to emerge through the exploration of the *goals* or *function* of the design task (Appendix 9f, lower diagram). The diagram was crude, and inaccurate, but nevertheless aided the development process. Appendix 9i, 9j (centre) shows some of the broad conceptions drawn from the the transcriptions. The concept of *image* in Appendix 9j, (indicated by 0259) denotes that transcript references 0259 and 0260 were relevant. Here, the additional comments of the designer, noted in brackets, were also of great value.

The diagram at the top of Appendix 9k shows the further development of the *image* concept. The designer was asked to characterise pertinent features of *image,* and these were identified as *what is the magazine trying to say, tradition,* and *to whom.* After depicting these three facets, the expert explained that it was *how you want people to feel about the magazine / article.* This was, at first, thought to be another sub-category (hence the "ho" underneath the last note "to whom"). However, before this was written in, the designer indicated the concept was a more general description of the term *image,* and the term was placed at the appropriate level of description. The above example illustrates the essence of the teachback method, where mediating representations (SGN diagrams) facilitate the common ground as a basis for communication.

Also, Appendix 9k shows the holistic development of interrelationships between *image* and other concepts *(communication, find way round, emphasis, impact etc).* The concepts were considered in the same conceptual structure, their development progressed simultaneously, and not through decomposition. In the developing diagram (Appendix 9k) the term *emphasis* was used extensively, and to clarify the term, the obvious question "what do you mean by *emphasis?*" was asked. The definition, aided by the structure of the diagram (noted at the top of the page 9k) is subsequently developed as a glossary definition. However, the difference between *emphasis* and *impact* (both are shown in the top diagram) was not resolved successfully at this attempt. As an aid to discussion, the diagram also helped in the further exploration of the term identified as *find way round.* Again, this resulted in valuable 'how to' knowledge (labelled "avoid"). Thus, the designer commented that the concepts :

a) *finding way round* relied on the "text (not being) in the wrong place" - relevant text should be in close proximity to the *headlines, pictures* other *text* etc.

b) *text* should be "associated with *pictures*" - the topic of the *text* should be related to the *picture.*

c) "the *headline* should be easily found" - the headline should not be too obscure and the page should direct the reader to the headline, through *emphasis,* for example.

The main diagram of Appendix 9g indicates that the diagrams can aid the reconceptualisation process, by providing a testable framework of understanding. Here, terms are duplicated in an attempt to find their correct place, are linked together, moved around and questioned. Many alterations were needed to this diagram, but it shows that the structure was developing successfully, since valuable criticisms were ventured against it.

The top of Appendix 9l (labelled 2/12/88) asked the question "does the concept of *image* subsume that of *subject matter,* and what does the *subject matter* subsume?" The expert stated that the *image* and *subject matter* were highly interrelated, and not decomposable in that way. Whilst the expert refutes the initial idea being tested, Appendix 9l indicated that the expert responded by giving useful information, and goes on to describe the nature of each construct. Hence, *image* is concerned with the "general way of communication" whilst the *subject matter* describes "the particular topic."

Appendix 9h shows an interim diagram of *communication*. Whilst developing the concept *(communication)* from other perspectives, it was immediately apparent that the diagram was an inadequate representation of the notions of *subject matter* and *image*. In fact, these important constructs were omitted from the diagram, and a note to that effect was made. From the perspective of the *image*, the diagram was a retrograde step. However, failures are necessary for evolution and the above example (9h) illustrates the exploration process, and it also indicates how the technique enables the global development of related concepts.

Armed with the additional information obtained through the above discussions, the (main) diagram of Appendix 9g was reviewed and modified resulting in the sketch at the top left hand corner (also labelled 2/12/88). However, some confusion with *subject matter* remained, as illustrated by the note above the diagram. Discussions with the expert concluded that the *subject matter* is relevant to all of the aspects depicted in this (fairly advanced) diagram.

More detailed facets of the particular example of *house magazine* were also elicited (Appendix 9l, label 9/12/88). Important concepts appeared to be those of being *friendly* and *inviting to read*. Further exploration yielded that having "big pictures," "less white space," "more pictures," "a feature" etc. were pertinent factors[8] of being *inviting to read*. The co-relation (curly bracket of the SGN representation) represents the notion that the above details were also important to the concept of being *friendly*. Thus, a *friendly* magazine has lots of big pictures, little white space and does not have big blocks of text. Whilst the diagram appeared to faithfully represent these features, other co-relations *(quality* and *flexible)* did not appear to fit quite so well. Having *less white space* does not necessarily make the magazine more *flexible*, for instance. Hence, the diagram was good, but not perfect.

The above example illustrates the value of diagrammatical techniques and how anomalies were quickly identified. Resolving such difficulties was a matter of development requiring much effort, patience, trial and error, and expert feedback. Appendix 9a and 9b (labels 3016-3019) also depict written data relevant to the features described by the diagram of Appendix 9l. The diagram, it is argued, concisely represents the knowledge in a form that can be quickly drawn, modified, absorbed and communicated. Further, the diagrams were checked against the summaries and actual transcript statements for consistency and adequacy of representation. As stated, further modifications and developments were always possible, and mostly inevitable.

Additional diagrams charting the development of some of the concepts discussed above are included (Appendix 9m-9s) to show the emergence of more coherent structures through subsequent development. In summary, the diagrams provided a powerful computer independent representational method for quickly testing a learned understanding, through the attempt to teachback the understanding to the expert.

5.4.8 Communicable Model of design knowledge

An overall objective of the elicitation process was to enable the knowledge engineer to acquire an

[8] It is worth noting that these factors are particularly targeted for evaluation in the next chapter.

understanding of some of the concepts and structure of the domain. The flexible teachback method allowed the exploration of the domain to progress to considerable detail. Whilst the structure of the domain emerged readily and rapidly, the information was disparate, and, in the form of isolated diagrams, too ad hoc to be of any great value.

In order to demonstrate the learned understanding of the domain, to attempt to collate the material into a more coherent account, to facilitate the testing of the concepts in a more complete form, to provide lasting documentation of the understanding now embedded in the knowledge engineer and to provide a computer independent representation of the domain, a written document was prepared to incorporate some of the more advanced diagrams resulting from the elicitation process. The report (Appendix 10) was also developed through considerable expert feedback, over several iterations, and provided a platform from which further criticism and modification occurred. The value of the document can be viewed in terms of the ease by which other experts can access the interpretation, and comment upon it. Criticism adds further feedback and can only be viewed positively. However, the document, written in English, and backed by diagrams and other information (such as the glossary of terms and the structured index) provides a suitable medium of communication to non-experts and those wishing to exploit the domain computationally.

5.5 Summary

A methodical strategy for knowledge elicitation in design, based upon the teachback methodology of acquisition and analysis (Johnson, 1987) has been described (Figure 19).

A cyclic, multi-stage refinement process results in the knowledge engineer acquiring an understanding of the domain. Valuable records are generated through discussion, interpretation and feedback resulting in a communicable model of cognition. A global, *holistic* building strategy facilitates progressive levels of interpretation, and allows elicitation of high and low, and deep and shallow design knowledge, from the simple and obvious to the subtle and complex.

The knowledge elicitation procedures yield design data in many (physical) forms and at various levels of interpretation. Transcripts, video and sound recordings, notes, indexes, glossaries and diagrams provide a lasting record of the knowledge elicitation process. Additional information, that is perhaps not represented in any physical medium, is also acquired by the knowledge engineer in the learning process of knowledge elicitation; the product of discussion and communication with experts. Progressive levels of interpretation placed upon the data reflect a shared understanding, and coherent explanations of the domain are developed through expert feedback.

A document (Appendix 10) describing the underlying concepts of the domain provides a lasting account of the acquired information, also developed through expert feedback, and is itself open to further scrutiny. Such an account reports data in a form that can be easily modified, as a better understanding of the domain emerges as a direct result of the elicitation work, or otherwise. It is therefore argued that the method of knowledge elicitation described here can produce design knowledge that will out-live any particular (computer) representation or computer implementation. The wealth of information arising from qualitative knowledge elicitation resulted in substantial data that may, in the future, yield further information and interpretation.

The development of such interpretations takes considerable time, effort and patience, and short-cuts are not immediately obvious. It is argued that the personal interview, the skills of the knowledge engineer and significant expert involvement are predominant factors that facilitate the communication and transfer of design knowledge.

Stage	Procedures	Techniques	Analysis
Preliminary	Casual Discussions	Create Friendly relationship Study environment	Study of preferred communication Prepare questions
	Preliminary Interview	Prepared Questions Design of problem solving Task	Transcription Initial Glossary Feasibility study Prepare questions
Stage 1	Problem Solving Design Task	Drawing Video records	Transcription
	Semi-Structured Interview	Prepared Questions	
	Categorisation	Perceptual Data	
Stage 2	Teachback	Review Transcripts Discuss Examples Drawing / Sketching	Notes / summaries Procedure Map Glossary of terms Simple Index Structured Index
		Diagram construction and refinement	Structure Diagrams Strategy Diagrams
		Communicable Report	Report Development

Figure 19 : Summary of procedures for design knowledge acquisition and analysis.

Diagrams and video records provide an important medium of communication in domains that incorporate a significant contribution from data that is 'visual' or spatial in nature. People are capable of asking pertinent questions, can formulate views by drawing upon a vast repository of common knowledge, and utilise an unsurpassed ability to talk, communicate and understand other people, in depth. The corollary is that computerised methods of knowledge elicitation do not, as yet, possess these skills, or sufficient knowledge of the real World. Computerised acquisition techniques do not appear able to elicit the sophisticated, complex, and sufficiently deep knowledge required for advanced Intelligent Knowledge Based Computer Aided Design Systems. In contrast, the examples of *image* and *Communication*, discussed above, are pertinent illustrations of the success that can be achieved through a strategy based on the personal interview approach.

The objective of the page layout design study was to achieve a shared understanding of some of the concepts of the domain, and to interpret and make explicit some of that data. The knowledge engineer is not trained in design, or related areas, and can be termed a 'design illiterate.' Therefore, the acquired understanding was the product of the elicitation procedures reported here, and not the result of prior experience. The page layout design experts were able to talk through, discuss, and explain the design task, readily and unselfconsciously, and in addition they appeared to enjoy doing so. Thus, explaining their activity appeared natural, and they seemed pleased that someone was interested in their skills. The quality and extent of the verbal information resulting from the page layout design study was surprising, since it was initially believed to be a predominantly visual and spatial task, perhaps less amenable to verbal forms of account. This suggests that other design tasks that involve a considerable contribution from spatial skills may also be more amenable to knowledge elicitation methods than previously conjectured.

Some perceptual and visual types of information were beyond verbal explanation, for example, when volunteered in the form 'it just looks right / wrong' or 'too light / too dark.' Empirical or perceptual studies may uncover the determinants of this form of judgment. A simple qualitative grouping study, using perceptual data, was used with some success in the study of page layout design.

The study of page layout design demonstrates that it is possible to elicit knowledge in a domain of design that involves visual information and spatial processing skills. In the age of desk-top publishing, the data also provides a significant contribution towards the construction of more powerful Knowledge Based Systems in page layout design. More importantly, many domains of design that incorporate visual and spatial forms of data may be explored using the knowledge elicitation and analysis procedures described here.

6 Evaluation Study

6.1 The need to evaluate knowledge

An important consideration of Knowledge Engineering philosophy is to ascertain the validity of the knowledge embedded in, and overall system performance of, Knowledge Based Systems (Sell, 1985; O'Leary, 1987; Green and Keyes, 1987; Shaw and Woodward, 1987; Benbasat and Dhaliwal, 1988). Sell (1985) argues that testing methods are required to ensure that data obtained from knowledge elicitation procedures provide an accurate reflection of the relevant expertise, and to ensure that resulting user-systems perform the functions for which they were intended. Verification, it is argued, is especially important where advice is required in the domains of critical decision support, the nuclear power or aerospace industries, for example, where inaccurate advice may be life threatening. It has been argued (Landsdown, 1988) that designers are subject to gross errors of misjudgment, even in critical areas, such as aerospace, automobile and architectural design. The *critical decision* is not a relevant facet of page layout design, but evaluation is no less desirable. For example, consider a health or safety warning in a graphic design task, where a failure of communication can, at least in principle, endanger life.

Benbasat and Dhaliwal (1988) argue that the development life-cycle of KBS progresses through four stages of knowledge base refinement, and three distinguishable forms of knowledge. Therefore, Benbasat and Dhaliwal (1988) argue that to address the problem of ad hoc validation, as identified by O'Keefe et al (1987), different methods of knowledge acquisition, and relevant validation, are required at each of the successive stages. The first stage of validation in the life-cycle, the testing of acquired knowledge, *Elicitation Validation,* is relevant to this discussion.

An issue of fundamental importance is whether design knowledge can be subjected to test, in a practical way. The problem of evaluating design knowledge is not trivial, and precedents have yet to be established. Design has been reported to be a domain greatly influenced by the designer's personal preference, style and idiosyncrasy (Jerrard, 1986) and design experts are likely to disagree between themselves and even lack self-consistency. The feasibility and practicability of testing design knowledge is an important aspect of design elicitation procedure. It has been argued previously that the teachback method is a significant verification procedure in its own right, however, a convincing practical demonstration would complement and substantiate the knowledge elicitation and analysis phases already discussed. The procedures identified below have general application for design evaluation applications, although the example is specifically targeted for the evaluation of page layout design.

6.2 Design of the evaluation procedure

6.2.1 Objectives of the evaluation

1 To indicate the competence of the acquired understanding.

2 Hence, qualify the validity of the knowledge elicitation procedures.

3 To indicate that design knowledge can be practically tested, and to present a suitable method of evaluation.

The evaluation study attempts to qualify the knowledge elicitation procedures by testing the accuracy, relevancy and completeness of the acquired understanding, and thereby substantiate the proffered approach to knowledge elicitation, and indicate that the methods are appropriate to design. Care is taken to ensure that the tests are rigorous and unbiased. However, it is important to note that the evaluation test can not provide hard incontrovertible evidence, but aims to demonstrate and give support through examples[1]. Interpretation is subjective.

A subtle hypothesis implied in the thesis, is that (page layout) designers possess some common, widely understood (shared) design knowledge, and that some general concepts can be acquired, identified and made explicit. The evaluation process undertaken here tests the hypothesis through determining agreement between designers.

As previously discussed, the initial stage of knowledge elicitation involves many experts, and the acquired understanding reflects the diversity. However, the understanding is iteratively developed, refined and verified by a single expert, and the personal preferences of the single designer are predominant. The teachback expert (E0) is used in the evaluation procedure (as J0) to test the knowledge elicitation procedures for the ability to acquire the knowledge and preferences of a principal designer.

Generality is tested through the targeting of a consensus of expert opinion, excluding designers from the elicitation phase. As stated previously, personal preferences are important aspects to be tested and the evaluation study also tests the acquired understanding against the actual preferences of the teachback expert (J0). Further, the preferences can be measured against the consensus of opinion offered by the independent designers (Ji).

The holistic nature of the design task must also be accommodated in design evaluation procedure. Segmenting, or decomposing design activity, or considering partial or incomplete designs fails to take into account important holistic interrelationships. Indeed, complex relationships (eg image, balance) must be targeted for evaluation and the selection of tests that involve whole, complete designs appears a suitable test strategy.

6.2.2 The evaluation procedures and the Critique

A significant aspect of the (page layout) design process involves reflective criticism, at many stages of the design (Appendix 10). It appears that page layout designers are able to criticise their own work and enjoy criticising other peoples. The most important evaluation is the final review of the whole, complete design, although the review may itself result in further stages of design and criticism. This is a method by which designers test and measure their designs, learn by other designers' success and failure, keep up to date with modern fashions, and perhaps, reassure themselves of their own convictions. The *critique* is a natural continuum of the design process and reflects the extent of a particular designer's expertise, and appears a convenient form of design evaluation. In addition, a critical and advisory KBS tool was envisaged to result from the elicitation process, and testing the acquired knowledge in the form of criticism is pragmatic for subsequent functional implementations of the design knowledge.

The method chosen to evaluate the page layout design knowledge was to present complete

[1] For example, the evaluation tests make unfounded assumptions that each judge will be self-consistent throughout, and the judges will be marking on the same basis.

layouts to both the knowledge engineer and to the designer for criticism; where criticism means considering both general and detailed aspects, and describing positive and negative features. Hence, criticisms can be compared. However, the experts are unlikely to know the extent of their own knowledge, and are unlikely to volunteer, directly, all of the required information without prompt. Hence, a multi-stage testing procedure was designed to ensure coverage, and to reduce the effect of biases or inherent inconsistencies of the testing procedures.

The Knowledge Engineer is not practised in layout criticism, but the critique forms an obvious expression of an acquired understanding of page layout design. Further, a competent understanding of the language, concepts, and structure of the domain is tested through the expression of criticisms that are readily understandable and meaningful to the experts.

6.2.3 The testing procedures

The teachback expert (J0) and a panel of ten independent designers (Ji) were subjected to a four stage evaluation process, described below, and the verbal data was recorded on tape for analysis. The objective of the study was to test the accuracy, relevancy and completeness of predictive statements on a number of page layouts.

It was estimated that the testing procedure would take between thirty and forty five minutes to complete for each layout. Clearly, the more layouts that could be used in the evaluation study, the better. However, the designers were unlikely to submit themselves for tests longer than three hours duration, and they would be unable to hold concentration for much longer, anyway. Therefore, in the evaluation of page layout design, four layouts were used, and the test procedure required between two and three hours to complete.

Four internal house magazine layouts (Appendix 11; termed Layouts A, B, C and D, in the following discussion) were chosen from a large number of samples. The test was broadened through a varied selection of designs. One of the layouts (Layout C), was deliberately chosen to be *out of character,* in order to test general aspects of the understanding, whilst the other three were chosen to be typical (discussed in section 6.2.4). A result emerging from the knowledge elicitation process suggested that it would, perhaps, be easier for designers to venture negative criticism, than it would be for them to offer positive criticism[2]. Hence, the four designs reflected rather more negative aspects than positive. A number of statements, or criticisms, were compiled for each layout (Appendix 12; termed A1, A2, B1, B2 etc), and a total of sixty seven were prepared. The term *statement* was preferred since *criticism* implies the singularly specific and negative detail, whilst positive and general aspects were also relevant.

It was important not to let the designers know that the study was a test, as this may have caused them distress or threat, and perhaps adversely affected the study. A carefully worded brief was prepared for the designers (Appendix 13), that described the testing process and declared the intention to *understand more about design.* The brief also encouraged a relaxed and friendly atmosphere for the study.

[2] The holistic nature of the design task may provide an explanation for this phenomenon, ie, if it works as a whole, it is not very easy, or meaningful, to identify aspects that contribute to that success, it just works. However, aspects that cause the design to fail as a whole, can perhaps be identified quite easily. 'Wholeness' in design is also discussed by Bijl (1985; 1987).

To reduce biases, the order of presentation of the four layouts was randomised for each designer (Table 32), and the designers were instructed to avoid making cross-comparisons between the four designs. The study of page layout design revealed that 'high level' criticisms are often presented first, and then specific details are discussed. However, establishing a precedent may have biased the judges into inferring the format offered by the prepared statements, and the judges may have attempted to mimic 'what is apparently wanted' in the presentation of their own criticisms. Further, there was the danger that the judges might be biased into marking the first statements *relevant* and the latter statements *irrelevant* on the basis of the order shown. Also, an inherent structure of presentation may have biased the designers' ordering in the sorting procedure, discussed below. Hence, the order of statement presentation was randomised in preparation, for each of the four layouts. This precaution had the disadvantage that the designers were occasionally required to judge the statements in perhaps a rather awkward order, but had the advantage that the designers were required to judge each statement on merit; the very last statement may have been the most important one, for example.

6.2.3.1 Stage 1

The first stage of the test process required the designers to criticise the design, in the normal and usual manner, blind to the prepared statements. The designers were not directed, and no restrictions were forced upon them. The open critique stage has two objectives. Firstly, the designer may present criticism that immediately indicates the accuracy and relevancy of the corresponding prepared statement. Secondly, important comments not covered by the prepared statements can also be identified, the extent of these indicating the completeness of the prepared coverage.

6.2.3.2 Stage 2

However, the designers are unlikely to comment on many of the concepts of their own volition, so it would be necessary to prompt them. The second stage of the evaluation procedure required the designers to read aloud the prepared statements and mark whether they believed them to be *Accurate* (whether they agreed or not) on a scale provided, shown below. They were instructed to indicate with a tick anywhere along the line, wherever they thought appropriate.

Accurate	Mostly Accurate	Partially Accurate	Mostly Inaccurate	Inaccurate
|	|	|	|	|

The statements occasionally presented compound issues, perhaps describing more than one (related) concept. Therefore, the designers were encouraged to break the statements into smaller sentences, if they wanted to, and they could mark each part separately. This facilitated a more flexible, selective and accurate method of marking.

6.2.3.3 Stage 3

Some concepts were predicted to be relatively more important than others. A card sort test was designed where a prediction of the *relative* importance of the statements was tested for each of the four layouts. The card sort provides a standard psychological testing method of ranking concepts. The statements were placed on a card with a key reference at the top to indicate the main point of the statement. For example, statement (B5):

b5 **Unbalanced design**
Design is not balanced, top-left, bottom-right diagonal split caused by too much white space on the top left.

Prior to the investigation, the cards were sorted by the knowledge engineer, and the order recorded. To check for self-consistency the cards were sorted a second time, after a break to clear short-term memory and an overall prediction was recorded (Appendix 22). In the evaluation procedure, the designers were allowed to contribute additional statements of their own, if they wanted to. The cards were shuffled and given to the designer to sort. The order of priority was the relative *importance* of the statement, with respect to the specific design, in the context of internal house magazines[3].

6.2.3.4 Stage 4

The final stage of the test procedure required the designers to directly indicate, on the scale provided, the relevancy of each of the statements, ie, whether the statement made a valuable point. For simplicity, the statement was judged as a whole, even if the designer divided it when marking for accuracy. *Relevancy* is measured from two perspectives:-

1 The relevancy of the statement to the particular layout (Relevancy 1), and
2 The relevancy of the statement to general issues of internal house magazine and page layout design (Relevancy 2).

Highly Relevant	Relevant	Valid	Of little Relevancy	Not Relevant

In addition to the test procedures described above, the designers were also repeatedly questioned, verbally, about the relevance, completeness and competence of the statements, and they were asked to comment on anything that they thought had been missed out, or any other comment that they wished to express.

6.2.4 Layout choice and targeting

It has been argued that the approach to design knowledge elicitation, described previously, can obtain deep and shallow knowledge, and high and low level concepts (chapters four and five). Therefore in the evaluation study, it was important to target different levels of conception, to indicate the success of acquisition in this respect. The four layouts were chosen with the

[3] Statement C17 is omitted in the sort test of layout C. Statement C17 is largely encompassed by statements C3 and C6, and a key heading for the card could not be prepared to be discernibly different from the key headings of cards C3 or C6.

objective of covering as much as possible. Table 20 indexes the relationship between specifically targeted concepts and the prepared statements of the evaluation study, and it also relates the section numbers of documentation, where the concepts are discussed in detail (Appendix 10).

6.2.4.1 High level concepts

The most important concept emerging from the study of page layout design was *image,* and the understanding of this concept clearly required testing. However, since the designers were instructed that the magazines presented to them were from *internal house magazine design,* then the designers may have failed to directly comment on the *image* in the open critique stage, since it would have, perhaps, been obvious to them, or was being stated to them implicitly in the outline brief. One of the layouts (Layout C) was a prediction of the 'wrong image' (eg C5, C1, C2) although still technically an internal house magazine. The remaining three layouts were typical in terms of *image,* and statement (A7) explicitly addressed the concept. Many other statements also described the concept of *image,* but indirectly (eg A4, A5, A8, A9; see table 20).

Balance was also an important concept that required direct testing. In particular, Layout (D) was chosen to look *balanced* (D13), and Layout (B) was chosen to be *unbalanced* (B5, B1). The importance of the concepts *image* and *balance* were indicated by their predicted relative importance in the card sort (Appendix 22):

Image : C5, C1, C2, (first, second and fourth); A7 (first) ;
Balance : B5, B1 (first and second); D13 (first).

In addition to *image* and *balance* other 'high level' concepts were targeted. *Clarity* was important, but was difficult to test independently of the lesser concept of *neatness and tidiness*.

Layouts A, C and D were *clear* (eg. A1, A3, C7, C8, D4, D8)
but layout B was *unclear* (B7, B8)
Layouts C and D were *neat* (C10, C11, D10)
but layouts A and B were *untidy* (A13, A14, A15, A18, B1, B2, B6, B7)

Complex issues of *readability* and *legibility* were also addressed through variations of layout *type*. For example, the *text* of layout C was predicted to be *small* (C6).

6.2.4.2 Targeted low level concepts (details)

The four designs also tested conceptually lower level (simpler) aspects. For example;

Layout A had a *picture across the fold* (A17),
Layout B had a *raised initial* for *navigation* (B6) and *attraction* (B12),
and *short measure of text* (B16).

The concept of *short measure* was particularly targeted (C16). In the elicitation phase, the experts did not universally agree, and *short measure* appeared to be a personal preference of E0.

Similarly, *uneven* and *awkward alignment* (encompassed by *neatness and tidiness*, eg A13, A14, B15, B16) was important to E0, but not to all of the experts who participated in the elicitation.

Concept	**Reference**	**Statement Number**
Image	1.2, 2.2, (2.2.7)	A4, A5, A7, A8, A9, A11, B4, B12, B13, B19, C1, C2, C5, C6, C9, D1, D5, D9, D11.
Balance	2.2.6.(3).	A2, B1, B5, B13, B18, C1, C11, D13.
Text style	2.3.1.1.	A10, A11, A12, B3, B4, B9, B10, B14, C3, C4, C6, C17, D2, D6, D9.
Follow/ Navigate	2.3.1, (2.3.1.2).	A1, B2, B6, B8, B10, B14, C7, C8, C9, C14, D4, D8, D9.
Picture over fold	2.3.1.2.(2)	A17.
Features	2.3.2.1, 2.2.6.4	A4, A5, B6, B12, B13, C9, D1, D9, D11, D12.
Clarity/ Neatness (short measure/uneven line)	2.3.2.2, 2.3.1.2	A1, A3, A10, A13, A14, A15, A16, A18, B1, B2, B7, B9, B11, B15, B16, B17, C4, C8, C10, C12, C13, C15, C16, D2, D7, D8, D10.

Table 20 : Concepts targeted for evaluation, references to documentation (Appendix 10) and corresponding statements in the evaluation test (Appendix 12). Statements may appear in more than one conceptual classification since the evaluation is not decompositional.

6.3 Presentation of evaluation results

Support for the reliability of the acquired understanding is shown in two stages of analysis. In the first stage (6.3.1), the verbal protocol data is discussed, qualitatively. A statistical analysis of the data is presented in the second stage (6.3.2). In the following discussion, the teachback expert (E0) is judge J0 and the independent judges (J1-J10) are collectively termed Ji.

6.3.1 The open critique and verbal protocol data

Appendix 14 presents each of the judges comments to the four layouts, as submitted[4]. The comments are indexed sequentially (A:J0:01, A:J0:02 etc) so that the context can be appreciated. The above transcripts (Appendix 14) are collated with respect to each of the corresponding statements of Appendix 12, in Appendix 17. Table 21 indexes the references, or possible references of the protocol, together with an interpretation placed on the individual references and, most importantly, an overall interpretation of support for each of the sixty seven statements.

The quality of response is an important issue, since the designers may explicitly state, or merely imply. Also, the designers may take a view that is diametrically opposite to the view of a prepared statement. The critique data is subject to interpretation and context is important. No attempt is made to apply hard rules of interpretation, and the analysis is subjective.

A1 q q 4/3 ?0:01, ?2:05, 2:06, -?8:11

For example, statement A1 above has four references, from three experts (column four). It is interpreted that, in criticism of Layout A, Judge J0 offers one statement that provides only questionable support for the statement (his first, A:J0:01, abbreviated to ?0:01 in Table 21). Judge J2 offers two references in support of the statement, one reference (A:J2:05) is also questionable (?2:05) and the other reference (A:J2:06) offers moderate support (2:06). Finally, Judge J8 offers a reference (A:J8:11) that possibly (questionably) contradicts the prepared statement (-?8:11). In Table 21 statements that offer clear support (or are clearly in disagreement) are highlighted in bold. A further level of indication, underlining, is used to highlight references of special interest, such as references that offer explicit support or explicit disagreement; where the very same terminology or language was used in the prepared statement.

The important information of Table 21 is conveyed in the overall interpretation of support for the prepared statements, Ji (second column) and the teachback expert J0 (third column). In the above example, the interpretation of the support for statement A1 is summed as *questionable* (q) from Ji, and also *questionable* from J0. The analysis of the interpretation is discussed below (section 6.3.1.1), summarised in Table 22, and the indications of overall interpretation are carried forward to the summary, Table 31.

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[4] A mechanical failure in the cassette recorder resulted in a loss of verbal protocol data from designer ten (J10). Also the statement check and relevancy check protocols of J0 were accidentally destroyed before they were transcribed. No relevancy (2) check data is available for J0, since the test procedure initially required the judges to submit the R2 data only verbally. The loss of data (J0) instigated a revision in procedure, so that judges J1 to J10 indicated directly their judgments of R2 on the scale, as for R1. However, it is worth noting that designer J0 indicated verbally that virtually all of the statements were highly relevant (2), and the R1 data provides a good approximation of R2 judgments, since he seldom marked the two differently.

	Ji J0	no	List of references
A1	qq	4/3	?0:01, ?2:05, 2:06, -?8:11
A2	pg	7/6	**0:02**, **1:10**, -?3:03, -4:01, (8:02), **-9:02**, -9:03
A3	ss	11/9	0:05, 1:06, -2:07, 3:06, 4:03, 4:04, ?5:11, 7:06, (7:08), (8:03), -9:03
A4	pg	12/8	**0:05**, 0:06, **1:06**, ?1:12, (3:04), -3:06, -4:4, -5:01, 5:08, (6:01), -7:08, -9:03
A5	pg	11/7	**0:05**, **0:17**, **1:06**, ?1:12, (3:04), -3:06, -4:04, -5:08, -7:08, -9:03, -9:05
A6	qu	4/4	(1:11), 2:03, (5:09), 7:02
A7	cg	10/7	0:01, **0:04**, 0:05, 0:07, ?1:15, -?2:01, -?2:06, -?3:02, ?5:15, **-8:06**, **-9:03**
A8	qu	2/2	1:10, ?9:01
A9	q-u	2/2	?1:10, 9:01
A10	su	5/5	1:13, **5:16**, ?6:07, 8:08, 9:04
A11	qs	4/3	0:08, 0:20, 6:07, 8:08
A12	gs	16/8	0:08, 0:20, **1:02**, 1:03, **1:04**, **1:13**, 2:04, 2:08, 2:09, 5:16, 6:07, **-7:09**, ?7:13, 8:08, **8:10**, 9:04
A13	gg	11/7	**0:09**, **0:11**, **0:19**, **1:08**, **1:09**, **4:05**, 6:05, 7:04, **7:11**, 8:05, ?9:07
A14	gg	9/6	**0:09**, **0:19**, **1:08**, **5:02**, **5:10**, **6:06**, **7:03**, 7:04, **7:11**, **8:05**
A15	pu	1/1	**5:14**
A16	qu	4/4	1:14, ?5:05, -7:10, ?9:05
A17	sg	3/3	**0:15**, 6:02, **7:01**
A18	sq	4/4	?0:10, ?3:07, 5:03, **7:05**
B1	gg	16/9	**0:05**, 0:07, 0:11, 0:12, 0:13, 1:01, **1:05**, **3:02**, ?3:07, 4:05, 5:03, **6:03**, **6:11**, 7:14, 8:03, ?9:07
B2	gg	12/8	**0:05**, 1:03, 2:02, (2:04), 2:13, 3:06, **6:07**, **7:11**, **7:12**, **8:01**, **8:02**, **9:04**
B3	qs	6/4	0:18, ?4:07, ?6:13, 7:08, ?7:21, ?7:26
B4	ss	9/6	0:18, **1:06**, 1:09, 1:10, -?4:07, 5:06, **6:10**, ?7:21, ?7:26
B5	sg	4/3	**0:13**, **4:01**, ?9:07, 9:08
B6	su	4/3	2:10, **2:11**, 5:05, 7:15
B7	gg	11/9	**0:06**, 0:17, 1:07, (2:05), 3:07, 4:04, **5:10**, **6:03**, 7:06, 7:14, (8:05)
B8	ss	7/4	0:12, **3:03**, **3:04**, ?4:02, ?4:04, 5:03, ?5:09
B9	qs	3/3	0:10, 2:12, -?4:03
B10	ss	5/3	0:10, 2:03, **2:10**, **2:12**, 7:17
B11	uu	2/2	?2:02, ?3:06
B12	pg	12/7	**0:01**, 0:04, **0:14**, -1:08, 2:05, ?2:09, -5:04, 6:06, (6:09), -7:18, -?9:01, 9:12
B13	su	3/2	2:07, 3:01, **3:05**
B14	ss	5/5	0:09, ?3:09, 5:12, **6:05**, 8:07
B15	pg	2/2	**0:07**, **5:09**
B16	pg	3/2	**0:08**, **0:13**, **7:09**
B17	gg	7/5	0:02, **0:09**, 5:08, **5:13**, **6:04**, ?7:02, **8:06**
B18	uq	1/1	?0:18
B19	cu	2/2	**-1:02**, ?6:12

C1	g	g	12/7	0:04, **0:05**, 2:02, ?2:11, **4:03**, 5:04, 5:13, **6:01**, **6:14**, **8:02**, ?8:06, **9:02**
C2	g	g	7/6	**0:04**, -1:06, ?2:11, 5:04, 6:06, **<u>9:05</u>**, **9:11**
C3	s	g	8/7	0:01, **0:15**, **1:03**, 2:07, -3:08, **7:02**, ?8:01, ?9:14
C4	u	q	2/2	?0:14, 2:03
C5	g	u	18/8	?1:01, **1:02**, **<u>2:06</u>**, **<u>3:01</u>**, **3:04**, 3:05, 3:09, 3:10, ?4:01, **4:04**, 4:05, **5:01**, 5:02, 5:05, 6:01, 7:08, **<u>7:11</u>**, **9:16**
C6	p	s	7/5	-?0:01, **0:08**, **-1:03**, -1:11, **3:02**, -4:06, -?9:12
C7	q	u	3/3	1:04, ?3:03, 5:07
C8	p	c	7/6	-0:07, 2:03, 3:07, -5:16, -?6:13, **-<u>6:14</u>**, **8:05**
C9	g	g	10/7	**0:06**, **1:08**, 2:04, 3:07, 5:06, 5:16, **6:02**, -?6:09, ?6:14, **<u>8:05</u>**
C10	s	u	5/4	**1:01**, 1:02, **2:08**, ?5.07, **3:03**
C11	q	u	5/4	?2:07, ?5:13, -?6:11, (8:03), -8:07
C12	u	u	1/1	(0:01)
C13	s	s	4/4	0:03, (5:14), **7:04**, 9:10
C14	g	g	5/4	**0:14**, **-1:07**, **<u>5:09</u>**, (6:07), **<u>6:10</u>**
C15	p	q	2/2	?0:09, **5:06**, **5:16**
C16	u	g	1/1	**<u>0:12</u>**
C17	p	s	12/8	0:01, 0:05, 0:16, **1:03**, -3:08, 4:06, **<u>5:08</u>**, 5:12, (6:03), **-<u>7:06</u>**, -7:08, **9:13**
D1	s	g	9/8	**0:06**, 1:06, ?2:02, 4:01, ?6:04, 7:07, ?8:02, ?9:01, 9:08
D2	s	g	12/7	**0:04**, 0:09, 0:10, ?2:04, ?2:05, ?3:02, 3:5, 5:07, 7:02, 7:04, -?8:05, **9:02**
D3	g	g	6/5	**0:07**, **3:08**, 5:05, **5:13**, **7:08**, **9:01**
D4	s	g	6/4	**0:01**, **<u>0:17</u>**, ?4:03, 4:04, ?6:03, **<u>8:04</u>**
D5	s	g	9/7	?0:03, **0:06**, 1:06, **4:01**, ?6:04, 7:07, 8:02, ?9:01, 9:08
D6	g	s	10/7	0:11, -?0:19, **1:02**, **1:08**, **2:06**, 3:07, 6:01, 6:06, 7:06, -9:07
D7	s	q	4/4	?0:12, ?5:11, **<u>7:09</u>**, **<u>9:06</u>**
D8	s	g	7/6	0:10, **0:14**, ?5:08, 6:02, ?7:06, 8:03, ?9:04
D9	c	g	5/3	?0:09, **0:10**, -3:02, -7:14, **-7:18**
D10	s	g	9/5	**0:01**, -?0:05, 0:17, ?1:01, ?3:10, **3:11**, 5:03, **<u>5:15</u>**, ?8:06
D11	s	g	6/5	?0:09, **0:10**, **2:04**, -3:05, -?5:07, **<u>8:05</u>**
D12	q	c	3/3	**-0:02**, -5:12, 6:09
D13	s	g	8/6	(0:03), **0:15**, ?2:09, 3:03, 3:04, ?5:01, 8:02, ?9:03

Column one : Statement (Appx 12)
Column two: Interpretation (Ji)
Column three : Interpretation (J0)

- g Good support
- s Moderate support
- p Preference
- q Questionable
- c Contradictory
- u Unsupported

Column four : Number of references / Number of experts.
Column five : Protocol References (Appendix 14 and 17).
eg D13; 9:03 := Judge J9 : reference 03 := D:J9:03.
Underline : Of special interest.
Bold : Clear reference.
Plain text : Reference.
Question mark : Possible, questionable reference.
Negation : Disagreement.
Brackets : Neutral use of concept/language.

Table 21 : Open critique protocol interpretation (references to Appendix 14 and 17).

6.3.1.1 Analysis

A large number of the prepared statements are covered by both J0 and Ji, and when these two sources are combined the overall support is good. Some disagreement exists between the experts, and the differences between J0 and Ji are particularly noticeable. Occasionally J0 offers support for a statement, whilst some of the other designers express criticisms that are in direct conflict. Disagreements are always likely and the result demonstrates the successful acquisition of some of the personal, perhaps idiosyncratic expertise of J0. Where the prepared statements are covered by considerable references from the experts, but meeting disagreement generally, or where support is offered by only a single expert, but lacking other additional support, such cases are interpreted as 'personal preferences' (p). Statements that receive poor (u) or questionable (q) coverage offer little information, but overall, such cases are relatively few.

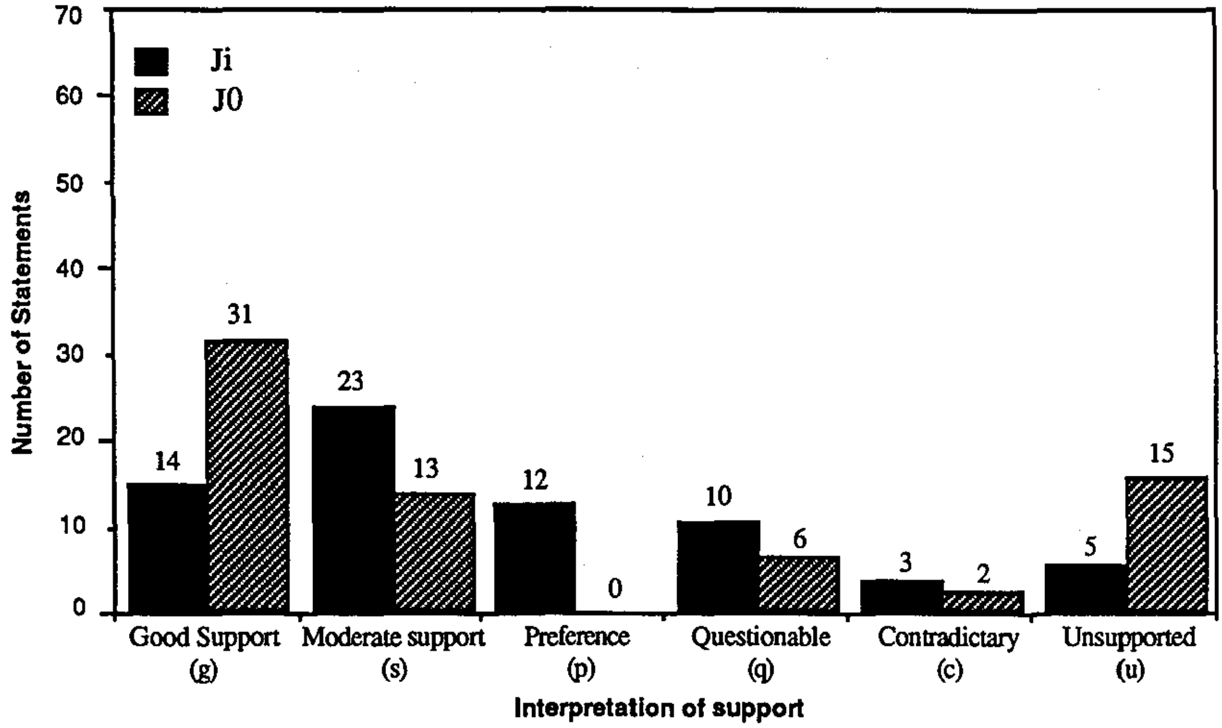

Table 22 : Summary of interpretation of open critique protocol (Table 21, Appendix 17).

Referring to Table 21 and Table 22, fourteen statements receive good support (g) from Ji (A12, A13, A14, B1, B2, B7, B17, C1, C2, C5, C9, C14, D3, D6). J0 offers good (g), or moderate support (s) for all but one (C5) of the above. Twenty three statements receive moderate support (s) from Ji (A3, A10, A17, A18, B4, B5, B6, B8, B10, B13, B14, C3, C10, C13, D1, D2, D4, D5, D7, D8, D10, D11, D13), of which seventeen also receive moderate support, or good support, from J0.

In addition, twelve statements are termed 'personal preferences' (p): Four statements (A15, B15, B16, C15) receive good support from a single expert, but lack additional overall support from Ji, although two (B15, B16) also receive good support from J0. The remaining eight 'preferences' (A2, A4, A5, B12, C6, C8, C17, D12) receive a number of both supportive and contradictory references.

Ten statements receive only poor or questionable support (q) (A1, A6, A8, A9, A11, A16, B3, B9, C7, C11) and five statements (B11, B18, C4, C12, C16) receive insufficient support to make an interpretation (unsupported, u). Three statements (A7, B19, D9) receive contradictory references (c) from Ji.

Thirty one statements receive good support (g) from J0 (A2, A4, A5, A7, A13, A14, A17, B1, B2, B5, B7, B12, B15, B16, B17, C1, C2, C3, C9, C14, C16, D1, D2, D3, D4, D5, D8, D9, D10, D11, D13) and twenty four of these also receive good or moderate support from Ji. In addition, thirteen statements are interpreted to be moderately supported (s) by J0 (A3, A11, A12, B3, B4, B8, B9, B10, B14, C6, C13, C17, D6) and eight of these are also moderately supported by Ji. Of the remaining twenty three statements, two (C8, D12) are in disagreement with the prepared statements (c), six receive poor or questionable (q) support (A1, A18, B18, C4, C15, D7), and fifteen do not receive support (u) from J0 (A6, A8, A9, A10, A15, A16, B6, B11, B13, B19, C5, C7, C10, C11, C12). Seven statements receive good support from J0, but not from Ji; four receive mixed support (A2, A4, A5, B12), one is unsupported (C16) and two are contradicted (A7, D9).

6.3.1.2 Targeted concepts

The following discussion reviews the coverage offered by the judges in terms of the concepts that were specifically targeted for evaluation (Table 20).

6.3.1.2.1 Image

As previously discussed, Layout (C) was deliberately chosen to look different, and the prepared statement (C5) described the *image* being awry from the normal *friendly* image of house magazines. The small area for pictures (C1) and the small pictures (C2) were also features of the image concept. In the open critique, statement (C5) receives very good support; eighteen references from eight judges and seven of the judges provide very good support. In addition, C1 and C2 also receive good support from J0 and Ji. An interesting observation is that J0 fails to volunteer support for the statement C5. However, J0 supports the statements in the subsequent stages by marking C5, C1 and C2, Highly Accurate and Highly Relevant and placing C5, C1 and C2 first, second and third, respectively, in the card sort (Appendix 22).

Whilst there is substantial support for the prediction that the design is 'formal and serious,' the judges disagree whether the image is wrong for the actual publication, and some of the designers considered that the article is perhaps designed with the correct image in mind. For example, in the accuracy check protocol (ac; Appendix 15, ac:C5:J1) :-

> ac:C5:J1 "Too formal? The problem is that's who it is to appeal to, the businessman. This is an internal house magazine, but the people reading this one are academics. Content does make a difference, that is the essence of visual communications, you present your graphics and typography for the readership. That design wouldn't go down well the readers of the 'Daily Mirror,' or 'The Sun,' but it is ideal for the readership. Well yes, that is true, the overall image is business looking. It will be friendly to some, but not others. 'An expensive looking production,' yes, that's true. 'Informative and technical,' yes, that's very true."

However, the above protocol indicates that the designer interprets the image from reading and understanding the material (also ac:A7:J1), and the designer was instructed not to do this. The image is possibly correct for the actual magazine content, but the layout is deliberately chosen to look wrong for a typical internal house magazine, the domain in which it should have been judged. Indirect support for the targeted concept of image is also offered in the critiques of other layouts, where the correct image is identified[5] (Appendix 14) :-

> B:J5:07 "The general impression is that it is the sort of thing of its type, about house magazines, it's got that look about it, a sort of functionalism."
> D:J6:07 "As a house magazine it's fine. I think it could have been a little more adventurous in its presentation, but it's what you expect from a house magazine."
> D:J7:17 "The image looks appropriate, looks earthy, more human. They're using more tones, blacks {introduction}, greys {body text}, light greys {'Tom'}."

Layout A also addresses the concept of *image* directly (A7, A4, A5, A8, A9) but support from the open critique for these statements is disappointing. Explicit support for (A7) is given by J0, but it is contradicted by Ji :-

> A7 The design has an overall friendly appearance through an attractive headline feature, a large picture area, large pictures, a smaller amount of friendly, readable text, and the design is clear, simple and easy to follow.
>
> A:J0:04 "It has an overall friendly look."
>
> A:J8:06 "Everything seems crammed and very large. There really isn't any space in it and its very unfriendly I've found. I want to really get onto the next page."
> A:J9:03 "I can't put my finger on it but I get an uneasy feeling about this layout ... The headline is a disaster in my view and contributes to the overall discomfort I feel about the spread."

Referring back to Table 21, the above reference A:J0:04 (Appendix 14 and 17, shortened to 0:04 in Table 21) is interpreted as giving good, explicit support, as indicated by the highlighting and underline. References A:J8:06 and A:J9:03 (8:06, 9:03) are interpreted to be significantly contradictory, as illustrated by the negation prefix and highlight. Taking into account another three questionably contradictory statements (2:01, 2:06, 3:02) and two possibly supportive statements, the overall interpretation of statement A7 is classified as 'contradictory' (c) for Ji. However, J0 offers another three moderately supportive statements (0:01, 0:05, 0:07) and the statement is classified as having good support from J0. Similarly, statements (A4) and (A5) are

[5] Judge J5 critiques layout B first, and judge J6 layout D first, therefore these references are free from cross-layout biasing and are truly independent. Judge J7 critiques layout D second, following layout C, and the concept of correct/incorrect image will have already been suggested. J0 critiques layout A first. Cross-layout biasing is discussed further in section 6.5, Table 32.

also directly supported by J0, but only receive mixed support overall, for example (A5) :-

A5 The headline feature gives a friendly appearance through a highly decorative (colour) box-border, decorative serif headline fount. This immediately describes the image as friendly and not formal serious or technical.

A:J0:05 "I like the isolated headline, it promotes a friendly competent design."
A:J0:17 "The Gold colour works quite well."

A:J1:06 "The border draws the reader's eye to the heading, and the heading can be put in a smaller typeface because the border is encapsulating the white space around it, creating the interesting focal point."
A:J7:08 "The colour and the border pattern look completely out of context, it looks like a Victorian dance ticket, or menu."

The lack of references to statements (A8) and (A9) from the critique protocol is particularly disappointing, each receiving only two questionable references. However, the accuracy check protocol (Appendix 15) indicates that support from the study as a whole is good, for example:-

ac:A8:J1 "Yes, I agree with that."
ac:A8:J2 "Yes, I like to see more pictures anyway."
ac:A8:J3 "That's partially accurate."
ac:A8:J4 "Yes, accurate."
ac:A8:J5 "I'd say that was mostly accurate, yes. You can digest a lot of images, you don't need to swamp through a lot of text."
ac:A8:J6 "Yes."
ac:A8:J7 "Mostly accurate."
ac:A8:J8 "Sure, that's partially accurate."
ac:A8:J9 "That is true."

The above point illustrates that a lack of supportive references does not necessarily imply that the prepared statement is not relevant or inaccurate. The check procedure (Appendix 15, 16) shows that when the designers are prompted, the support is often good, and relevant comments may fail to be submitted in the open critique stage. However, it is worth noting that, in contrast to above, statements C5, C1 and C2 receive a large number of references from the judges. The assumption that it would be more productive to target negative criticism (ie.the wrong image of Layout C) than presume that the judges will offer equivalent positive criticism, appears justified in the example of *image*.

6.3.1.2.2 Balance

Balance was also a high-level targeted concept (B5, D13), but the resulting support is moderate:-

B5 The design is not balanced, top left, bottom-right diagonal split caused by too much white space on the top left. The headline is too overpowering resulting in the design being top heavy."

B:J0:13 "Really, it looks very unbalanced and badly considered, the white space has not been used in any purposeful way ..."
B:J4:01 "Too crammed down in the right-hand corner and too much space top left."

The two references above (0:13, 4:01) are interpreted to offer good support. The statement receives four references overall, from three experts and the statement is interpreted to be moderately supported overall. Below, statement D13 receives eight references from six judges. J0 offers good support (0:05) but the support from the remaining judges is again moderate (3:03, 3:04 and 8:02).

D13 The design gives the appearance of a well balanced design. The headline is not too overpowering. The tones of the pictures are balanced with the colour of the text and the area of text is roughly equal to the area of pictures. Perhaps the pictures are too visually similar.

D:J0:15 "The tones of the large picture works well with the bold and light effect of the text. The pictures are repetitive and it would have been better to use a couple, or just the one big picture."

D:J3:03 "The overall combination, or relationship between the type and photographs is good."
D:J3:04 "There is a nice weight of type, colour."
D:J8:02 "There is a good mix of text and pictures."

However, the check procedure illustrates that although the statement was broadly accepted as being accurate, Balance in itself was not universally accepted as a good thing :-

ac:D13:J1 "Well balanced design, it is so well balanced that it is boring..."

6.3.1.2.3 Alignment and short measure

Of the detailed concepts targeted (6.2.5.2) the *short measure* is particularly interesting, and is identified in statements B16 and C16. Statement B16, below, receives very good support from J0 (0:08, 0:13), and quite remarkably, explicit support from J7 (7:09), although not receiving references from any of the other judges. Statement C16 receives explicit support from J0, but receives no other references from the independent judges.

B16 The text is not properly aligned in the last column, causing a visual distraction (the bottoms of all the other columns of text are aligned).

B:J0:08 "The page finishes four lines out of alignment at the end of column six. That use of white space is arbitrary and there is no need for that to be there."
B:J0:13 "...the space at the bottom of the final column is either too large or too small."

B:J7:09 "At the bottom of the last column, it is excessive, that four lines there. It looks as if there's something missed out there, lack of copy, too short."

C16 The text at the bottom of column three does not align with the bottom of column two and edge of coloured shape (one line short, and is slightly odd).

C:J0:12 "Columns two and three don't align, it looks like they are one line short."

B16 and C16 are interpreted as receiving good support (g) from J0. There is a general lack of support for the concept, and the statements are interpreted as a preference (B16) and unsupported (C16) overall (Ji). The above result supports the evidence of the elicitation study, where in general, the other elicitation experts were not as enthusiastic about the concept of *short measure.* However, it is worth emphasising that the personal preference of J0 is successfully predicted in this example.

6.3.1.2.4 Picture over the fold

The placement of *pictures over the fold* of the page is also a targeted detail (that should not occur), and some support for this concept is given. Only the three references shown below are given, but all of them are very supportive.

A17 The pictures run over the centre fold. This degrades the pictures (but is not significant in this instance).

A:J0:17 "The fold across the centre, is acceptable."
A:J6:02 "Putting the half-tones across the centre, you've got this white line going up it."
A:J7:01 "The crease has broken the image into pieces, in fact there is definitely a crack."

Again, it is noticeable that J0 offers explicit support for the point made in the statement, ie, that there is, in general, a problem associated with a picture across the fold (that is present in Layout A), and J0 further agrees that whilst it is something that should be avoided generally, in the particular example the impact of the problem is not so bad, and is in fact "acceptable."

Also, in Layout (B) the headline and sub-title text is placed over the centre of the page, that results in a problem of similar effect to the point described in statement A17. However, the impact of this fault was predicted not to degrade the readability significantly, and hence, no statement of criticism was prepared. However, some of the designers commented on the feature, and it generally supports the acquisition of the concept (described in section 2.3.1.2, Appendix 10).

For example:-

B:J6:02 "The heading and the sub-title go right across the middle of the page. If it had been inside the booklet, on another page, it might not have lined up."
B:J7:01 "My first impression is the problem of the headline going across the crease of the page and the way it breaks up the word (headline)..."
B:J7:19 "I don't like the running headline being split across the fold in the way it is, that should have been resolved some other way."
B:J8:08 "There is a large heading which tends to be uncomfortable at the top, going across the middle. Although it is a centre page, it still feels rather uncomfortable, with the fold in the middle."

6.3.1.2.5 'Features'

The concept of *features* (to provide the higher level concept of attractiveness, appeal and friendliness) is also tested. The use of *colour, box-borders, raised initials and headline features* are identified in the layouts (A4, A5, B12, C9, D11). Below, a selection of the supportive references for the statements B12 and C9 are cited, followed by a selection of references that contradict B12 and C9, or generally contradict statements A4, A5 or D11.

B12 The design has slightly attractive features to improve its appeal (and friendliness); (red) colour border that incorporates the page numbers (as text) and the running title of the publication, the raised initial feature, and large pictures.

B:J0:04 "The raised initial looks good, but I think it should have been dropped rather than raised."
B:J0:12 "The red rules, the border, it makes it look more attractive. Well it helps a bit, but it makes the gutters look too big."
B:J0:14 "It lacks formality, it doesn't look unfriendly but it is not inviting to read. If it wasn't for the raised initial and red box it would really be bad, they help a bit and are the only redeeming features."
B:J2:5 "It attempts to break up the text by using a raised initial ..."
B:J6:6 "The raised capital works quite well in the first paragraph."
B:J9:12 "There is quite an interesting idea to start the article with this superior capital with quotes around it, that's not so bad, that's an interesting way of starting it but it doesn't continue, it is not finished ..."

C9 The light blue colour feature improves the appeal (decorative/interesting) of the design. This simple feature, used sparingly, adds appeal without causing unnecessary distraction and also facilitates the location and identification of sub-sections."

C:J0:06 "The use of blue makes it look a little more interesting ..."
C:J1:08 "Nice use of second colour. Not too much of it, restrained pleasantly."
C:J6:02 "They've tried to make interest by putting these blue bands in it."

C:J8:05 "The blue bands, with the text, actually helps because at least it breaks the design up a bit more, makes it more interesting to read."

Contradictory references to the feature concept.

B:J3:10 "All the different components interfere with each other. It's just a mess, really."
A:J3:06 "I can't cope with the way this headline has been set. It uses white space in this border, but it looks like a desperate attempt to try and make the design more interesting."
A:J4:04 "It needs the white space and it needs the border, but not that border."
A:J5:08 "The fact that there's a second colour neither adds nor detracts from it. A wasted effort changing the colour, for the difference it's making."
A:J9:09 "The second colour does little or nothing for the whole thing, it's a waste of a colour really."
B:J1:08 "This weak red line is not really doing much."
B:J5:04 "I'd question whether you need this red around the edge, it is a bit distracting, I think."
C:J6:14 "It is a good example where there is lots and lots of text with no break, no visual break. They've tried to break it with sub-headings and blue rules, but it just doesn't work."

The use of *attractive features* is believed to be quite an important concept, and the above examples provide good support for the successful acquisition of the concept. However, the *features* in the chosen designs are perhaps not very successful, and not particularly *attractive* or *friendly*, and they did not really work very well. The appearance of a feature in a design does not necessarily mean that the design will be *friendly* or *attractive*. This facet is perhaps poorly predicted, and the above comments tend to contradict the supportive references.

However, the raised initial is also a feature of navigation (B6), and is predicted not to have been very well done in the example of Layout (B). Below, all of the references are given, and the support is interpreted to be moderate (J2 provides particularly good support in this example).

B6 The raised initial "I" is distracting and visually awkward. However, it indicates that the body text starts in column one (opposed to the top of column three after the sub-title paragraph), avoiding ambiguity.

B:J2:10 "There is no doubt about where the eye should go first, that's to the headline, and then the sub-title, and then to the raised initial 'I'."
B:J2:11 "Having said that, there is perhaps a doubt in my mind whether you should go first to the paragraph at the top of column three, or to the raised initial 'I'."
B:J5:05 "This quotation is picked out as a feature, but I'm at a loss to see where it finishes. It is a bit awkward."
B:J7:15 "I have some problems with this raised initial, it just doesn't work with that bold 'I' and lowercase 't'. I don't like the way it is set inwards from the text. I guess it has too many punctuation marks."

6.3.1.3 Concepts not covered by evaluation procedure

The prepared statements fail, on a few counts, to address all of the criticisms volunteered by the designers. However, many of these comments were dependent on specific content. The study did not address information of this nature, and these criticisms are disregarded here.

The most prominent omission in the prepared statements is in the lack of attention to the text *word spacing* (the space in between words) and *letter spacing* (space between characters of a word). The issue is raised by most of the designers, for example in Layout (A) :-

> A:J0:07 "The typography for 'Gala Day' is not quite right, it doesn't work...It is too light and the letter spacing is too obvious."
> A:J1:13 "Because the type size is right for the width it's being set to, we only get a few lines which have too much space between the words."
> A:J2:09 "It {body text} is within the right constraints of number of characters per line."
> A:J5:05 "...It's justified which you do get odd lines with strange open things."
> A:J7:7 "It is a bit too white, the headline, too much letter space in between the characters. The 'a' and the 'y' seem to be distanced, the letters need kerning."
> A:J7:13 "Justified {text}, it looks alright. The space between the words is a bit excessive It could be tightened, the word spacing."
> A:J8:09 "Justifying the text does cause problems with word spacing. That is quite apparent in a few of the paragraphs."

The designers also discuss the *external margins,* the *paragraph indication* and the *paragraph leading* considerably more than in the prepared statements. The overall impression of layout (A) is described as "old fashioned" :-

> A:J3:01 "Very stayed, old fashioned."
> A:J5:04 "It's got a very dated look."

In preparation of the statements, the above comment appeared too obvious, and content related to mention, yet the criticism from the judges suggest that it is important.

6.3.1.4 Additional Support from the verbal protocol

As stated previously, the designers were asked to comment on the competence and completeness of the prepared statements. The designers, without exception, agree that the statements are, on the whole, competent and extensive, although the judges often qualified the opinion. The most notable point, the lack of attention to details of word spacing, discussed above (6.3.1.3), was reiterated :-

> J7 "There is no mention of word spacing, I think that is important to the degrading of the quality of type setting."

Some general concepts are only passively tested in the evaluation procedure. However, the designers comments are believed to be highly supportive of these concepts as described in the report. For example, the duality of *attraction* (appeal) and *readability* (organisation) (Appendix 10, sections 1.3 and 2.3) :-

J1 "Really, to me there are only two basic elements that you need for a successful double page spread. One is to attract the reader, so your heading, attractive heading, helps do that, and so do the large pictures. The next thing, which is very important, is the size of the typeface so it makes it easy for people to read, and the readability, the positioning, the fact that it is easy to follow, so we know where to go. So I think those two things are important. A too balanced design is sometimes not attractive. The element to attract the reader and the element that once you've got their attention the need to make the rest of it as easy as possible for them, which is a broad view of communication, which it is all about."

J2 "I think they are all reasonable things to say, when combined with the initial critique. You tend to go into detail before talking about basic factors, which is very much to do with design, like Readability and Legibility and the fact that the first problem in any communication design is to attract the eye to that design. If that doesn't happen then everything else is irrelevant. To keep that eye and that person entertained sufficiently to take, hopefully all of that information. Then they can go away and not before."

6.3.1.5 Summary of open critique procedure

In general, many of the prepared statements were supported by the judges. In particular, the comments of J0 were often very supportive. However, occasionally the judges offered comments that contradicted the prepared statements, and sometimes disagreement between the judges was noticeable. Some statements received insufficient references from the judges to make an interpretation, but these were relatively few. Interpretations placed on the open critique data is subjective and difficult to analyse, but the data is rich in information, and additional support for the general competence of the acquired understanding is indicated through coverage of concepts that were not directly covered by the prepared statements.

6.3.2 Statistical Interpretation of data

The interpretation of the Accuracy and Relevancy indications, and the Card Sort test are treated statistically (Appendices 18, 19, 20, 21 and 22)[6]. Nonparametric statistics must be adopted since the data is no better than *ordinal* and assumptions on the allowable operations of parametric statistics are not valid (Siegel, 1956,p23).

6.3.2.1 Inter-judge agreement of Accuracy and Relevancy

The major objective of the evaluation procedure is to test the sample statements for agreement with the experts, ie whether the experts thought the statements are Accurate, Relevant to the particular examples (R1), and generally relevant to page layout design (R2).

The judges indications of accuracy and relevancy provides a statement-independent measure of belief of each of the statements, although it is assumed that the judges will be marking consistently throughout. This procedure is in contrast to the card sort test, where the ranking is specifically interdependent on all objects in the sort. Ranking ensures that the correlation calculation is dependent on the relative rank, and not the absolute values of the indications (for example one judge marking consistently low, and another marking consistently high will not adversely affect the calculation).

The Kendall Coefficient of concordance (W) is a test that indicates inter-judge agreement[7]. Siegel (1956, p237) notes that "A high or significant value of W may be interpreted as meaning

[6] Appendix 18 shows the detailed indications of the Accuracy check as presented by the judges, and includes the sub-divisions of the statements (Appendix 15). Appendix 18 was simplified for analysis in Appendix 19, where the most important aspect of the statement was considered

[7] The Kendall Coefficient of concordance (W) is a calculation that measures the likelihood of the occurrence of correlation between sets of ranked objects, compared to a randomly cast rectangular distribution (approximating to $\chi 2$ for $N > 7$, with $df = N-1$).

A k by N table is cast, where N is the number of ranked objects, that have been ranked by the k judges (here, k=10 (J1-J10), and N=67 (A1-D13) in Appendices 19, 20 and 21). W is calculated using the following procedure, as described by Siegel (1956, p229-239):

The sum of ranks, Rj, is calculated for each of the N objects. The mean value of Rj is calculated by summing the Rj values, and dividing by N. Then, for each Rj the square deviations from that mean are calculated. The deviations are summed, and W is found by the formula:

$$W = 12s / k^2(N^3 - N), \quad \text{where } s = \Sigma(Rj-\Sigma Rj/N)^2.$$

For the card sort data (Appendix 22) the above procedure is straightforward, since the data has been explicitly ranked by the judges, and there are no ties. It is important to note that the N objects need to be ranked, and the data shown in Appendices 19-21 are not ranked. To perform the calculation, each entry in the table (eg A, MA, PA, MI, I) is assigned an arbitrary relative (ordinal) value, for example, A=5, MA=4, PA=3, MI=2, I=1. Then, for each of the k judges, the N (67) values are ranked. However, only five values are used to classify the above objects, in this particular example, and a large number of the ranks are tied. Tied ranks are accommodated by averaging their values. Finally, the tied rankings have a slightly depressing effect on W, and an additional calculation is required to account for the ties (Siegel, p235).

that the observers or judges are applying essentially the same standard in ranking the N objects." If the experts are in agreement (when W is significant), then it follows (Siegel, 1956, p238) that the ordering provided by the sum of ranks (Rj) is a reliable estimation of relative order of the objects (Table 31). This information provides an indication of relative "goodness" (ie accuracy or relevancy) and is particularly useful for the card-sort test (Appendix 22), discussed in section 6.3.3 below. For agreement, the level of significance is set at $\alpha = 0.01$.

N= 67, df = 66	**W**	χ^2	**<< p**
Accuracy	0.280	185.395	0.001
Relevancy 1	0.247	163.275	0.001
Relevancy 2	0.273	180.387	0.001

Table 23 : Inter-judge agreement of Accuracy, and Relevancy.

The results (Table 23) indicate that the judges generally agree that some statements are relatively more Accurate, Relevant (1), and Relevant (2) than others. Hence, it is assumed here that the relative reliability of the acquired design knowledge (to be incorporated in a Knowledge Based System, for example), can be assessed. It is important to identify aspects that have been shown to be unreliable, or require further attention.

It is interesting to note that the inter-judge agreement (W) for relevancy(1) is lower than for relevancy(2). This suggests that the elicited concepts met a broad acknowledgement of their general usage, but were perhaps applied and utilised differently by the individual designers. The diverse and rather personalised use of terminology encountered in the knowledge acquisition phase may also account for this phenomenon. In the context of knowledge acquisition, the above results are sensible, where application of an applied understanding (R1) is always more difficult than simply identifying pertinent concepts (R2). However, it is also important to demonstrate that the acquired understanding of page layout design could be applied, and the high count of accuracy and relevancy(1), detailed below in the frequency tables, generally supports this supposition.

6.3.2.1.1 Frequency tables of J0

The individual marks of accuracy and relevancy (1) for J0 are detailed in Appendix 19, and Table 31. The frequency distributions (Tables 24 and 25) illustrate the overall level of indication associated with the (67) prepared statements. Tables 24 and 25 indicate that, in general, J0 agrees that the statements are Accurate and Relevant (1).

Accuracy

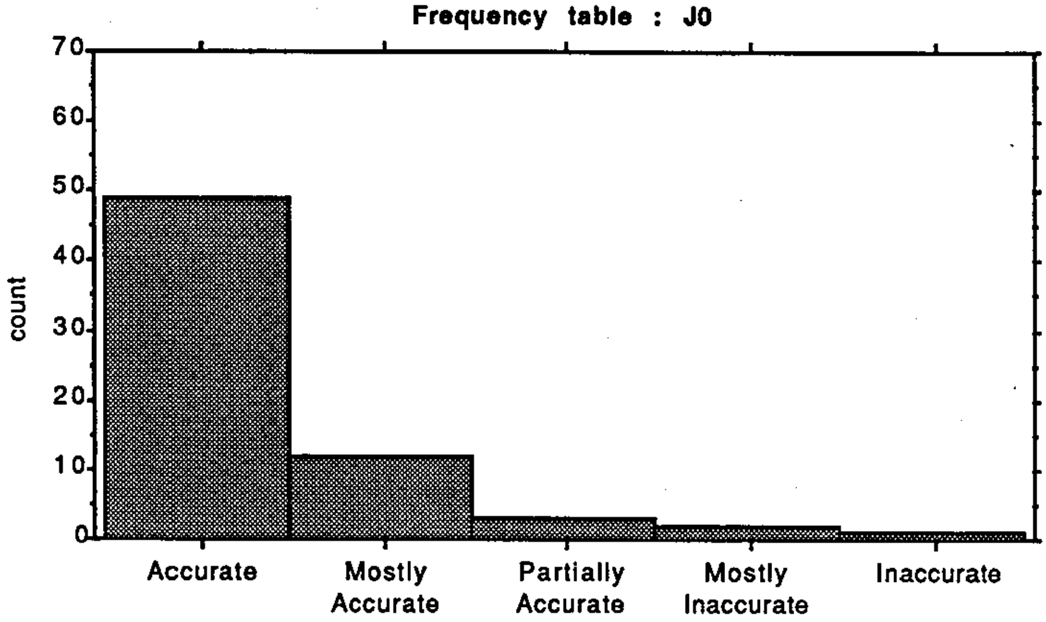

Table 24 : Frequency distribution of Accuracy from the teachback expert (J0).

Relevancy (1)

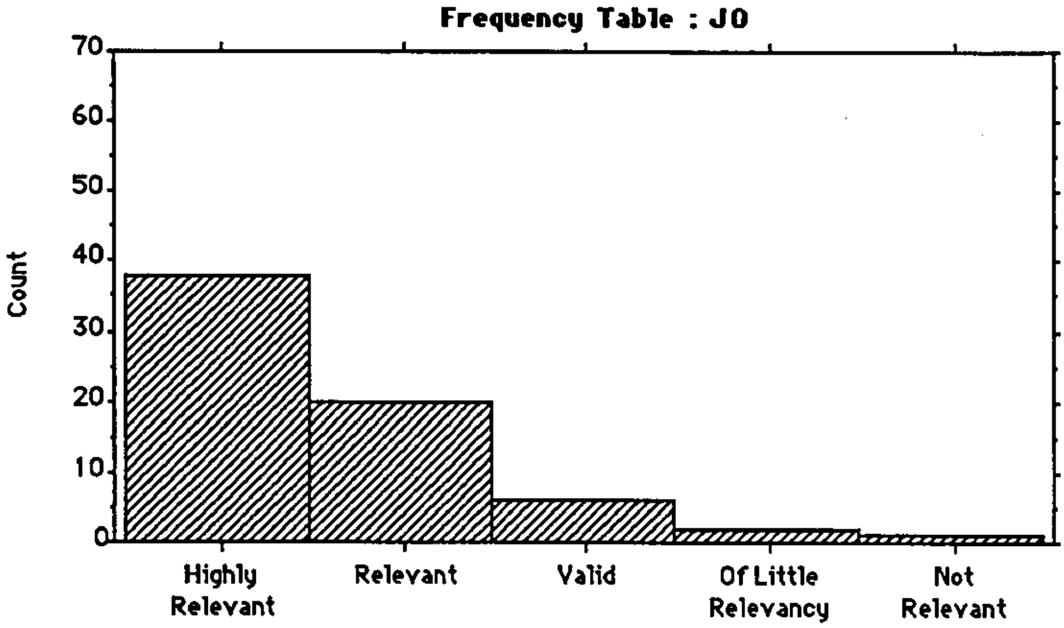

Table 25 : Frequency distribution of Relevancy (1) from the teachback expert (J0).

6.3.2.1.2 Frequency tables of Ji

Tables 26, 27 and 28 indicate that, in general, the independent judges (Ji) agree that the statements are Accurate, Relevant (1) and Relevant (2). Sample 670.

Accuracy

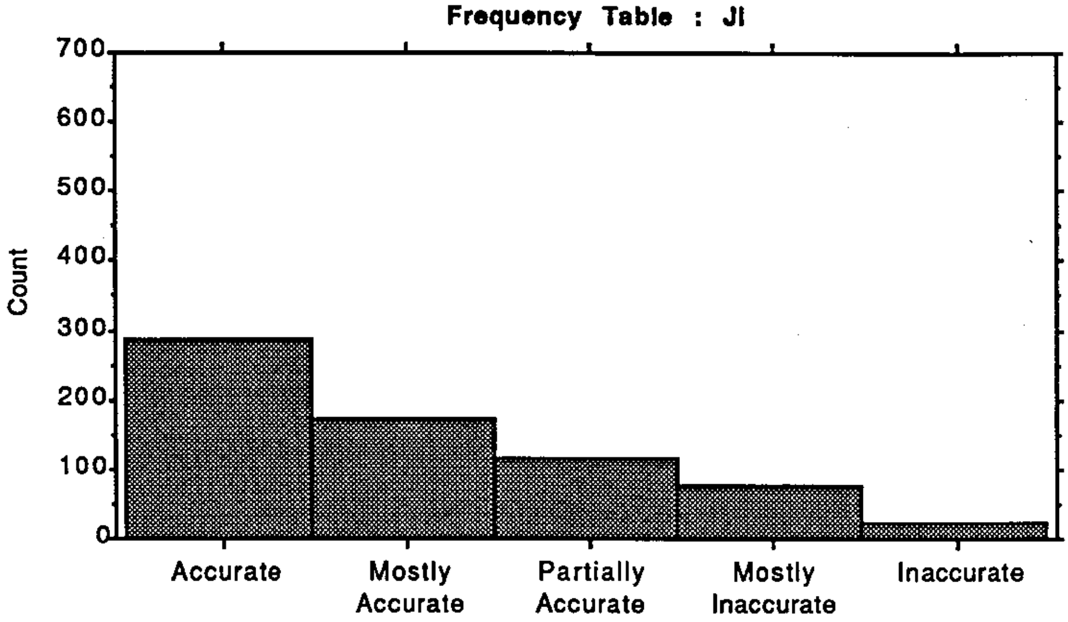

Table 26 : Frequency distribution of Accuracy of combined experts Ji.

Relevancy (1)

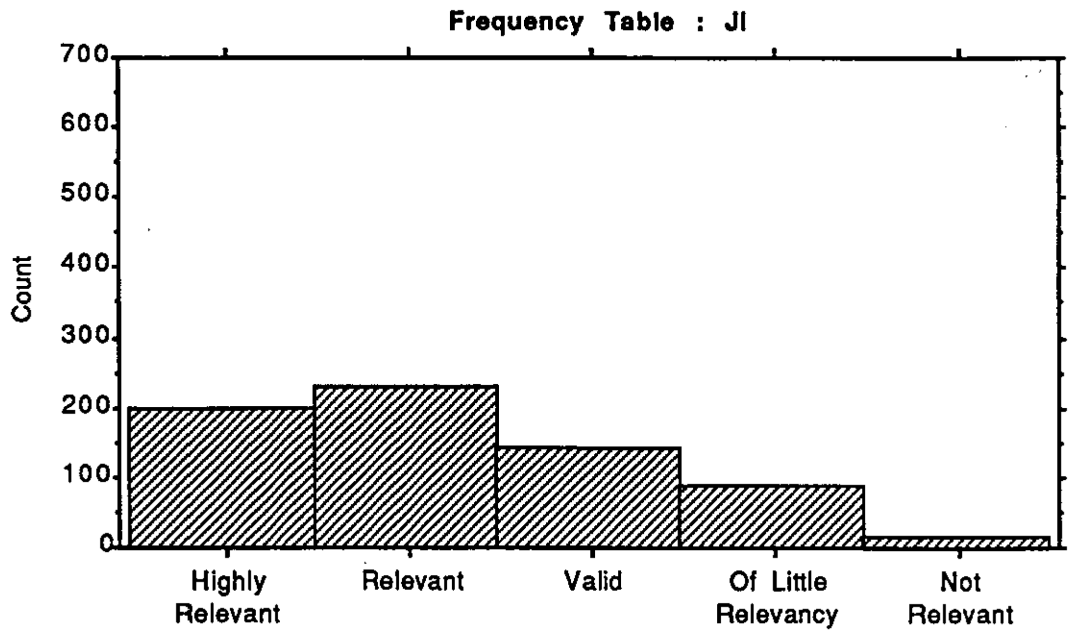

Table 27 : Frequency distribution of Relevancy (1) of combined experts Ji.

Relevancy (2)

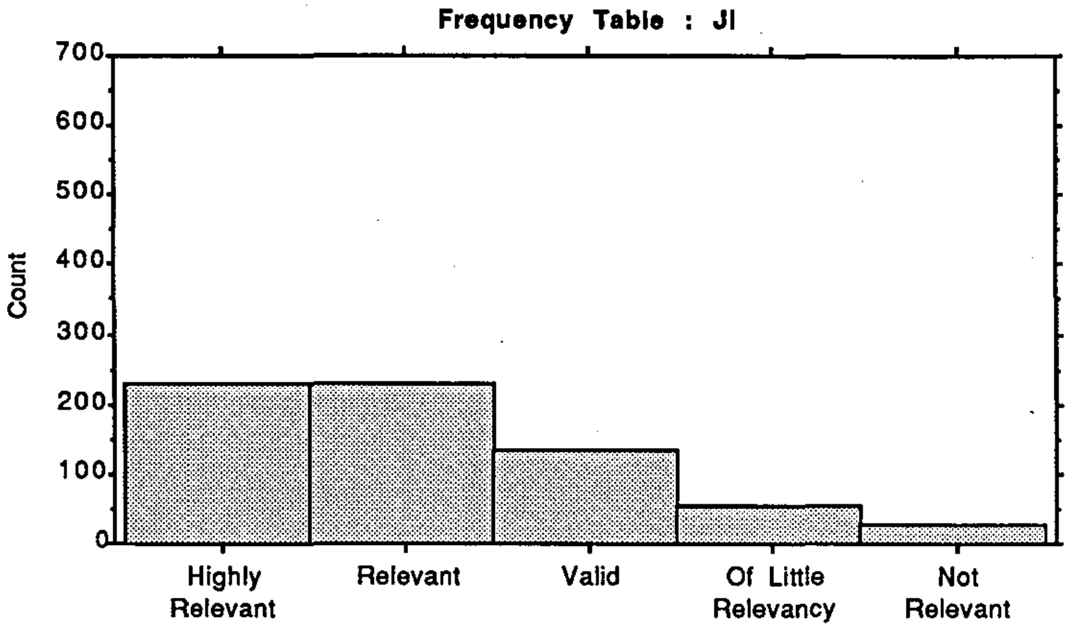

Table 28 : Frequency distribution of Relevancy (2) of combined experts Ji.

6.3.3 Card Sort

6.3.3.1 Inter-judge agreement

Referring to Table 29, the results indicate that the judges are in general agreement that in all four of the card sort tests, some of the cards are relatively more important than others ($\alpha = 0.01$). Therefore, the judges agree on the ranking of the relative importance of the cards (Appendix 22).

	N	df	W	χ^2	< p
A	18	17	0.390	66.37	<< 0.001
B	19	18	0.243	43.70	0.001
C	16	15	0.205	30.73	0.01
D	13	12	0.339	40.63	<< 0.001

Table 29 : Inter-judge agreement in card sort.

6.3.3.2 Correlation

The Spearman Rank Correlation coefficient (r_s) provides a measure of correlation between ranked samples (eg Siegel, 1956, p202). The relative orderings provided by the independent judges, Ji, are taken from the sums of ranks (Rj) in the Kendall concordance calculation (Appendix 22). The allocation of the probability of significance, α, is rather arbitrary, however, a general figure of $\alpha = 0.05$, is taken here to be the accepted level of significance.

Sort A	**N=18, df=16**	**r_s**	**z**	**< p**	**< α**
	Self / Self	0.951	3.919	0.00005	*
	Self / J0	0.835	3.442	0.0005	*
	J0 / Ji	0.592	2.439	0.007	*
	Self / Ji	0.632	2.605	0.005	*
Sort B	**N=19, df=17**	**r_s**	**z**	**< p**	**< α**
	Self / Self	0.856	3.632	0.0002	*
	Self / J0	0.335	1.422	0.08	-
	J0 / Ji	0.406	1.725	0.04	*
	Self / Ji	0.204	0.864	0.2	-
Sort C	**N=16, df=14**	**r_s**	**z**	**< p**	**< α**
	Self / Self	0.926	3.588	0.0002	*
	Self / J0	0.456	1.766	0.04	*
	J0 / Ji	0.429	1.663	0.05	*
	Self / Ji	0.341	1.341	0.09	-
Sort D	**N=13, df=11**	**r_s**	**z**	**< p**	**< α**
	Self / Self	0.989	3.588	0.0003	*
	Self / J0	0.610	2.113	0.02	*
	J0 / Ji	0.724	2.506	0.006	*
	Self / Ji	0.831	2.879	0.002	*

Table 30 : Correlation tables of card sorts A, B, C and D (* significant at $\alpha = 0.05$).

6.3.3.3 Interpretation

The results of the card sort test (Table 30) indicate that :

Self/Self	A high degree of self-consistency.
Self/J0	A, C and D are significant
J0/Ji	A, B, C and D are significant
Self/Ji	A and D are significant

6.3.3.4 Discussion and implications of card sort data

Table 30 indicates that two of the layouts (A and D) achieved significant consensus between the teachback expert (J0), the judges (Ji) and self. In contrast, Layouts C and D are poorly correlated, or achieving only marginal significance. It is concluded that Layouts A and D were more amenable to a sorting procedure, whilst in contrast, many of the designers reported difficulties in the sorting of statements from Layouts B and C. This implication is also generally supported by the coefficients of concordance (table 29), where agreement between the judges is better for A and D than for B and C; the difference between A and C is quite notable.

It is worth reemphasising the point that layout C was deliberately chosen to be "wrong" for the particular scenario of internal house magazine design. A number of the judges reported that they were rather confused in the sorting of the Layout C statements. They commented that the given page was considered to be self-consistent (ie technically correct for the type of publication it actually was), but perhaps incorrect for the given scenario as described in the brief. For example, negative criticisms of the layout appearing in the statements (of the form "wrong image", eg C5), were judged by some of the experts to be inaccurate or irrelevant, and placed last in the ordering sequence (ie J2, J8), whereas, other judges (also J0 and self in this example) indicate that the statements (eg C5) make important points. The focus of the knowledge acquisition study was not of the type of publication depicted by layout C. A predicted ordering for this type of layout was always likely to be disadvantaged by a lack of directly acquired knowledge, but such knowledge arising here as implications and inference abstracted from the particular domain of study. It is worth noting that a knowledge based system resulting from the study of page layout design, as reported here, was not intended to provide advice about layouts of the type described by layout C. To do so would require a focused knowledge elicitation study in that particular domain. However, it is believed to be important for a knowledge based system, based upon this study, to be able to offer high level advice of the form "wrong image" etc, and that the study has identified pertinent concepts which are the essence of sound design advice of the type described by the statements in C. {Whilst investigating farmyard mammals one can easily conclude that a pig should not attempt to fly, but the same investigation is unlikely to shed light on the type of animals that can fly, yield useful information about how flight is achieved in such creatures, or identify important considerations that a pig should observe in order to go about the task of flying}.

Layout B was particularly badly designed, from many perspectives. Many of the judges commented on the paucity of its appearance, for example, judge J3 (B:J3:10 Appendix 14) concludes that "It's just a {bloody} mess, really." In a design that fails from many perspectives, it is perhaps difficult to assign an order to various contributing factors. {Does one attribute a relative importance to the reasons why your car won't get you to work in the morning when the problems with your car include a flat battery, the wheels are missing, it has no petrol, and the clutch is broken ?}. In contrast if one or two subtle, or catastrophic failures are present, then it is perhaps much easier to allocate a relative ordering. This once again suggests the need for holistic strategies of acquisition and evaluation. A relative order sort may, in many cases of visual design, be less than satisfactory. This is an important point since psychological testing methods, such as MDS, that attempt to elicit structure, may be inappropriate to design elicitation as designers may not cognise in terms of decomposable structures. Indeed, testing methods that rely on decompositional techniques, such as card sorting, appear less relevant to evaluating design knowledge than holistic methods such as criticising complete layouts. The extent of failure in layout B makes it unlikely to be applicable for an advice giving KBS, where the range of errors may be beyond the comprehension of the system (as it perhaps was for the experts). An advisory KBS tool based upon this study would, it is assumed, prevent designs from ever reaching the stage represented by layout B.

An interesting observation is that with respect to the independent judges, self correlates marginally better than J0 in Layouts A and D. However, in layouts B and C, J0 correlates with the independent judges better than self, but significance is still only marginal. It is postulated that the diversity of using many (ie four) experts in the knowledge acquisition phase accounts for this result, where the personal preferences of J0 have been identified as not necessarily being universal. The prediction of order in A appears more biased towards J0, where, as expected, self correlates better with J0 than Ji, but in D, self correlates better with Ji than J0.

In general, J0 correlates well with the independent judges, and the card sort test provides additional support for Table 29 (general agreement between the experts). This is an important result that also indicates that the teachback expert was competent, in comparison to the independent group of designers. This suggests that an acquired understanding based on E0 constitutes a reliable source of design knowledge. Self correlated well with J0, in general and this suggests that it is possible to acquire knowledge from a single expert, with reasonable success.

6.4 Summary of Evaluation Data

As previously stated, the agreement between experts indicates that the order provided by the sum of the ranks (Rj) is a reliable estimation of relative rank. Table 31 collates the information from various stages of the evaluation procedure. Note that the order is a reliable statistic. The average Accuracy and Relevancy calculation, Ji*, is statistically unfounded, but it still provides a useful indication because it can be quickly and easily interpreted. In table 31, the orders have been chosen to depict high values of sums of ranks (Rj) as low order values, for example, the "most accurate" object is first and the least accurate is sixty-seventh (ie A13 and A5 respectively).

Statement B1 is a good example of where agreement is consistently high. The orders are all high (4, 1, 6), Ji and J0 place the statement first in the card sort and self also predicts the card in second place. The statement receives good support (g) from both Ji and J0 in the open critique test, is interpreted to be accurate and relevant by average (Ji), and J0 directly marks the statement as being accurate and relevant. Similarly, statements A12, A13, B2, B7, B8, B15, C1 and C14 are also good examples of the type described above.

B12 provides an example of consistently low order (66, 65, 66), with an inaccurate and irrelevant average (Ji). Further, Ji places statement B12 eighteenth (out of nineteen) in the card sort test. However, B12 is interpreted as a preference (p) in the open critique stage overall. J0 offers good support in the open critique (g) and marks the statement both accurate and relevant. B19 is also a good example of a statement that is consistently ordered low (65, 49, 62), is contradicted in the open critique and has an inaccurate average. B16 and C6 are similar examples.

D12 provides a good illustration of the consistent marking of judge J0, where the statement is contradicted in the open critique test, is marked inaccurate and not relevant in the check tests, and is placed last in the card sort test. It is interesting to note that both Ji and self also predict statement D12 to be last in the card sort test, and it is also ordered low in accuracy (60) and relevancy$_1$ (56) by Ji.

However, it is worth noting that a statement that is generally accurate need not necessarily also be highly relevant, but a statement that is highly relevant$_1$ (to the particular layout) should be accurate. Statements ordered high in terms of relevancy are, in general, also ordered high in

	Critique		Accuracy				Relevancy 1				Relevancy 2			Card	
	Ji	J0	Order	Rj	Ji*	J0	Order	Rj	Ji*	J0	Order	Rj	Ji*	Ji	J0
A1	q	q	41	323.0	MA	A	29	361.5	R	H	13	416.0	R	1	1
A2	p	g	59	216.0	PA	A	26	373.0	R	H	25	373.0	R	9	3
A3	s	s	27	361.5	MA	A	40	327.0	V	H	39	330.5	R	=7	7
A4	p	g	54	267.0	PA	A	50	281.5	V	H	44	300.5	V	12	8
A5	p	g	67	108.0	MI	MA	35	334.5	V	H	31	350.0	R	16	5
A6	q	u	=30	357.0	MA	MA	45	316.5	V	V	28	363.0	R	15	16
A7	c	g	63	196.0	PA	A	11	434.5	R	H	11	440.0	V	3	2
A8	q	u	20	396.5	MA	MA	16	406.0	R	V	32	345.0	R	2	10
A9	q	u	42	322.5	MA	A	36	333.5	R	H	15	414.5	R	5	9
A10	s	u	38	330.0	MA	A	48	286.5	V	H	47	284.5	V	=7	11
A11	q	s	40	324.5	MA	A	19	395.5	R	H	33	342.5	R	4	6
A12	g	s	23	380.0	MA	A	2	497.5	R	H	4	485.0	R	6	4
A13	g	g	1	510.0	A	A	=8	444.0	R	H	10	460.0	R	13	12
A14	g	g	10	454.0	MA	A	39	328.0	R	H	9	461.0	R	14	13
A15	p	u	19	399.0	MA	MI	53	270.5	V	V	12	423.5	R	11	17
A16	q	u	48	291.0	PA	PA	64	177.0	V	R	45	298.0	V	17	14
A17	s	g	28	360.5	MA	A	63	207.5	V	H	36	338.0	R	10	18
A18	s	q	8	458.5	MA	A	52	273.5	V	H	34	340.5	V	18	15
B1	g	g	4	475.5	MA	A	1	559.0	H	H	6	480.5	R	1	1
B2	g	g	2	498.0	MA	A	3	488.0	R	H	22	385.5	R	5	3
B3	q	s	33	351.5	MA	A	6	458.0	R	H	7	478.5	R	=9	15
B4	s	s	61	208.5	PA	MA	20	392.5	R	H	5	482.5	R	13	17
B5	s	g	26	362.5	MA	A	25	374.5	R	H	41	325.5	V	4	2
B6	s	u	39	326.5	PA	MA	28	364.5	R	V	2	499.5	R	7	19
B7	g	g	7	469.0	MA	A	12	430.5	R	H	16	414.0	R	6	5
B8	s	s	13	431.0	MA	A	4	487.5	R	H	1	515.0	R	8	4
B9	q	s	29	358.5	MA	A	32	348.5	R	R	37	335.0	R	=2	9
B10	s	s	25	363.5	MA	A	=41	325.5	V	R	61	224.5	V	=2	12
B11	u	u	=30	357.0	MA	MA	27	371.0	R	V	52	275.0	V	12	10
B12	p	g	66	120.5	MI	A	65	174.0	L	H	66	125.5	L	18	6
B13	s	u	57	239.0	PA	PA	51	277.5	V	V	51	276.5	V	14	18
B14	s	s	15	429.0	MA	A	33	343.5	R	R	24	379.0	R	17	11
B15	p	g	6	470.0	MA	A	5	484.5	R	R	3	488.5	R	11	8
B16	p	g	56	251.5	PA	A	66	157.5	L	H	65	132.0	L	19	4
B17	g	g	3	493.5	A	A	34	342.0	R	R	50	278.0	V	=9	13
B18	u	q	64	172.5	PA	A	62	209.0	V	R	58	248.5	V	16	7
B19	c	u	65	136.5	MI	MA	49	284.5	V	R	62	204.0	V	15	16

Critique			Accuracy				Relevancy 1				Relevancy 2			Card	
	Ji	J0	Order	Rj	Ji*	J0	Order	Rj	Ji*	J0	Order	Rj	Ji*	Ji	J0
C1	g	g	22	382.5	MA	A	23	383.0	R	H	=19	399.5	R	2	2
C2	g	g	55	264.5	PA	A	=21	390.0	R	H	40	328.0	R	10	3
C3	s	g	43	319.5	MA	MA	24	377.0	R	R	26	369.5	R	3	9
C4	u	q	47	295.0	PA	A	43	324.0	V	R	57	257.0	V	5	12
C5	g	u	32	356.0	MA	A	15	412.0	R	H	21	396.0	R	6	1
C6	p	s	62	203.0	PA	A	61	209.5	V	R	54	273.5	V	15	11
C7	q	u	53	281.0	PA	A	44	323.0	V	H	29	362.5	R	4	5
C8	p	c	50	288.5	PA	A	13	425.0	R	R	14	415.5	R	11	16
C9	g	g	45	314.5	PA	A	31	351.5	R	R	49	282.0	V	8	10
C10	s	u	21	386.0	MA	MA	59	224.0	V	R	60	229.5	V	1	7
C11	q	u	37	330.5	MA	A	47	291.0	V	R	67	116.5	L	9	13
C12	u	u	58	232.0	PA	A	54	265.0	V	L	46	289.0	V	16	15
C13	s	s	51	288.0	PA	A	=41	325.5	V	L	56	261.0	V	13	14
C14	g	g	14	430.5	MA	A	14	412.5	V	H	18	406.0	R	7	8
C15	p	q	44	316.5	PA	A	38	329.5	R	H	23	383.0	R	12	4
C16	u	g	36	339.5	MA	A	67	145.5	L	H	63	191.5	V	14	6
C17	p	s	18	404.0	MA	A	10	436.5	R	R	27	365.0	R	‡	‡
D1	s	g	17	410.0	MA	MA	=8	444.0	R	H	55	271.5	V	8	11
D2	s	g	52	282.5	PA	A	55	263.5	V	H	=19	399.5	R	12	6
D3	g	g	=11	432.5	MA	A	46	305.0	V	H	59	240.5	V	11	8
D4	s	g	5	471.0	MA	A	7	451.0	R	H	17	409.5	R	4	3
D5	s	g	46	310.5	MA	A	17	399.5	R	H	48	283.0	V	7	10
D6	g	s	34	349.5	MA	A	18	396.0	R	H	8	465.0	R	=2	4
D7	s	q	=11	432.5	MA	A	57	227.0	V	H	38	332.0	R	9	9
D8	s	g	9	457.5	MA	MA	30	358.0	R	R	35	338.5	R	6	5
D9	c	g	35	342.0	MA	PA	60	215.0	V	H	64	154.5	V	10	12
D10	s	g	16	416.5	MA	MA	=21	390.0	R	H	43	301.0	V	1	1
D11	s	g	49	290.5	PA	MI	58	226.0	V	R	42	313.0	V	=2	7
D12	q	c	60	213.5	PA	I	56	229.0	V	N	30	360.0	R	13	13
D13	s	g	24	371.0	MA	A	37	331.5	R	R	53	274.0	V	5	2

g good support
s moderate support
p preference
q questionable support
c contradictory
u unsupported

A accurate
MA mostly accurate
PA partially accurate
MI mostly inaccurate
I inaccurate

H highly relevant
R relevant
V valid
L of little relevancy
N not relevant

Table 31 : Summary of Evaluation data.

* The average is not a valid statistic.

‡ refer to footnote 3.

accuracy[8], but notable exceptions are A5, A7, B4 and C2. These four examples are particularly disappointing, but it is worth noting that the teachback judge, J0, indicates these statements are accurate and relevant, and he also provides good support for them in the open critique test. This suggests that the acquired concepts are competent products of the acquisition procedures, but are not broadly accepted, as generalisations, in these cases.

6.5 Conclusions of the Evaluation study

6.5.1 The Evaluation Procedure

The designers appeared to enjoy the evaluation process, and were interested to see how their own criticisms compared to the prepared statements, to which they were able to state an opinion of accuracy and relevancy. The judges expressed a desire to see the results of the study. The evaluation procedure was rather lengthy, between two and three hours duration, and required the judges to concentrate throughout. Each judge was required to make over two hundred decisions, excluding the card sort and open critique stages.

The main difficulty of evaluating design knowledge emanates from the impact of personal style, and the idiosyncratic behaviour of designers. A panel of ten judges was used in the attempt to counter the problem. Further, it was possible to measure the acquired and actual preferences of the teachback designer (E0/J0) against the consensus (Ji).

	J0	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
1st	A	D	A	C	D	B	D	C	C	B	B
2nd	D	B	D	A	C	D	C	D	A	D	C
3rd	C	C	B	B	B	C	B	B	B	A	A
4th	B	A	C	D	A	A	A	A	D	C	D

Table 32 : Order of critique evaluation.

The order of presentation of the four layouts for each judge, and the order of the statements in preparation were randomised in order to reduce the risk of introducing erroneous trends (although it is acknowledged here that a prepared pseudo-random order which would have resulted in a more balanced design for the presentation of the layouts may have been better). The open critique test was designed to allow the experts to criticise the layouts naturally and without guidance, and as a consequence the volunteered data should be minimally prejudiced or biased. However as the test progressed through each of the four layouts, the designers might have become familiar with the type of prepared information, and perhaps attempted to mimic or predict the prepared statements. The later open critique data is also likely to have been subject to cross-layout biasing. These observations are valid criticism of the test procedure.

However, the first critique of each judge is free from cross-layout biasing and is submitted

[8] This point is illustrated by the predominantly high accuracy count, shown in Table 26, the agreement between the judges in Table 23 and the general consistency of marking of the statements that are judged to be 'inaccurate' in the examples given above (B12, B19, B16, C6).

without prior knowledge of any prepared statement. Therefore, the first critique data (Table 32) can be used to qualify the competence of the open critique data as a whole, by illustrating that the data is typical. For example, designer J0 evaluates layout A first, and makes identical statements to the prepared statements A2 (A:J0:02) and A7 (A:J0:04) (Appendix 14). Judges J3 and J7 criticise layout C first, and provide independent support for the targeted concept 'wrong image' (C5), for example[9]:

C:J3:01 From the whole layout it would be a serious magazine...
C:J7:11 It hasn't got the image of the institution, it's like an insurance image, or a bank image, that sort of image because of the lightness.

In retrospect, all of the open critiques should have been completed before the prepared statements were checked. However, jumping between the layouts might have confused the designers and the test would have become tedious for the judges because they would have needed to familiarise themselves with each layout at least twice. However, the effect of cross-layout biasing is not believed to be significant. The layouts are quite different from each other, and the judges criticised each layout before viewing the prepared statements associated with the particular layout.

The predictive statements covered the many views expressed in the initial elicitation phase. Also, in preparing the statements, a lack of certainty about the required depth of detail was encountered. The wide range of criticism offered by the judges suggests that the situation was not easy to predict. For example, Judge J4 volunteers very little verbal data, whereas J9 is quite verbose. Thus, irrelevant statements were, perhaps, likely to have been prepared, although all of the statements were expected to be accurate. When questioned, all of the designers agreed that the statements were, in general, competent and sufficient. Further, they all declined to make additional statements in the card sort exercise (but perhaps the complexity of the sort task is a significant factor here, where additions would have made the task even more difficult for them).

In general the designers found the card sort test a bit confusing. They expressed difficulty in deciding whether or not they were sorting on the basis of what they normally look for, or what was most apparent in the given design, despite being instructed to sort on the basis of the importance of the statements, to the given design. The biggest problem occurred when a designer disagreed with the *Accuracy* of the statement, but thought the concept was generally important. The prepared statements consisted of both positive and negative criticism, this occasionally caused confusion. Also, the designers reported difficulty in assigning an order to statements that, when combined, formed an important concept, but when viewed in isolation they described similar or identical concepts, and were much less important.

Layouts B and C were poorly correlated in the sorting procedure. As previously discussed, Layout C was chosen to be atypical of the target domain of internal house magazine design, in the fundamental respect of *image*, and the knowledge elicitation procedures never concentrated on examples of this kind. Layout B was particularly poorly designed, and chosen for evaluation because it was easy to identify pertinent design flaws. There were many mistakes

[9] Further support is cited in section 6.3.1.2.1, footnote 5.

in Layout B, and it was perhaps difficult to assign a relative order to the importance of those problems. The knowledge acquired form this study was not intended to support a knowledge based tool for layouts of type C, and should prevent the calamity of errors depicted in Layout B. However, the main objectives of the evaluation study, reported here, concentrated on the identification and expression of pertinent design features (particularly flaws), and the relative ordering task was less important since it was conceived from the outset that the designers may have difficulties, and that the test was not necessarily most suitable.

6.5.2 Main conclusions of the Evaluation study

The main objective of the evaluation procedure was to test predictive statements; *all* were assumed to be accurate. Table 24 indicates that J0 marked most of the statements accurate, and Table 26 indicates that the independent judges generally marked the statements as being accurate.

Many of the prepared statements were covered by the judges in the open critique procedure and this generally indicates that the statements were accurate and relevant. In addition, the analysis of the open critique data was able to identify a few concepts that were inadequately covered by the prepared statements, demonstrating the areas of weakness in the acquired understanding. Also, other general concepts that were not directly covered in the evaluation procedure were supported.

In the accuracy and relevancy check and card sort procedures, the experts were in general agreement. This result is particularly interesting due to the general belief that design is perhaps idiosyncratic and agreement between designers is unlikely. The result also supports the hypothesis that there are general features and concepts of design domains that can be identified, and elicited. Hence, it also follows from the above result that the support given for Accuracy and Relevancy is meaningful, and the relative rankings are significant (Table 31 and Appendix 22). Also, the overall levels of scoring of Accuracy and Relevancy are good (Tables 24 to 28), and supports the view that the acquired understanding is competent. The judges reported, when questioned, that the statements were generally competent and thorough.

Support from J0 was particularly good, and in many instances better than the support offered by the independent experts Ji. This result was expected, and suggests that the the elicitation procedures were successful for obtaining the personal preferences of the teachback expert, E0. The test allows, to some extent, the identification, measurement and interpretation of preferences against a consensus of opinion, the attitude to *short measure* being a pertinent example.

The acquired understanding of the domain language, through an appropriate use of terminology, is also demonstrated in the open critique and protocol data. For example, the terms *formal, serious, business-like, unfriendly image* were used in the prepared statement (C5) and also by the experts (C5, Appendix 17).

It is therefore concluded that the evaluation study supports the view that the acquired understanding is competent. This is demonstrated through the testing of the principle teachback expert (J0), and ten independent judges (Ji). Hence, it is concluded that the knowledge elicitation procedures for design, discussed previously, are effective, and the methods of acquiring, analysing and developing design knowledge are practical. The results of the evaluation procedure provide a further level of qualification to the acquired knowledge, for the purpose of constructing a competent Knowledge Based System. A framework for the testing of design knowledge has also been illustrated, however, the need for further research in methods of testing and evaluating design knowledge is clear.

7 Conclusions

This thesis has been motivated by the desire to develop Computer Aided Design through the application of Knowledge Based Systems techniques. 'Intelligent CAD' literature reported that current computer tools could not assist the designer with 'intellectual' aspects of design, and the quality and extent of embedded design knowledge was poor. Knowledge Engineering was viewed by the ICAD community to be the mechanism by which the above inadequacies would be overcome. However, it was observed here that the issue of design knowledge elicitation was not being convincingly addressed, since techniques appeared to miss the special requirements of design. Therefore coherent, systematic methods of design elicitation still needed to be developed.

In this chapter three important subjects of significance to design elicitation are discussed. Section one summarises the necessity and role of design elicitation procedure in the domain of Intelligent Computer Aided Design (ICAD), the most likely area of application for the techniques discussed here. Section two establishes general conclusions emerging from knowledge elicitation research. The activity called design introduces further implications for the process of knowledge elicitation, and the more specific considerations of design elicitation are discussed in section three. In section four, the conclusions emerging from the page layout design study are discussed. The thesis is summarised in section five, and a discussion and final comments appear in sections six and seven respectively.

7.1 Intelligent Computer Aided Design.

7.1.1 The need for intelligent ICAD systems.

The philosophy of Artificial Intelligence, Expert Systems, and Knowledge Based Systems technologies suggest a desirable strategy for Computer Aided Design systems development. Indeed, the approach has been fervently pursued in recent years (Duffy, 1987; Topping and Kumar, 1989). However, the proffered 'Intellectual' support has not been realised (Bijl, 1985; 1987; Tomiyama and Yoshikawa, 1985a,b; Landsdown, 1988). Here it is argued that the above predicament can be primarily attributed to the paucity, extent, and reliability of embedded design knowledge.

7.1.2 Knowledge elicitation is accepted, but not practised.

The knowledge acquisition process is widely understood as the most crucial stage in the development of Knowledge Based Systems. Despite the principle also attaining widespread acceptance with ICAD constructors, systematic methods of knowledge elicitation do not appear to be practised in the construction of ICAD systems. Knowledge elicitation, as a whole, is inadequately reported in the ICAD research literature, and the issue is often glossed over. Paradoxically, considerable attention is often afforded to the matter of the representation of design knowledge.

7.1.3 The need for design elicitation method.

Knowledge elicitation methods for design applications are poor, and the need for their development is imperative. The problem of knowledge elicitation in design, however, rests firmly on knowledge elicitation research, since ICAD research is essentially a net consumer of AI and KBS technology. Few attempts have been made to address knowledge elicitation in design applications, and the apparent paucity of embedded design knowledge in ICAD systems suggests that it is timely to adopt a more focused approach.

7.1.4 Popularity of automatic computer elicitation techniques.

Automatic design elicitation techniques are now emerging in the ICAD literature, seemingly promoted by the abundance of automatic elicitation methods that appear in the knowledge elicitation research literature. Automatic elicitation methods appear to have been embraced from the traditional domains of knowledge elicitation, such as classification and diagnosis, often without adaptation, and certainly without due attention to the special requirements and problems posed by design.

7.2 Knowledge Elicitation.

7.2.1 Construction of models.

Focusing the knowledge elicitation process on the development of predetermined computer structures, such as the production rule, whose principle assets are in their ease of installation into computer systems is not a feasible strategy (Collins et al, 1985; Partridge, 1987; Gaines, 1987b; Johnson and Johnson, 1987a). The purpose of knowledge engineering is to construct creditable models of cognition (Clancey, 1985; Johnson, 1985; Musen, 1988; Schreiber and Wielinga, 1989), an activity which is itself likened to a creative design task (Musen, 1988). Developing a competent model is difficult. Here procedures for constructing a competent model of design knowledge have been expounded. The methods have been demonstrated through the study of page layout design. The approach, and the competence of the model is supported through the results of an evaluation study.

7.2.2 Evaluation must precede implementation.

An acquired understanding must be evaluated before it is subjected to the covert restrictions of a computer implementation. When embedded, an observed lack of system efficiency can not easily be attributed to inconsistencies, or lack of depth, in the (design) knowledge itself, or to the restrictions of the computer architecture, the unsuitability of the computer representation, or our lack of understanding of the complex process of communication and interpretation of knowledge (Gaines, 1987b).

Therefore, the prototypical strategy for Knowledge Based Systems development, where knowledge is gradually amassed and embedded, does not appear viable (Johnson and Johnson, 1987a). Rapid (disposable) prototyping appears advantageous as a learning exercise, only when the results are, indeed, disregarded. However, the Draconian measures that are needed are unlikely to be followed in many scenarios, particularly in commercial applications.

7.2.3 Communicable machine-independent models of cognition.

The development of a human communicable and machine independent model of cognition, in the form of an intermediate representation, is widely regarded as an essential strategy of knowledge engineering. Here Mediating Representations (Johnson and Johnson, 1987b) were argued to provide a useful aid that can facilitate the construction, development, checking and refinement of design knowledge. The method has been demonstrated in the page layout design study.

7.2.4 Global approach to Knowledge Elicitation.

It has been argued that knowledge elicitation strategies must address a broad spectrum of the domain conception, including both deep and shallow knowledge. Adopting a global elicitation strategy (generally termed *holistic,* here), and including different techniques and methods, has been argued to provide a suitable approach. For example, it has been argued that protocol analysis in conjunction with a flexible (semi-structured) personal interview provides a balanced technique for design elicitation. A holistic approach to the subsequent development and interpretation of an acquired understanding is also an important strategy to enable the refinement of a broad cross-section of the domain issues. Here the teachback technique in conjunction with a progressive analysis method was argued to facilitate an interrelated elicitation and analysis strategy.

7.2.5 Automatic elicitation.

Automated methods of knowledge elicitation currently offer less cognitive power than people possess for learning, understanding, modelling and communicating with other people (ie experts, in the first instance, and systems constructors in the second). Language has been argued to be our most sophisticated method of communication (Johnson and Johnson, 1987b). Here it has been argued, through the example of page layout design, that personal interview techniques are viable for design elicitation applications. This point is continued in section 7.3.6.

7.3 Knowledge elicitation for Design Applications.

7.3.1 Design is ill-defined.

Design is widely accepted as a problem that is largely 'ill-defined' (Simon, 1973). Given requirements do not provide sufficient information to enable designers to reach a solution through the simple transformation or optimisation of the provided information (Archer, 1979; Thomas and Carroll, 1979). Designers contribute goals and information not explicitly known before designing, but such data emerges as a direct result of the design process (Landsdown, 1987). Further, in design the initial requirements are also subject to transformation and for a given set of requirements, any number of design solutions may be produced. Therefore, it is concluded that automatic computer induction methods of design knowledge elicitation, where design strategies are inferred from a sample set of requirements and solutions, are not appropriate.

However, inductive techniques may provide some interesting data for the interpretation of perceptual design skills, in the situations where designers are unlikely to have verbal access to their own thought processes. However, the data arising from such procedures are the product of external inference only. The absence of evidence supporting the view that such data accurately reflects actual thought processes, implies that such data is unreliable and cannot be realistically termed 'knowledge.' Psychologically based perceptual studies (Colley and Breach, 1989) may also provide interesting design information, and promote plausible theories of cognition. Categorisation and grouping elicitation techniques also appear useful, particularly when spatial and perceptual data is used. However, strategies relying on decomposition are suspect in design elicitation, as discussed below.

7.3.2 Design is not classification or diagnosis.

The solution focused strategies of design contrast the problem focused strategies of science (Lawson, 1972;1979a). In particular, domains involving classification and diagnosis are the ones of greatest endeavour in knowledge elicitation research. However, the acquisition techniques of classification and diagnosis have not been shown to be appropriate to the solution focused, and constructive (Marcus, 1988) nature of the design activity.

7.3.3 The Holistic nature of design.

Design cannot be completely described by (hierarchical) decomposition or component level views of problem solving (Bijl, 1985; Carroll and Rosson, 1985; Holt, 1985; Landsdown and Roast, 1987). In contrast, design encompasses a form of thinking that is more holistic in nature (Cross and Nathenson, 1980; Edwards, 1979; Tovey, 1984; Bijl, 1985). A *holistic* paradigm, where information is elicited as a staged, global learning and refinement process, has been argued here to be a pertinent strategy for the elicitation, analysis and development of design knowledge. However, such a strategy is not restricted to design problems, and the approach is perhaps just as appropriate for many domains of human problem solving, where reductionist philosophies to knowledge elicitation appear unsuitable because of the complex nature of interactions between domain concepts or entities (consider the acquisition of knowledge from a chess Grand Master).

7.3.4 The role of preferences in design knowledge elicitation.

Design solutions are greatly influenced in nascency, but early decisions may be arbitrary, a matter of personal preference or based upon information that is of little importance to the design requirements (Darke, 1979).

The role of the personal preference is now regarded as an important aspect of knowledge elicitation research (Boose and Bradshaw, 1990). Personal preferences are integral to the process of design, perhaps as *style* (Radford, 1986), and the acquisition and recognition of style appears an essential pursuit of design elicitation. The analysis and classification of design judgments to those that are based upon well-founded and widely accepted principles of the domain, and those that are a matter of preference is clearly desirable. However, the interpretation of this data, as a process of comparison and contrast, is unlikely to submit into neat classes of distinction, and is certainly difficult. Analysis requires the participation of many designers in the knowledge elicitation process, with careful attention to the background and circumstances of each, and procurement of how their skills are acquired and practised (eg Gaines, 1987b; Ogborn and

Johnson, 1984). The personal interview remains the best technique for eliciting the 'depth' of knowledge required to form such interpretations (eg Johnson, 1987; Welbank, 1987).

The individual designer is likely to be self-consistent. Complex decision-making may result in a 'style' that incorporates expertise based upon established principles of experience. Thus, perhaps, the designer's style constitutes a compiled understanding of the domain, that also includes equitable decisions of arbitrary and personal likes, that have been tried, tested, adapted and trusted through design practise. It is suggested here that perhaps other complex human problem solving activity, typically the target of KBS or ES application, is also subject to the argument above. It is unlikely that a panel of experts can agree upon a single 'correct' answer, on the basis of logic alone, and preferences are manifest in all areas of problem solving, although the impact is more noticeable in design. The above discussion is continued in section (7.3.8).

7.3.5 Design tasks.

Design researchers argue that design activity should be observed rather than postulated (Eastman, 1970; Akin, 1979; Lawson, 1980). Introspective or retrospective accounts of design are untrustworthy and design elicitation must incorporate studies of design activity. Therefore, automatic acquisition techniques, that wholly require the designer to offer design knowledge, when not engaged in a natural problem-solving task, are suspect. For example, it is questionable whether designers can volunteer valuable design knowledge, in the form of repertory grids, being 'interviewed' by a computer. In contrast, it has been argued here that a design task, monitored through protocol analysis, is appropriate.

7.3.6 Verbal reporting of design information.

Despite the caution associated with verbal reporting of design tasks involving spatial data, the page layout design study has demonstrated that protocol analysis is a viable technique for design knowledge elicitation. The verbal data acquired in the page layout design study is considerable, and certainly more substantial than initially conceived. The success is partly attributed to the selection of a design task where explanation is a natural process of the activity, and concentrating on subjects familiar with, and hence unrestrained by, talking whilst designing, ie lecturers of (graphic) design with considerable practical experience.

7.3.7 Styles of cognition.

It is argued that the value of *styles of cognition,* recognised in design research literature, is inadequately accounted for in the knowledge elicitation research literature. In particular, it has been argued that the type of thinking generally termed *holistic* is of great significance in design, and the associated modes of thought such as divergency, impulsiveness, holism and field-dependency must be accommodated in design elicitation. In contrast, current (design) elicitation researchers concentrate on the *analytical* modes of thinking associated with scientific problem solving (convergent, reflective, analytic and field-independent styles) through reductionist decompositional strategies.

Cognitive explanations of the design activity also recognise the importance of the duality of the human brain. Studies indicate (Edwards, 1979; Cross and Nathenson, 1980; Tovey, 1984) that the design activity relies on thought processes commonly associated with the 'right brain' (Bogen, 1969; Gazzaniga, 1983). Perceptual and spatial skills in particular are attributed to right hemispheric function. Further, *holistic* styles of thought (Cross and Nathenson, 1980) are argued to be a predominantly right brain process (Tovey, 1984) important to early stages of design.

The internal representation of spatial information is, perhaps, different from propositional and analytical forms of knowledge (Ward, 1984; Smythe, 1988), traditionally targeted in knowledge acquisition studies (Collins et al, 1985; Kornell, 1987). The importance of spatial thinking in design (Anita Cross, 1984) must be recognised by design elicitation methods, and the form and communication of spatial information needs careful consideration. Here, video recording, drawing and diagrammatical techniques have been employed.

Many design tasks involve the communication of information that is visual and spatial in nature (eg Landsdown, 1987; Bijl, 1987). The information may be, for example, initially given in a spatial form, and the result of the design activity may be a visual product. In such tasks, drawing is a predominant feature of the design activity. The designer, perhaps, uses diagrams as an internal communication medium (communicating with himself), and the finished product is in many cases a refined drawing, page layout design being a particular example. In such domains, it is essential that the design elicitation methods include drawing tasks.

Further, diagrammatical methods of communication (SGN diagrams, for example) constitute a valuable mechanism by which design knowledge can be communicated, and refined, through a medium that is widely accepted by designers, who are familiar with diagrammatical and spatial methods of representation and communication (ie Landsdown, 1987). The value of diagrams in knowledge elicitation has also been recognised elsewhere to be a generally useful technique (eg Lee et al, 1990).

Whilst it may not be possible to acquire all facets of design knowledge using qualitative methods (the elicitation of perceptual-based design skills, for example), design elicitation techniques can incorporate methods that address the spatial nature of the design task, through typical design situations, and record spatial information for review and interpretation. Once again, automatic elicitation techniques are less than adequate in this respect, whilst the video recording of drawing tasks offers a more likely approach.

7.3.8 Combining design knowledge from more than one expert.

Any number of designers can independently produce any number of distinctly different designs, all of which form acceptable design solutions. The complex interaction between design practices, design lore, and arbitrary style based decisions suggests that cross-matching design skills may be suspect as a source of sound design advice. The selection between successful alternatives inevitably involves personal choice. Although individual designers are likely to be self-consistent, combining design expertise from more than one expert does not appear practical, due to the overwhelming profusion of personal preferences and arbitrary decisions in design. What is being suggested here is that amalgamating design knowledge from many sources, into a single 'coherent' knowledge base appears unrealistic. However, it is not suggested that the knowledge base be restricted to design expertise from a single source, on the contrary, many sources are desirable so that a choice between (possibly conflicting) advice can be polled.

As previously discussed, design elicitation studies should involve many designers in an attempt to determine which decisions are, perhaps, more general and those that are likely to be a matter of personal preference so that, in analysis, the individual preferences can perhaps be disambiguated from the underlying, and widely accepted principles of the domain. A thorough testing procedure involving many experts may also provide useful information with regards to the analysis of preferences, as illustrated in the example of page layout design.

It is asserted here that the ICAD system based upon such design knowledge could offer advice on the well-established principles of design lore, to keep the designer within acceptable constraints, that might otherwise lead to failure, or be transgressed in the designer's pursuit of more alluring objectives (Landsdown, 1988). Also, the system could offer an alternative suggestion on a preference-based decision, to provide the designer with a creative (or innovative) input to the design task, by facilitating options that may not normally be considered (Schank, 1986; McLaughlin and Gero, 1989). Therefore, it is ventured here that such a computer system would surely constitute an important development towards the 'intellectual support' so desperately sought by the ICAD community.

7.4 The page layout design study

7.4.1 Types of knowledge

The design knowledge acquired from the study of page layout design is predominantly of the type that is widely categorised as "declarative" (as opposed to the "procedural"). The value of making such distinctions is not always useful. However, it is worth noting that holistic types of knowledge are perhaps more closely associated with the declarative classification. It was clear that whilst the designers in the study were using simple, high-level "procedural" types of knowledge (ie Appendix 7), a detailed procedural account was not realistically obtainable; they did not appear to design procedurally. Repeatedly decomposing aspects of the design activity appeared inappropriate, and unlikely to yield useful, or accurate design knowledge. Support for this observation can also be taken from the absence of useful publications about how to design, in which the attempt to describe design in terms of a number of procedural decompositions is not particularly effective (Lawson, 1980; Landsdown, 1988; also see Appendix 2, E0:277-284).

Here it is suggested that the page layout design study supports the view that design knowledge is likely to be predominantly declarative (assuming one believes in such a distinction). Therefore, it is recommended that design acquisition procedure should favour methods that target declarative forms of knowledge. The qualitative methods adopted in the study of page layout design were believed to be particularly effective in this respect.

7.4.2 Visual Data

The acquisition of visual and spatial information is an important aspect to be addressed for studies of design. A video recorder was employed in the page layout design study. It is concluded that the video recorder is an essential item of equipment. In the page layout design study it would not have been possible to reconstruct and interpret visual aspects from the sound track and (final) drawings alone. Further, intermediate and temporal aspects (ie partial solutions, order and sequence of actions/drawings) were also faithfully recorded for review and analysis. The recordings were also used for subsequent stages to confirm and verify interpretations placed on the data. The need for diagrammatical methods of communication in design have already been highlighted (eg section 7.3.7).

It is concluded that the methods of design elicitation, as described in this thesis, were effective in the elicitation of visual aspects of page layout design knowledge. However, it is clear that further attention to visual forms of communication is needed. In particular, although the video recorder was most useful, the transitory nature of the sketches caused a number of analysis problems. Final sketches show only the completed design, in which the details predominate, whereas in earlier stages of the design task, the sketches are often simple and the design issues being considered by the designers are at a higher level of conception.

The efficacy of these methods relied on the integrity of the designers to (remember to) explicitly sketch what they were considering, as the designs progressed. In general, the designers were comprehensive and reasonably comfortable with the procedure. The penalty for the conscientiousness was that they were perhaps being sidetracked. Further, it appeared that the exploration process, where the explicit (diagrammatical) elimination of possible (or impossible) solutions was a natural and typical aspect of the design activity.

The initial procedures of acquisition are straightforward, and are likely to capture large amounts of information relatively easily and quickly. The difficulties, and endeavour, arise from the analysis phases of the study, where an acquired understanding is developed. Such a process is not easy, is demanding on the knowledge engineer and the experts, and may take considerable time and effort. The quality of the resulting knowledge base primarily depends on the intellectual capacity of the knowledge engineer to structure and interpret, and the effort devoted to the study. Alternatives to the reliance on the human input to knowledge engineering appear, so far, unconvincing in design.

An interesting observation is that some forms of diagrammatical knowledge, prevalent in visual design tasks, is perhaps open to external observation in a way that the equivalent traditional "analysis and diagnosis" types of knowledge are not. For example, a designer will produce, and develop, a number of sketches before choosing one to develop into a complete product, the development in many cases can be clearly seen, and the critical decision points analysed. The sketches and diagrams providing a permanent record. In contrast, in medical diagnosis a physician taking a decision is less likely to show any mechanisms by which a decision was taken, often supplying just the result as a product of the input.

Contrary to initial expectations, a common opinion expressed by the designers used in the study was that designers of worth should be able to explain the form of their design, the options considered, and the basis of decisions taken. This suggests that design is far less idiosyncratic and preference based than many consider. However, it is worth noting that the "explanations" offered by designers are likely to incorporate visual aspects, many of which may be implicitly understood by fellow designers, as acquired visual skills.

7.4.3 Structuring design knowledge

The apparent holistic nature of design, in general, and visual design in particular, raises doubts about the usefulness of representing design knowledge as decomposable structures. In the page layout design study some entities appeared realistically and naturally suitable for subdivision, for example, the elements that constitute the "sources of information" (Appendix 10, diagram 3). However, it is most important to note that other concepts, especially those forming complex visual relationships (eg balance, weight, impact), could not be meaningfully decomposed, and that it is impractical and unrealistic to attempt to do so.

However, the process of knowledge acquisition is a learning exercise, and the methods discussed here permit the transference of understanding, even if external representations are not immediately obvious. For example, after discussing a number of page layouts, some of which the expert says "are balanced", some are "acceptable" and the remainder are "unbalanced", then the knowledge engineer will have acquired an understanding. This is a natural process of design education, which is generally termed the 'apprentice' approach.

From the knowledge engineering perspective, it is not clear from the outset which aspects of design knowledge can be meaningfully subdivided and those that are and must remain holistic in nature. The page layout design study suggests that competent design knowledge can be acquired as a knowledge engineering exercise. It is concluded that for domains of design it is important to adopt a mixed and investigative strategy.

7.4.4 Role of a Knowledge Based tool

As a result of this study an advisory knowledge based tool was envisaged to be developed. It is conceived that advice offered by such a system would be at two levels of abstraction. The first type of advice would be targeted at the simple and rather straightforward aspects of detailing. A simple example being the recommendation that a light picture on the edge of the page be contained by a border (Appendix 10, Diagram 27. Sections 2.3.1.2 and 2.3.2.2 illustrate some other pertinent examples).

The second type of advice corresponds to the higher level (and possibly more holistic) knowledge acquired from the study (Appendix 10, sections 2.1 and 2.2). In this case, the advice may include aspects of image, organisation, balance, and overall impact of the design. For example, a recommendation for the size and style of the body type or headline, a visual preview showing the density of tones on the page (ie balance of weight), advice for the need to make the article visually appealing (ie through the use of a feature or colour etc).

The provision of simplistic visual interpretation tools, such as line-tracing and regional tone mapping, that would be capable of recognising situations where, respectively, for example, problems of "alignment and visual ambiguity" (2.3.2.2.2), or balance may occur, would be potentially useful, and relatively easy to construct.

An interesting observation is that although the advice offered by such a tool may be ignored, at the discretion of the designer, the provision of the advice may in itself provide useful creative input. For example, recommending that an "initial letter" is required to visually enhance the design, the designer may choose another mechanism, of personal preference, to achieve the same effect. As long as the advice is at the appropriate level, and is not too distracting (ie the designers request the advice rather than it being shovelled at them), then it will probably be productive, as it can, as is likely, be ignored or explained away if desired. This discussion is continued in sections 8.3 and 8.4.

7.5 Summary

The central tenet of this thesis addressed the appropriateness of the knowledge engineering strategy to design problems. In recent years, considerable developments have been made in knowledge acquisition techniques for scientific applications, such as classification problems, whilst in contrast, techniques for design applications have been slow to emerge. It was observed that systematic knowledge elicitation procedures are not being applied in 'Intelligent CAD' systems developments, despite widespread acceptance that such methods are in fact necessary. The absence of realistic procedures for design elicitation was identified as the main cause of the lack of application of elicitation techniques in the development of design KBS.

Current elicitation methods fail to recognise the underlying conception of the design process, and elicitation procedures have been slow to adapt to meet the special requirements of design. Design is difficult to study, and information about the nature of the design activity remains sketchy, however, important implications for design elicitation research have emerged from design research, in particular, design can not be regarded as scientific problem solving. Therefore, many methods of elicitation are currently unsuitable for design applications, despite being promoted otherwise (eg Boose and Bradshaw, 1987b).

Automatic, and particularly inductive, elicitation techniques appear to be gaining popularity in design applications, however, their general applicability to design has not been established, and the precedent appears unfortunate. Whilst inductive and automated techniques may be appropriate for 'well-formulated' design situations, the approach is too restricted to offer a general strategy for design elicitation, and current automatic elicitation techniques are unsatisfactory for design tasks that involve visual and spatial components.

Here design problems that include a visual and spatial contribution have been targeted. A philosophy for the elicitation of design knowledge, based upon the teachback method of acquisition and analysis (Johnson, 1987), was argued to be a more convincing alternative. The method was demonstrated and tested in the domain of page layout design. It is therefore concluded that systematic knowledge acquisition methods can be applied to design problems.

7.6 Discussion.

The methods and procedures advocated throughout this thesis are, in the main, 'traditional,' involving people and personal interview situations. It has been suggested that whilst computer automation may, arguably, provide a valuable, time saving approach to knowledge elicitation in general, such methods have not been proven in design. Computerised techniques for design elicitation may develop, over a period of time, but they must first take into account the nature of the design activity. What is being suggested here is that we examine the process of knowledge transference, as communication between people, in design, a domain that must be viewed quite differently from traditional problems subjected to knowledge elicitation procedures. Only after the illumination of the requirements of design elicitation, and the clarification of competent design elicitation procedures, can the question of automation arise. Certainly, we do not understand design sufficiently, and it is not yet feasible to immediately instantiate design knowledge into the meticulous precision of computer representation schema from computer interviews alone.

The lack of attention paid to the task of knowledge elicitation by current developers of ICAD is disturbing, and it begs the question "where does the intelligence come from ?" It is, therefore, hardly surprising that there is an observed lack of intelligence in current systems (eg Tomiyama and Yoshikawa, 1985a,b). This situation suggests that considerable developments in the field of design elicitation are needed. Indeed, ICAD researchers are not concerned with developing principles of knowledge elicitation research for themselves, and they clearly rely on whatever methods and strategies are promoted in the knowledge elicitation literature (eg Akman et al, 1988). Thus, perhaps, resulting in the current enthusiasm for automated techniques in ICAD, since there exists a profusion of automatic elicitation strategies appearing in knowledge elicitation literature. The seductive promise of the fully computerised, of-the-shelf procedure to obtain knowledge quickly, and without effort is all too alluring (sounds wonderful, I'll have one!). However, the process of knowledge elicitation in all reality remains a difficult, time consuming, and often labour intensive activity. Short-cuts to the elicitation of design knowledge do not yet appear viable, and should be treated with caution.

This thesis aims to begin the process of providing realistic, and systematic, methods of elicitation in design, but it is no panacea. The strategy, it is hoped, will be acceptable to those who are most likely to use it. Therefore, the developers of the next generation of Intelligent Computer Aided Design Systems will be able to base their systems on systematically elicited design knowledge, and truly name them 'Intelligent' and 'Knowledge Based.' Perhaps the most important function of this discourse is to elucidate foundations, enabling a bridge between the domains of knowledge elicitation and design and ICAD research to be established, extending a springboard to expound credible design elicitation techniques.

7.7 Final comments.

Design is commonly understood as a complex, often creative activity, involving mental processes that cannot be observed or explained. Such a view tends to raise questions about the value of attempting knowledge acquisition in this domain. Certainly, understanding of design is in its infancy, and it is perhaps too early to put too much importance on a reductionist view of design. However, until, and unless, knowledge about design is acquired in a systematic way it will not be possible to establish just how much of the design process can be understood and explained.

It is therefore concluded that sound knowledge elicitation methods, although costly in terms of time and effort, are viable for design applications and that it is pertinent to explore other design tasks using such techniques. In this way design data, like scientific data, can be accumulated as a basis of interpretations and theories. Thus, it will perhaps be possible to arrive at a better understanding of the nature of design.

8 Further Discussions and Future Research

8.1 Perceptual and empirical studies of design

It has been argued that qualitative studies of design can provide considerable information. A qualitative categorisation procedure was also employed in the study of page layout design, using perceptual data. The above study resulted in useful information about likely categories considered by the designers, but verbal explanations of largely perceptual information was clearly suspect. However, the information provides a framework by which focused empirical study may progress.

In empirical studies it may be possible to test qualitative, or other, theories. In the page layout design study it was observed that pictures with the visual property of being light at the top and dark at the bottom, separated by a form of horizontal line were termed "landscape." In empirical tests a number of pictures with various visual properties can, perhaps, be submitted to a large number of experts in the attempt to generalise and theorise pertinent visual features. For example, the "Aesthetic" problems (section 2.3.2.2, Appendix 10) are concerns that appear testable using empirical perceptual studies, to establish more precisely the factors under which the identified conditions occur.

Also, many factors were identified (section 1.3.1.1, Appendix 10) to constitute text *legibility* and *readability;* the fount, the size, the width, the leading, the weight, the amount of text, the type of paper etc. It was observed that the interaction between these attributes was complex, and it was not possible to meaningfully decompose them, because the designers did not appear to consider the merits of component factors, they just viewed the text perceptually (holistically). However, through empirical study, the overall combination of facets (ie the results of combination) may perhaps be tested. Thus, perhaps by asking experts to judge the readability and legibility of text, through many variations of attributes. Indeed, many of the designers used in the studies expressed that many perceptual and psychological studies of text have been conducted using such techniques. General theories concerning individual attributes may be postulated, although it is presumed here that such theories are questionable.

However, the actual results of empirical study (in contrast to theories relating individual attributes), may form valuable information for knowledge based systems. It is envisaged that a designer, using an advisory page layout design system for example, may be informed that a selected text (consisting of many attributes), may be *illegible, unreadable* or even possibly *unfriendly.* Similarly, visual data from studies of pictures (or magazine layouts, for example) may provide useful perceptual information that will compliment the explanation based mechanisms of qualitative studies, described in this thesis. Inductive elicitation techniques may be of value. However, it is worth reemphasising that the framework for such study, as illustrated in the page layout design examples above, emerge from competent qualitative acquisition methods as described in this thesis.

8.2 The significance of the Bilateral Brain and Cognition

Constructing accurate models of cognition appears an important development of knowledge-based and expert systems research (Johnson, 1985). Currently, computational models of the design activity appear to ignore the notion of duality. Even if the strong evidence supporting the link between brain research and cognitive styles is fallacious, the evidence of two quite different types of thinking has been clearly identified in design literature. Current knowledge-based systems in design, and other domains, do not appear to recognise duality, and therefore, perhaps fail to competently model (design) cognition.

Further, it is also suggested here that the more general class of problem other than traditional KBS application may also benefit from notions of duality that is so apparent in the domain of design. The 'holistic' form of thinking can, perhaps, be identified and utilised together with the subtle implications of *communication, collaboration and confrontation* to enable greater computational success in areas of complex human problem-solving.

In the page layout design example (Appendix 10), the co-relation (curly bracket) is predominant[1], and indicates that the domain is largely dependent on complex interrelationships. It is important to note that the diagrams do not represent hierarchical decompositions; they are interdependent and an alteration to any aspect can result in many changes to the whole[2] (eg Bijl, 1985). The overall effect of a change cannot be mapped as a succession of decompositions of such changes. The diagrams constitute a communication medium, not a road map (Paul Johnson et al, 1988) of the domain. Perhaps there is a need for further research into 'holistic' and 'spatial' representation schemata, but the page layout design example illustrates that SGN diagrams are suitable, powerful, and adequately expressive enough to represent complex descriptions of design, yet also simple enough for the communication of knowledge to experts and others.

It is believed that further elicitation studies of design might specifically target the types of information and communication associated with the right brain mode, especially spatial data and holistic principles. Clearly better methods of design elicitation are required, and diagrammatical techniques offer a likely strategy.

8.3 Computers for design

An underlying objective of the project was to improve the power and usability of computer aided design systems. The adopted philosophy of producing a machine and computer representation independent model is believed to facilitate the development of ICAD systems. Further, it is asserted that the acquired information can be easily maintained and developed, and will probably out-live any particular (computer) implementation.

Also, the machine independency means that the information can be used in a variety of forms of computer application. The notion of an advisory 'Expert System' was foremost, but the data could, perhaps be used as the basis of user interface requirements for word-processing packages such as MacWrite or Word, or in existing page layout design packages.

In the early stages of the project, the preliminary assessment of the domain, through casual discussions with designers, investigated whether or not a knowledge based tool is viable, and if

[1] For example, Diagrams 1, 2, 3, 4, 6, 7, 8, 13, 14 and 15 in Appendix 10.

[2] For example, a change in text style can result in a change of *Aesthetics* (Diagram 15), *Visual appearance* (Diagram 13) and *Organisation* (Diagram 8). Also, the *Readability* (Diagram 6) and the *Legibility* (Diagram 7) is affected by such a change, independent of the above factors.

so, where and how it could be used. The domain of (internal) 'house magazine' was identified as an area where the design task is often performed by someone with little or no formal training in visual communications skills. Thus, it was observed that the designs are often poor and frequently low in basic design accomplishment. It is therefore reasonable to suggest that a system offering expert advice to a less experienced designer is potentially useful. Many page layout systems are currently on the market (Aldus page maker, for example), but they only provide basic drafting packages, and offer no design advice. Further, it was also observed that even the most experienced designers are prone to making basic errors of design, especially when time is short (Landsdown, 1988). For example, in the evaluation procedure, statement C14 identifies a mistake of *navigation* in the layout. In the open critique, designers J0, J5 and J6 explicitly remark on the feature (Appendix 14, C:J0:14, C:J5:09 and C:J6:10) and in the accuracy check protocol (Appendix 15), J5 reiterates the problem:

ac:C14:J5 "Yes, I found that. I didn't even think it had one, initially."

However, not all the designers spotted the mistake, J7, for example remarks :

ac:C14:J7 "My god yes ! Accurate, definitely. I lost that completely, it is in the wrong column, probably."

The above examples indicate that design errors can go unnoticed in page layout design. Designer E0 describes (Appendix 2, E0:267) a basic design error he noticed in "The Design Council" magazine, a 'house magazine' for designers. Such examples indicate that, firstly, an advisory knowledge based system would be useful, and secondly, that the knowledge elicitation procedures advocated here are valuable, and they can obtain pertinent design knowledge.

Therefore, it appears that a computer tool that was 'aware' of the designers' actions, identified and reminded them of possible errors in their design, offered advice on correction, or postulated suitable alternatives or ideas when asked to do so, would be helpful. This supposition is also supported in the evaluation procedure, where the designers occasionally appeared to learn new ideas (eg Appendix 15; ac:A2:J1).

To investigate the potential of computers in the domain of page layout design more thoroughly, and to verify the initial assumption that knowledge elicitation is a worthwhile endeavour, specific questions are put to the designers, in the interview stage of the elicitation process (Appendix 1b, E0:031-082; Appendix 2 E1:149-159, E2:170-184 and E3:117-132). The questions ask the designers whether they thought computer tools valuable, and if so how they should function, and how they should communicate. The main points emerging from the transcribed, and other discussions, are summarised below :

1) Computer tools should not hinder the usual flow of design by placing additional restrictions on the designer. General aspects of computer technology will need to be greatly improved before the medium is widely accepted. In particular, the accuracy and scope of the screen representation (especially for characters of text) was noted as currently being much too poor and the inability to draw directly on to the screen with familiar pen control. The 'paper'

method offers the most flexible and non-restrictive way of designing and is still used in virtually all professional situations. Desk-top publishing is more widespread at the non-professional end of the design market, where the designers are less experienced and the reliance on computer software is greatest. The opportunity to provide support in this area is both practical (since Desk-Top Publishing systems are already widespread) and necessary because here expert advice would be most useful, and is not currently available.

2) Computer systems are able to quickly manipulate the design elements and rapidly make alterations to the design in order to show, visually, the changes of decision. Visualisation plays a key role in the design task and although designers are good at predicting overall results, a concrete 'preview' is always preferable, when the preview is of adequate standard. For example, once the choice of style for the headline text has been made, a precise visualisation can be used to aid other decisions, such as the choice of picture (tones). However, the visual evidence in conjunction with other elements, for example the pictures, may necessitate a revision of the initial decision (of headline style). If the previewing process is sufficiently fast it will enable the designer to explore and experiment, and to find better design solutions for any time restriction. It is also postulated that such a system will help generate more accurate designs, since the preview will (visually) indicate design flaws that are simply beyond mental visualisation.

3) A computer system criticising the completed design, or interim design decisions was suggested as offering a likely and useful tool. The criticism could easily be ignored or explained away if not wanted. The designer has much to think about and mistakes often occur, especially when time is short. Reminding the designer of possible errors appears to be useful, and a deep explanation facility will enable the designer to rapidly respond to the report, or ignore it. Some skepticism was voiced by the experts on the ability of the system to spot mistakes that the designer would not. However, this on the surface appears natural protectionism. Most of the designers agreed that a useful contribution would be made if the computer system could report basic design mistakes, thereby providing the designer with greater freedom to address more important, perhaps creative decisions, requiring human input that would be based upon experience and world knowledge, or merely for matters of personal preference and style.

4) Further, a system that can offer advice was generally considered as being useful. The generation of options and alternatives, particularly in the early stages of design is an important aspect of the design activity. Here, the visual presentation of many alternatives, that could be ignored, explored or developed by the designer would be advantageous and likely to encourage creativity. In later, *detailing* stages of the design, the exploration of alternatives would also speed up the design process as even minor adjustment can have profound effects on the whole design, that are usually only realised once the changes have been tried. A system that can 'look-ahead, and report likely problems before unnecessary exploration was considered most useful.

5) A system that would offer advice to non-expert designers was readily accepted as being a good idea. However, the designers expressed doubts to the usefulness of offering advice to experienced designers (E1:159). This again appears a natural statement of protection ('computers can't do my job; but they might be able to do his'). Nevertheless, the warning is worth noting, since the designers may be reluctant to accept such a tool, even if, (or especially if) 'perfect.' As indicated previously, the intended system would be an aid to support the designer, and form a

cooperative partner, not replace him. Great care must be taken to highlight this distinction for the distribution of a successful 'Expert's' system.

6) The given advice should not lead or restrict the designer' actual decision making process (E3:132), only offer advice and possible options. This sentiment again demonstrates the lack of confidence that the designers have in computer systems, and the need for the human input in a cooperative system.

8.4 Towards an Intelligent Knowledge Based page layout design tool

It is asserted here that computer systems attempting to aid the design process should be aware of the possible cognitive styles of the designer. Smyth (private discussion) postulates that a Knowledge Based computer 'partner' could support the design activity by facilitating a match of cognitive styles between the computer system and the designer at the appropriate stages of the design development. However, there would be significant difficulties in assessing the particular 'style' of the user. Hence, a more feasible system could be developed through the recognition of the divergent (creative) nature of the earlier design processes, such as divergency and impulsiveness. Thus, the computer system can contribute to the design activity by independently postulating a large number of initial alternatives. In this way the diversity of thought from the two separate sources is likely to be better than just the user's own ideas. It is also argued that the input, even if it is completely 'off-track' may provide a source of stimulation, through diversity, that is likely to trigger the designer's own divergent thinking processes.

It is postulated that a more useful computer tool might be developed through the concept of a computer partner that adopts a radically different and 'complimentary' style to the designer's own preferred cognitive style. The contribution from such a system could provide an input that the designer would either not think of, or is reluctant to try. At the very least it could perform some of the tasks that the designer finds tedious through the lack of preference. Surely the problem of current 'Expert' and 'Knowledge Based' systems technology is that these systems attempt to *model the expert*. Since the expert is always going to be more cognitively advanced (and adaptable) than the model, then these computer systems do not achieve expert status, and they are unlikely to make a significant contribution to the design process. The systems are then passed down to the secondary role of teaching and training of non experts, and although they may be useful teaching tools, they fail to accomplish their main objective of aiding the expert (designer).

Integrating the antagonistic style with the (complimentary) style for the particular stage of design (Figure 9) may cause significant problems of practicability. The designer should not be deterred from the impulsive/divergent thought (initially) or the reflective/convergent thought (latterly) at the appropriate stage of the design development. Moreover, it may be important to encourage the "correct" style of thought for the appropriate stage of design (eg Christopher-Jones, 1963), particularly as the computer tool will inevitably be used as a teaching aid.

In future elicitation studies of the design, it may be possible to target the likely types of information, thought processing and communication medium associated with distinct stages of design, (early and late) or the modes of thought discussed above. In the study of page layout design a global strategy was adopted, through considering a natural and complete design task and no attempt was made to decompose the task. The merits of a 'holistic' strategy have been argued, but an alternative approach may also yield interesting information.

8.5 Evaluation of design knowledge

Qualitative and psychological evaluation studies were shown to be of some success in the page layout design study, and nonparametric analysis appears to offer a useful technique for interpreting the results. Further investigation in methods for testing and evaluating design knowledge are clearly required, and methods for testing and evaluating spatial types of information requires particular attention.

8.6 Creative design knowledge elicitation ?

The study of page layout design specifically avoided making interpretations on creativity, although creative thought was not altogether eliminated from the design tasks. However, the specific investigation of creativity is an interesting area of research. For example, questions arise to whether creativity can be observed, and if so, what likely interpretations and generalisations are possible ? Can creativity be considered a skill or is it an inbuilt mechanism of cognition, like perception, and is creativity open to verbal explanation mechanisms ? The value of studying creativity from the knowledge engineering viewpoint appears suspect at this juncture, although valuable information may emerge through its investigation.

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